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Abstract

Russian Federation possesses an enormous volume of hydrocarbons. A significant part of the hydrocarbons is located in offshore areas, mostly in arctic and sub-arctic regions, where field development is relatively complicated and expensive in comparison with traditional onshore projects. The economic need of such projects is dictated by the fact, that in the nearest future the Russian domestic petroleum industry will face the problem of the conventional deposits' depletion. That is why there is a need to develop unconventional and offshore projects. The Sakhalin Shelf, and especially Sakhalin-5 project, is believed to be the most perspective in the near-term. The Sakhalin-5 project is located in the north-eastern part of the Sakhalin Shelf and belongs to the sub-arctic region. Harsh meteorological and ice conditions have a great impact on field development.

The Kaigansko-Vasyukankoe-more field; the Sakhalin-5 project, and more specifically the Pela Lache deposit, is selected as the reservoir of interest because it is considered to be the main one for the Kaigansko-Vasyukankoe-more field. The objective of the current master's thesis is to identify and analyze the main meteorological and oceanographic conditions, their impact on the offshore field development and propose a development concept with minimal ecological risks. Due to the fact, that the field is on the early stage of design development, there is a great lack of data regarding the main properties and characteristics. For estimation of field production trends, there is a need to implement the analogue method and identify such deposit, which allows one to conduct such kind of calculations. After that, based on the analyzed results, to propose the most effective potential field layout and estimate its cost. Also, it is necessary to identify the optimal solution for transportation of the produced oil. In order to approve or disprove the feasibility of such a project, it is necessary to analyze the economic efficiency and ecological safety.

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I would like to thank everyone who is involved in the creation and support of the joint master program between the University of Stavanger and Gubkin Russian State University of Oil and Gas (National Research University), which for many years allows students not only to obtain relevant and necessary knowledge but also opens up new horizons in the students minds.

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Introduction

The shelf of Sakhalin Island is one of the most important regions of oil and gas production in Russia. The sea of Okhotsk boasts significant potential of energy resources. For today 16 petroleum deposits have been discovered. Only 6 of them are in the production stage: Odoptu, Chayvo, Arkutun-Dagi, Piltun-Astokhskoye, Lunskoye, and Kirinskoye fields. Sakhalin offshore oil and gas fields are divided into projects or blocks. Commercial development is carried out within the framework of major international projects "Sakhalin-1", "Sakhalin-2" (in production since 1999), "Sakhalin-3" (in production since 2013). Shelf development is conducted with collaboration between companies from different countries as Russia, USA, Japan, India, and China. In 2016 hydrocarbon production amounted up to 18 million tonnes of oil and about 30 billion m^3 of gas. The Sakhalin-4 and Sakhalin-5 projects are on the stage of exploration drilling and feasibility study development. Figure 1 shows a map of the projects.

Figure 1. The map of the Sakhalin projects [1].

The Sakhalin-6 project is suspended by the operator for an indefinite period of time. The progress was stopped after seismic research, which had been conducted in 2002. The reasons for the freezing of all activities are unknown.

The Sakhalin-5 project is considered to be the most promising in the nearest future. The fields of this project are at the stage of design development. The objective of the work is to conduct a feasibility study for one of two Sakhalin-5 offshore oil fields. The Sakhalin-4 and Sakhalin-5 projects are located in the most northern part of the Sakhalin Island shelf. The area of development is located in the sub-arctic region associated with additional challenges and complications, such as ice and climate conditions, also the influence of the Pacific Ocean, seismic activity, etc.

The Sakhalin-5 project includes two areas: Kaigansko-Vasyukanky and East-Shmidtovsky blocks [2]. By today only Kaigansko-Vasyukansky area (7200 km^2) is being considered because this block is believed to be the only cost-effective project [3]. In 2005 the "Kaigansko-Vasyukanskoe more" (in other resources also known as "Kaigansko-Vasyukanskoe sea") field was discovered in the location presented in Figure 2.

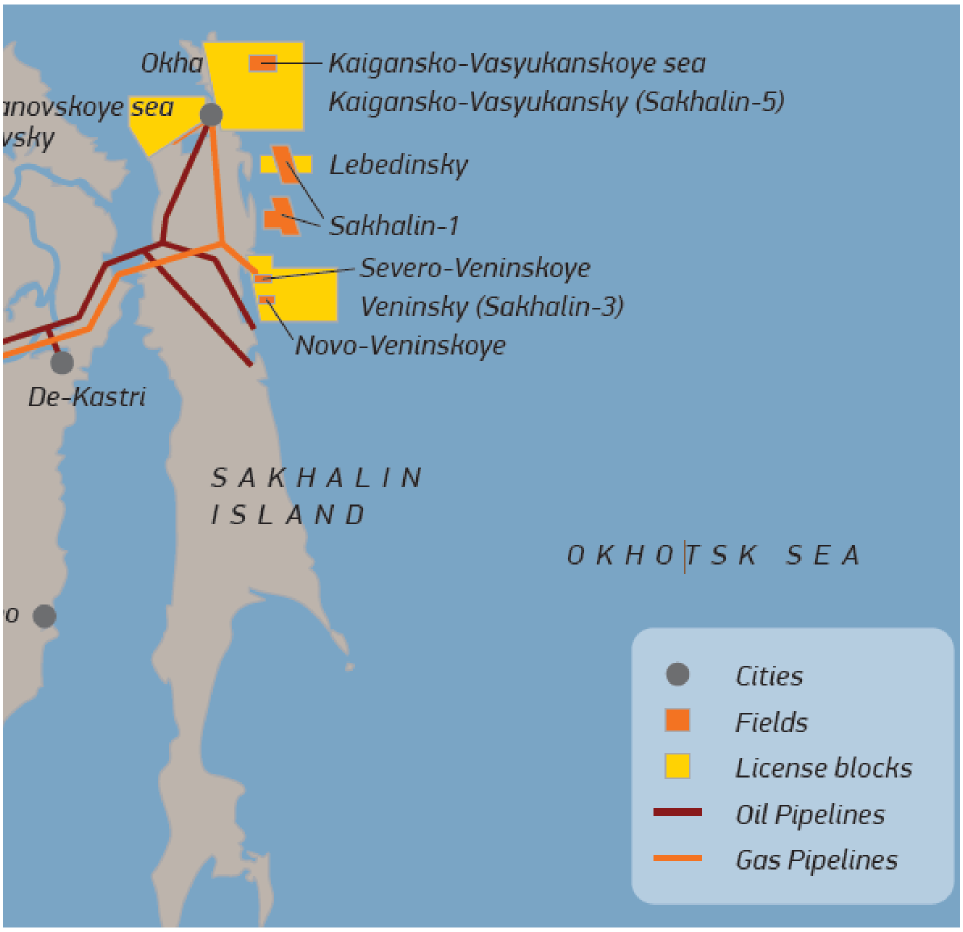

Figure 2. Sakhalin-5 description (adapted from [2]).

In 2007 it was announced that the field's recoverable ABC1 reserves amount to 16,14 mln tonnes of crude oil and gas condensate [4]. This oil-gas condensate field is located in the Okhotsk Sea on the northeastern shelf of Sakhalin Island in 40-50 km from the coast. Sea depths within the license area vary between 100 and 125 m. The nearest major seaport — Moskalvo is

200 km away. Kaigansko-Vasyukanskoe-more field (KVM) consists of three deposits, which are shown in Figure 3, from left to right: Udachnaya, South-Vasyukanskaya, Pela Lache.

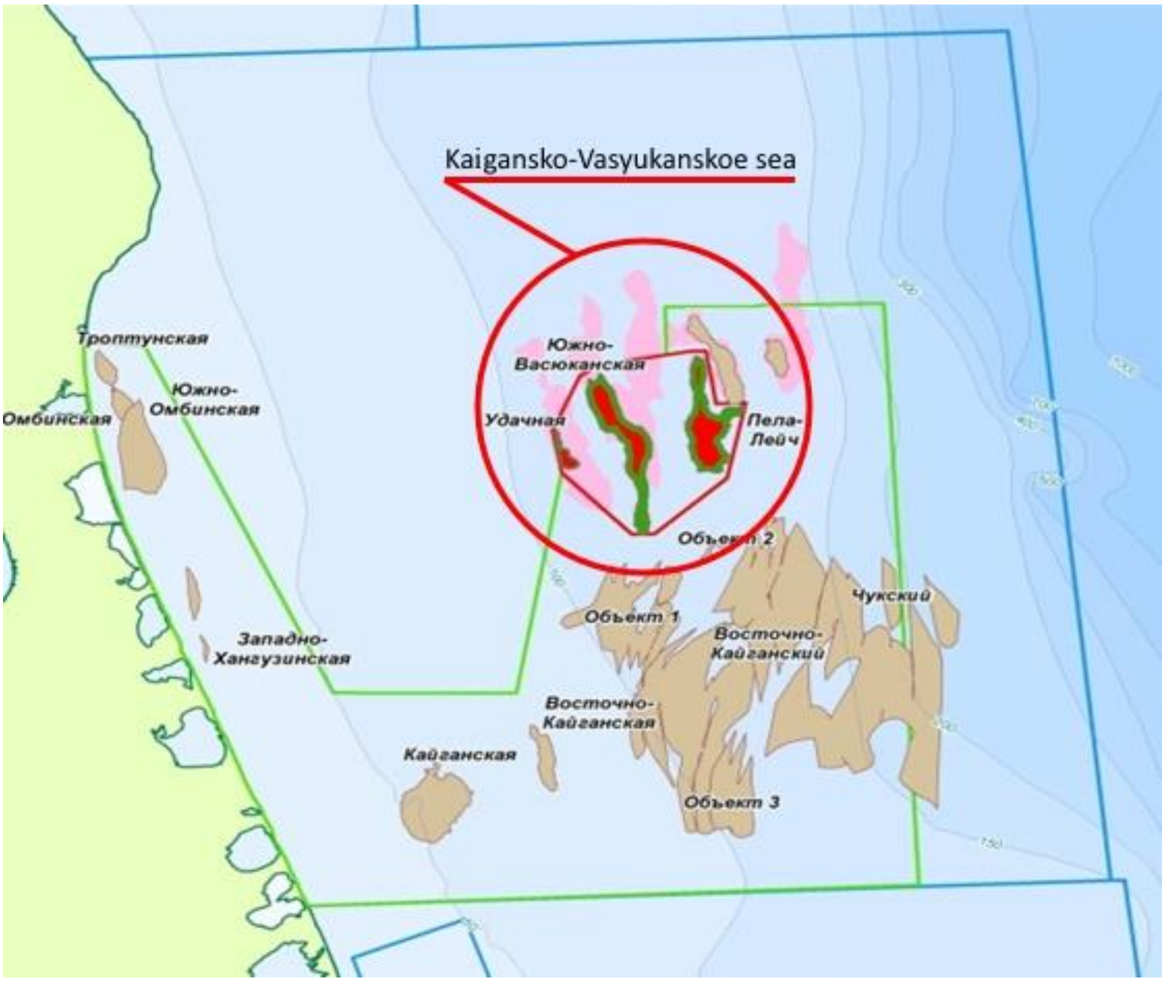

Figure 3.Kaigansko-Vasyukanskoe sea deposits (adapted from [5]).

Chapter 1. Meteorological and Oceanographic conditions

The climate of the north-eastern part of Sakhalin Island and the Sea of Okhotsk is formed under the influence of the Asian continent and the Pacific Ocean. The influence of the continent manifests itself mainly in winter when dry and heavily cooled air on the continent reaches the Far East from the north-western and northern streams. Impact of the Pacific Ocean is apparent in the warm period of the year when the southeastern and southern streams bring to the region cool and humid air. The north part of the island with an adjacent offshore area belongs to the subarctic climate with pronounced monsoon circulation.

1.1 Air temperature

The average annual air temperature at all meteorological stations in the northern part of the Sakhalin Island and the adjacent waters of the Sea of Okhotsk is below 0°C. The average monthly air temperature for six months is negative (November – April) and for the other six months is positive (May – October). The coldest month is January with an average temperature between -16,8°C and -19,9°C. The absolute minimum equals to -39,7°C. The warmest month is August with an average temperature between 11,3°C and 14,3°C. The absolute maximum is 34,9°C, which was observed in July. The average daily temperature is observed to be above 0°C at the end of April and early May. The change to negative temperatures occurs at the end of October. Duration of the period with positive average daily temperatures is 169–179 days. In Table 1 the average, minimum and maximum temperature values are presented for each month from different meteorological stations [6, 7].

Location of the stations can be seen in Figure 5.

Table 1. Air temperature, °C (adapted from [6, 7]).

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average													
Val	-19,3	-17,3	-11,3	-3,1	2,1	6,6	11,2	13,1	10,3	3,3	-6,8	-15,4	-2,2
Nogliki	-18,5	-15,9	-10,0	-1,9	3,5	9,0	13,1	14,3	10,5	3,2	-7,3	-15,2	-1,3
Komvro	-16,8	-14,7	-10,0	-2,4	1,6	5,1	8,9	11,3	9,3	3,3	-5,9	-13,2	-2,0
Minimum													
Val	-38,4	-39,6	-36,1	-27,7	-9,4	-3,8	0,5	2,2	-4,4	-17,8	-25,4	-36,8	-39,6
Nogliki	-39,7	-37,6	-32,3	-24,4	-8,3	-3,9	-0,6	1,5	-3,4	-19,5	-27,3	-37,5	-39,7
Komvro	-36,4	-36,3	-34,7	-24,5	-9,5	-5,3	-2,4	1,0	-3,0	-16,1	-25,3	-34,4	-36,4
Maximum													
Val	4,5	3,6	8,4	15,9	26,5	27,8	31,9	30,1	25,8	18,9	14,5	8,4	31,9
Nogliki	9,4	11,7	11,1	17,3	26,7	32,4	34,4	32,9	27,2	19,0	11,0	8,9	34,4
Komvro	3,3	2,0	14,5	19,4	26,2	25,1	34,9	31,5	26,7	21,7	14,7	10,3	34,9

1.2 Water temperature

During winter the water temperature in the northern part of the sea is -1,5°C to -1,7°C [8]. In summer only superficial layer receives enough energy to heat. The maximum temperature is recorded in the surface layer at 17-18°C; at the 30 m depth, the maximum temperature is 7-8°C. There is a cold intermediate layer underneath, which remains with a temperature of about 2°C. The seasonal change of temperature influences only on the water at the depth less than 200-300 m. The water freezing temperature is -1,9°C. During the winter season from October until June, the sea is covered with ice. In the ice-covered area the temperature of water column under the ice varies between -1,7°C and -1,9°C.

1.3 Wind

The movement of air masses over the Sea of Okhotsk occurs due to the prevailing influence of monsoon circulations. As a consequence, there are two main periods in the year when the wind is most likely to be in a certain direction. According to the [6,7], the wind speed increases from summer to winter period. In comparison with summer winds, the winter ones are approximately as twice as strong. The autumn and spring are transitional periods when the directions change one to another. The months of change are April and October. Table 2, the repeatability of the wind's direction is obtained from [6, 7].

Table 2. Repeatability of wind's directions, % [6, 7].

Station	Direction of the wind								Calm
	N	NE	E	SE	S	SW	W	NW	
January									
Val	10,55	1,60	5,26	3,36	1,51	1,84	45,86	24,19	5,82
Nogliki	12,37	1,61	1,92	1,01	4,17	22,40	39,94	13,80	2,77
Komvro	12,88	1,18	1,44	1,49	2,15	1,92	40,39	33,48	5,08
July									
Val	6,86	4,73	16,01	20,65	20,84	6,11	11,36	4,06	9,39
Nogliki	8,61	5,19	20,59	21,53	10,86	9,25	14,13	2,08	7,76
Komvro	15,02	3,20	7,49	26,13	21,17	1,08	5,33	3,01	17,53

As it can be seen from Table 2, during the winter the west and north-west direction of the wind are prevailing. The total repeatability varies between 53,74-73,87%, Nogliki and Komvro stations respectively. In summer the monsoon circulation is not so obvious, nevertheless, total repeatability for Nogliki station in south-east and east direction is 42,12%.

The average wind speed in the northern part of Sakhalin Island is fluctuating between 4-5 m/sec. The data recorded in Val station and presented in Figure 4 for the period from June-December. The maximum mean monthly wind speeds are recorded in December-January with 5-6,5 m/sec, the minimum in July-August with 3-4 m/sec [9].

Annually, in Val station, 26 days with strong wind (more than 10 m/sec) are observed on average. During the "warm" period (May-October) there are 5 days with such wind, for the "cold" period the number of days is 21 days. The highest number of days for one year with a wind velocity of more than 10 m/sec can reach 78 days.

The maximum wind speed observed at Val station is 40 m/sec. For wind gusts, the maximum velocity can reach 49 m/sec. The highest wind velocities for Nogliki and Komvro stations are 31 m/sec and 34 m/sec respectively. The maximum speed is observed predominantly during winter months. The maximum wind speed in summer is usually less than 20 m/sec. According to the [10], the mean wind speed over the northeastern part of the Sakhalin Island in the area of Sakhalin-3 project is 6,5 m/sec, the mean maximum is 20 m/sec.

The wind regime in the region of interest has monsoon circulations. The main feature of such a regime is the seasonal change of the wind direction. The north-western direction is dominating from October to April. There is a change of seasons in April when winds' directions are not stable. During summer the south winds are prevailing.

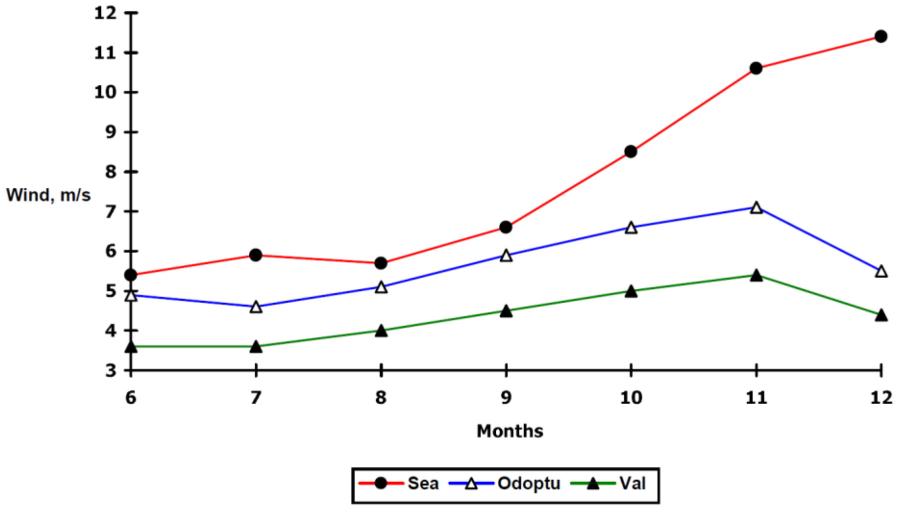

Figure 4. Mean monthly wind speeds over land and sea (adapted from [10]).

The highest values of the wind speed, which are possible to occur once a year, 10, 100 years in a specific direction with duration 1 hour, 10 minutes and 5 seconds (gust) [6, 10], see Table 3.

Table 3. The highest wind speeds, m/s, possible once a year, 10, 100 years [6, 10].

Recurrence interval, years	N	NE	E	SE	S	SW	W	NW
1 hour								
1	22	21,2	22	21,2	18,4	17,7	20,5	22,8
10	27,5	26,9	27	26	23,5	22,9	25,4	27,7
100	33,1	32,5	32,1	30,9	28,7	28,1	30,3	32,7
10 minutes								
1	23,9	23	23,9	23	19,8	19	22,2	24,7
10	30,2	29,4	29,6	28,5	25,6	24,9	27,7	30,4
100	36,6	35,9	35,5	34	31,5	30,8	33,3	36,2
5 seconds(gust)								
1	28,9	27,8	28,9	27,8	23,7	22,7	26,8	30
10	37,3	36,2	36,5	35	31,2	30,2	34	37,6
100	46,1	45,1	44,5	42,5	39,1	38,1	41,5	45,5

1.4 Sea level

The highest mean sea level in the region of interest is observed in the period between October and November. The lowest value of the mean sea level is recorded between March and August. Two periods with the transitional regime are identified in February and September. There is the highest rate of change in the mean sea level during these months. The maximum difference in mean monthly sea level is 14 cm. Nevertheless, monthly mean sea level deviation can reach significant values. The difference between the absolute maximum and minimum among average monthly heights can be 0,5 m [7].

Figure 5. Location of the Nabil Gulf and meteorological stations (adapted from [11]).

Long-term observations were conducted in a shore research station located in Nabil Gulf. Nabil Gulf is located in the northern part of the island, shown in Figure 5, so the data obtained by this station can be used in characterizing the annual mean sea level deviation for Block-5 projects. Based on [12] the data are analyzed and visualized in Figure 6.

Changes in sea level within a year (seasonal variation) are relatively small. The minimum is recorded at the end of April or early May, the maximum in December.

The tides in the sea of Okhotsk are generally formed under the influence of the tidal waves, which spread from the Pacific Ocean in the south-western direction along the Kuril Islands. These waves lead to significant fluctuations of sea level, direction, and velocity of currents. Diurnal tides dominate in the coastal region. In open water wrongly shifted diurnal tides prevail.

The sea level fluctuations are also affected by meteorological conditions as surface atmospheric pressure and wind stress. The average amplitude of these oscillations is relatively small. During autumn-winter season such deviation fluctuates in limits of 8-10 cm, for summer it is 4-5 cm. The special case is the change in sea level due to a storm. Storms surges appear as a consequence of a rapid decrease in pressure and strong winds. The sea level fluctuations are most influenced by meteorological conditions in October-November and February-March due to the great number of cyclones, which move above the sea of Okhotsk during these periods. The lowest impact of the meteorological conditions is observed in summer.

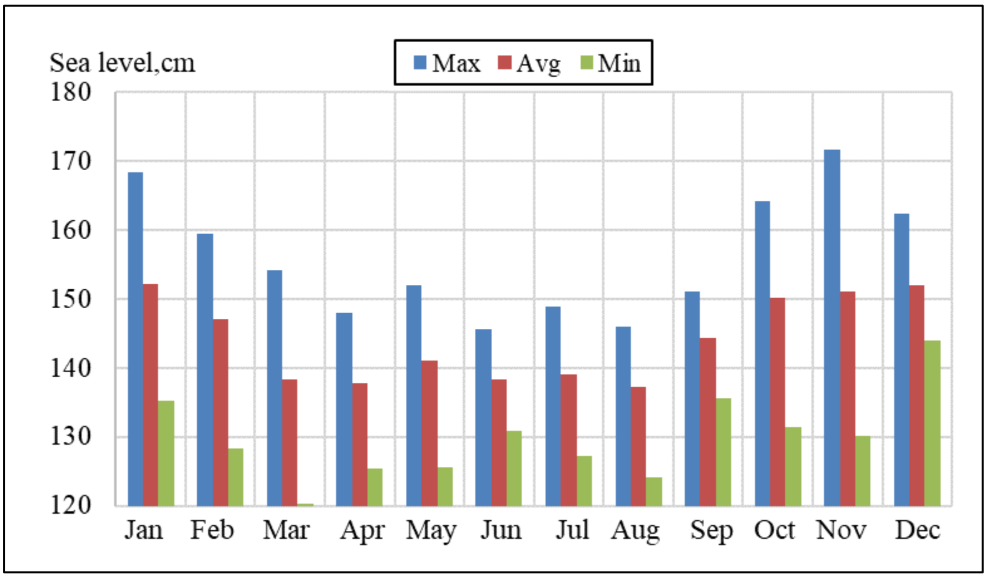

Figure 6. Annual mean sea level, Nabil Gulf (based on [12]).

1.5 Currents

The East-Sakhalin Current is the main factor that influences the hydrometeorological conditions of the region. According to the [13], this current is cold due to the fact that the duration of the ice melting, which is located in the northern part, is long. The nature of the current based on the presence of a difference in density between the relatively light waters near the shore and the dense waters in the Derigun Basin. The velocity of the current depends on the season. The maximum speed reaches 15 cm/sec. The higher rates of velocity can be observed in the coastal strip due to the aggregated flows. The direction of the current can be described as a movement from North to South.

With the increase in the depth, current velocities can reach 50 cm/sec near the surface and 30 cm/sec at the bottom layer. The highest rates of velocity are observed for the currents of the main direction, southern. The special feature of the East-Sakhalin current is the presence of the aperiodic currents and their direct dependence on the direction and intensity of the wind. The average value of the non-periodic currents' velocity at 15-30 m depth is 7-9 cm/sec and 5 cm/sec at the 1m above the bottom. The maximum velocity of the non-periodic currents can reach the values in 2-3 times higher near to the coast in comparison with the open sea.

One of the main features for the Sea of Okhotsk is the fact, that this sea is a tidal one. Because of that, there are daily reversing tidal currents. The direction of the tidal current is to the South, for the ebb is to the North. In the open sea, the reverse character of the tides is not observed. The speed of flow during the tide is high, and it can reach 120 cm/sec. Increasing the depth of the sea decreases the speed of the tidal flow [9].

1.6 Waves

The greatest wave heights in the region of interest are observed during deep cyclones with consisted of north-eastern and north-western winds. The extreme values of the waves' height, period, and length are presented in Table 4 for the probability of exceedance 13% and 3% [7,13]**.**

Table 4. Extreme wave statistics [7, 13].

Characteristic	Height, m		Period, sec		Length, m	
Recurrence interval, year / Probability of exceedance, %	13	3	13	3	13	3
1	6,3	8,3	10	10,5	155	170
10	10,3	13,6	12,8	13,4	256	281
100	15,7	20,7	15,8	16,5	388	426

1.7 Tsunami

Kuril-Kamchatka Trench is one of the main regions of tsunami genesis in the Pacific Ocean. According to the [13], it can be said that Sakhalin Island is located near one of the most seismically active region in the world. In spite of this fact, the energy of tsunamis, by the moment of reaching the north-eastern coast of Sakhalin Island, is significantly decreased due to energy absorption of Kuril Islands. In [12] the research based on available data (black dots on the graph) was conducted to identify the reoccurrence period of a tsunami with specific wave height. The obtained graph can be seen in Figure 7. The log-normal approximation was used, the diagonal straight. According to the [12], it is said that the spreading speed of the tsunami waves can be from 400 up to 800 km/h and with a several kilometers length.

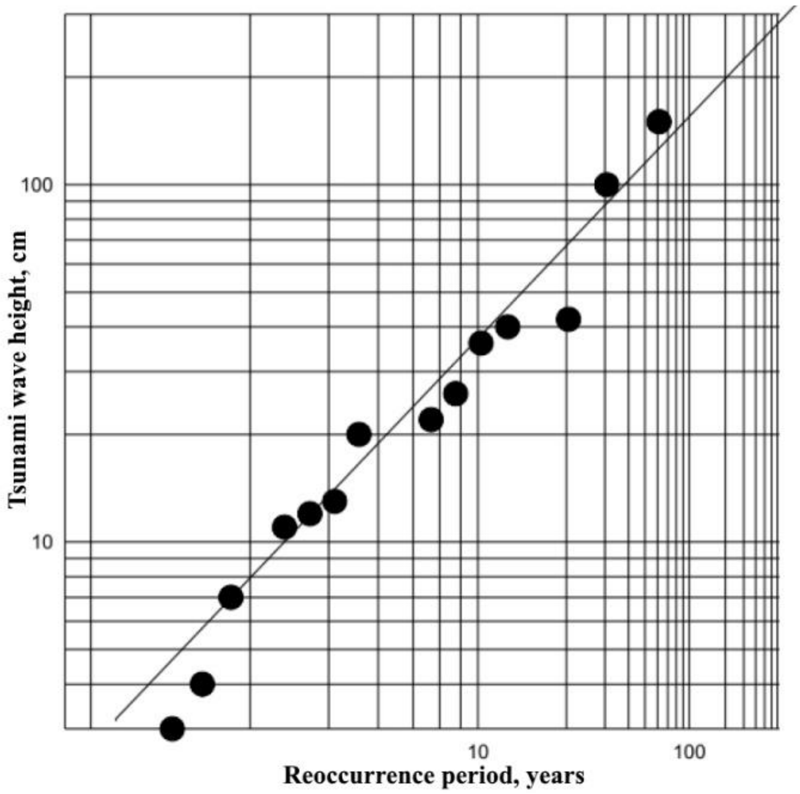

Figure 7. Tsunami recurrence on the eastern coast of Sakhalin Island [12].

1.8 Ice conditions

Ice conditions in the north-eastern shelf of Sakhalin Island basically can be characterized as severe. In particular, severe ice conditions are the most dangerous factor for production facilities and transportation of petroleum products [14].

Every year in the sea of Okhotsk severe ice conditions are observed, which make difficulties for shipping. At the end of October ice begins to occur in shallow waters. In the second part of November ice starts to form in the coastal region. By the middle of January, waters are covered by drifting ice sheets with thickness less than 70 mm. In February ice ridges start to occur in water depth less than 10 m. The period from March until April is the most difficult and dangerous. The thickness of drifting ice reaches the thickness to 200 cm and more. The height of the ridges starts to be in the range 5-6 m, covering 60-80% of ice. The maximum square of drifting ice fields 500-600 km^2. The highest rate of ice exaration, which was recorded, is 2,16 m [7].

Ice formation in north-eastern part Sakhalin shelf starts in November and quickly spreads from north to south. Ice is formed in the narrow coastal strip as slush, later as pancake ice. In January first-year ice starts to be formed under the influence of the currents and winds. In March-April the drifting ice reaches the most eastern location. The western part of the sea is always full of drifting ice, despite the degree of winter severity.

From the middle of April, the destructive processes of ice cover start to prevail. The active melting starts in May and leads to ice fields crush. In June newly formed ice disappears and only first-year ice can be found. By the end of June, all ice in the north-eastern region of the sea is gone. The process of melting goes from the south to north.

1.9 Ecological conditions

There is no accurate information regarding the ecological status of the north-eastern Sakhalin Island shelf. According to the research, which was carried out by the Pacific Research Institute of Fisheries and Oceanography and Zhirmunsky National Scientific Center of Marine Biology, by 2014, the results of the report show the typical rates for this region [15]. There were tests of spatial patterns of water temperature, salinity, dissolved oxygen content, and concentrations of inorganic phosphate and silicon. Some minor impairments in the development for Scaphechinus mirabilis embryos were observed. The area of the Sakhalin-5 project is considered as one the most unaffected by human and petroleum activities from the ecological point of view for the Sakhalin Island shelf [15, 16].

1.10 Seismic activity

The north-eastern shelf of the Sakhalin Island is located in the area of high seismic risk, near to the epicenter of destructive Neftegorsk earthquake which was in 1995 [17]. The Hokkaido-Sakhalin fault is considered to be the main source of possible earthquakes in the region of interest. The intensity of the earthquake is appraised by the MSK-64 scale. The MSK-64 is the acronym, which is used for the Medvedev–Sponheuer–Karnik scale, which was introduced in 1964. The scale has 12 categories of force, where the first is described as “Not felt. Registered by seismic instruments only” and the last, 12th, “Great disaster. Changes in the crust reach enormous proportions. Numerous cracks, landslides, landslides. The permanent relief changes. None of the structure can withstand.” [18].

In Figure 8, Left (a) gives the MSK-64 intensity with a 10% probability of being exceeded in 50 years (475 years return period), right (b) the same with 1% probability. According to the

Figure 8 [13], the MSK-64 intensity is approximately 9 for a return period of 475 years (10% in 50 years) and approximately 9.8 for a return period of 4975 years (1% in 50 years) [13].

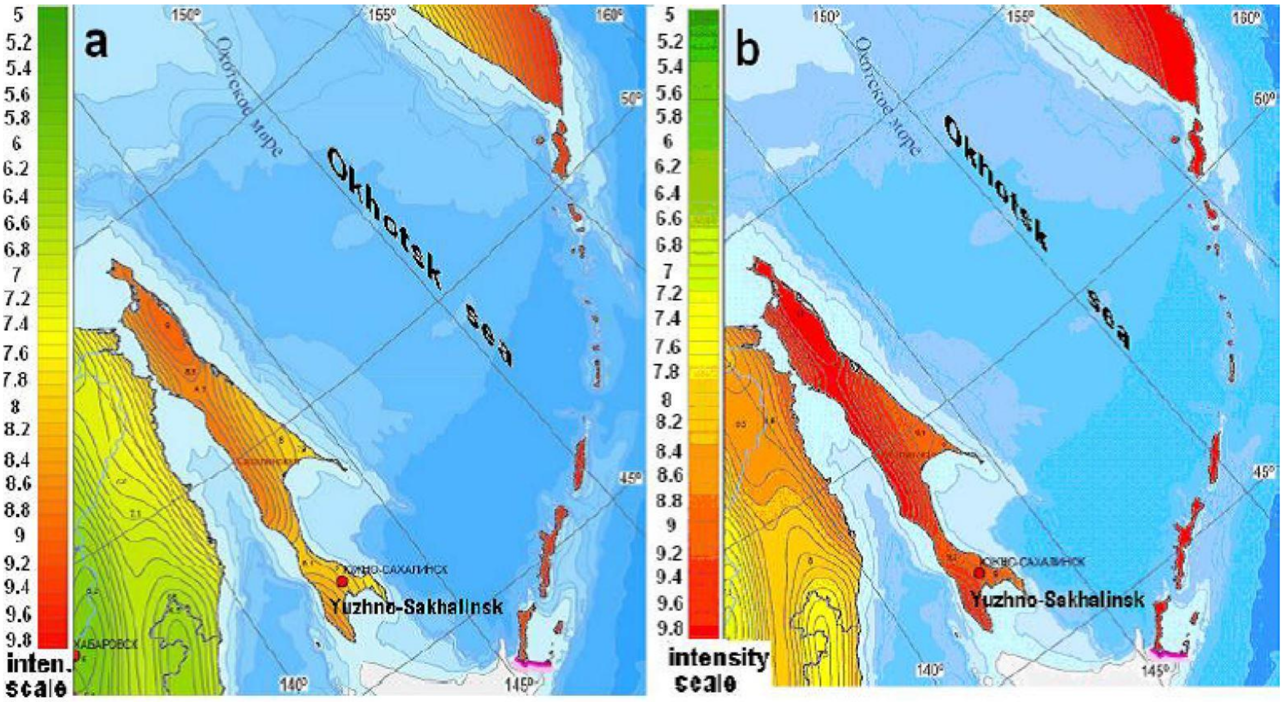

Figure 8. Maps of General Seismic Zoning 2012. Left (a) gives the MSK-64 intensity with a 10% annual probability of being exceeded. Right (b) gives the MSK-64 intensity with a 1% annual probability of being exceeded [13].

1.11 Conclusion

One of the main features of the Sakhalin Island shelf is the fact that it belongs to the sub-arctic region. In the cold months ice covers the sea that leads to restrictions on the duration of marine operations in the open sea. In general, the area belongs to seismically active zone that leads to additional costs to achieve the required level of objects' reliability.

Chapter 2. Field development

The KVM field, like other fields of the Sakhalin-5 project, is in the stage of design development. The Sakhalin-5 block is believed to be one of the most promising projects with sufficient amount of hydrocarbons. By today, there is almost no accurate information regarding the reserves and resources for the Kaigansko-Vasyukankoe-more field. According to the official website of the Rosneft Oil Company [3], the major shareholder and operator of the field, it is presented, that the field reserves, C1 and C2, are 41,6 million tonnes of oil and gas condensate, 44 billion cubic meters of gas or 16,14 mln. tonnes of oil and gas condensate under the ABC1 category.

The idea of this chapter is to overview the basics of perspective field assessment and principles of reserves estimation, to calculate oil resources, reserves, and production profile for the Pela Lache deposit, as part of KVM field, based on the available information and the analogy with known field with the relatively same characteristics.

2.1 Assessment of the perspective field

A common practice in the assessment of the perspective field is to conduct a division into two relatively independent tasks: reserves and risk assessment [19].

1) The reserves estimation at the first stages of development usually is conducted by material balance analysis and volumetric method.

2) The estimation of geological efficiency. There should be the implementation of conditions for the use of the volumetric method. The efficiency is associated with the processes, which are not directly linked with volumetric method parameters such as generation and migration of hydrocarbons, presence of the reservoir and trap.

In the result of this method, the probability distribution of the reserves' volume (N), taking into account the risk, can be presented as "risked reserves" [20].

$$f_{risk}(N) = \lfloor 1 - P_g \rfloor \cdot \delta(N) + P_g \cdot f(N) \tag{1}$$

Where $f(N)$ — normalized density of the original "risk-free" distribution of resources, P_g — geological efficiency, $\delta(N)$ — Dirac delta-function.

For this distribution the mathematical expectation $— E_{risk}(N)$, dispersion $— D_{risk}(N)$ and variation coefficient $— R_{risk}(N)$ are calculating by analogical values of original distribution $f(N)$:

$$\begin{aligned} E_{risk}(N) &= P_g \cdot E(N) \\ D_{risk}(N) &= P_g \cdot \left(D(N) + (1 - P_g)^2 \cdot E(N)\right) \\ R^2_{risk}(N) &= \frac{D(N) + (1 - P_g)^2 \cdot E^2(N)}{E^2(N)} = R^2 + (1 - P_g)^2 \end{aligned} \tag{2}$$

2.2 Volumetric method for estimating hydrocarbon reserves

The volumetric method has found widespread application for estimation of oil reserves. The resources are calculated as a product of input values. Usually, for oil, the formula takes the form:

$$Oil\ resources = V_{os} \times S_o \times \varphi \times \rho \times \theta \tag{3}$$

Where V_{os} is a volume of oil-saturated formation (m^3); S_o is oil saturation factor (fraction); φ — porosity (fraction); ρ — oil density in standard conditions (kg/m^3); θ — a correction factor [21].

Usually, the volume of an oil-saturated layer can be found by the formula:

$$V_{os} = A \times h_o \tag{4}$$

Where A — the area of the oil-saturated formations; h_o — the thickness of the oil-saturated layer.

In case when the net to gross ratio is known, it is possible to calculate the net productive thickness by the following equation:

$$h_o = h_{total} \times NTG \tag{5}$$

Where h_{total} — total thickness of the formation (m); NTG — net to gross ratio (fraction).

The reserves, which can be extracted, can be distinguished by the recovery factor:

$$Recoverable\ reserves = Resources \times RF = Resources \times E_D \times E_S \tag{6}$$

Where RF is the recovery factor, which is calculated by the product of the displacement E_D and sweep efficiency E_S.

The formula for estimating the initial resources of free gas deposits by the volumetric method is as follows:

$$Gas\ resources = V_{gs} \times S_g \times \varphi \times \theta_T \times \theta_P \tag{7}$$

Where V_{gs} is a volume of a gas-saturated formation (m^3); S_g is gas saturation factor (fraction); φ — porosity (fraction); θ_T — thermal coefficient; θ_P — pressure coefficient.

$$Gas\ condensate\ resources = Gas\ resources \times S_c \tag{8}$$

Where S_c is a gas condensate factor (fraction).

For gas and gas-condensate reserves estimation, there is a need to multiply their resources by their corresponding recovery factors.

2.3 Principles of probabilistic estimation

Existing probabilistic reserves estimation models use the distributions of quantities as input parameters. The following conclusions are common for the volumetric method. According to Rose (2001) [22], the experience in the observations from different hydrocarbon bearing formations shows that the probability distribution of the most part of parameters can be lognormal approximated. There is a very important task of setting the average value diapason, dispersion, and limits of parameters. That leads to the fact that the results can be obtained with the same accuracy with the use of normal, lognormal, triangular and other approximations. There is a need to take into account the correlations between the input parameters. For example, Murtha (2002) makes the list of typical pairs of correlated variables [23]:

- area and net pay zone;
- porosity and hydrocarbon saturation;
- net pay zone and recovery efficiency;
- net-to-gross ratio and porosity.

At the same time, the correlations between input parameters lead to an increase in the mean of the reserves up to 10%. The increase of result depends on the number of correlations and their strength.

In opposite to the deterministic method of reserves estimation, for probabilistic method, all parameters, which are taken into account, have not one fixed value, but the intervals of values, which limits are obtained from open-source analog-fields. Based on the frequency of occurrence of the value of the estimated parameter, the probability of an event is determined, at which this parameter reaches some value or more. As a result of multiplying the intervals of the calculated parameters, the distribution of all possible values of hydrocarbon volumes in the deposit is obtained from 1-100%, as it is shown in Figure 9.

Every field has a range of its reserves, express with three main probabilities: P90, P50, and P10.

According to the Guidelines for the Evaluation of Petroleum Reserves and Resources [24]:

- P90 — there is a 90% probability that some quantity of hydrocarbons will be actually recovered equal or exceed this quantity. In reserves estimation, P90 is the proven value. The pessimistic evaluation.
- P50 — there is a 50% probability that some quantity of hydrocarbons will be actually recovered equal or exceed this quantity.
- P10 — there is a 10% probability that some quantity of hydrocarbons will be actually recovered equal or exceed this quantity. The optimistic evaluation.

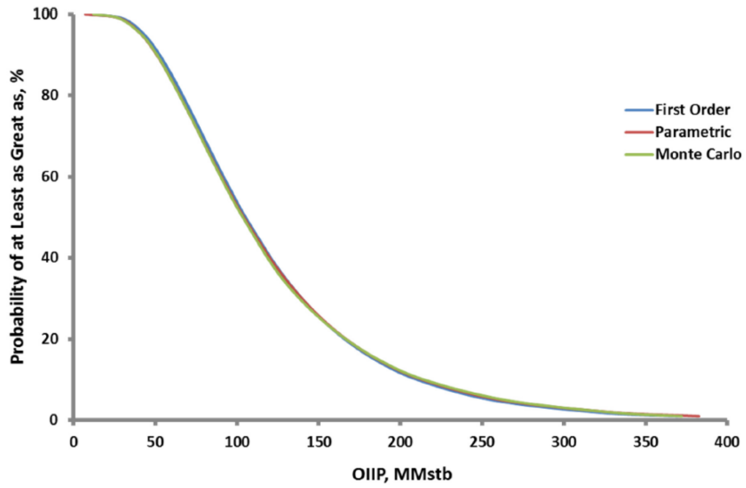

Figure 9. Example of appraised discovery [25].

The main tasks for conducting a probabilistic estimation of resources are:

1. The accurate selection of fields with analogical features.
2. The selection of the probability distribution function of the estimated parameters values.
3. The distinguishing the P10 and P90, which reflect optimistic and pessimistic values. As the limits values of parameters, P1 and P99.

2.4 Analogue field selection

There are three main methodologies used for resources, reserves and main development trends estimation: hydrodynamic modeling, material balance method, and method, based on the analogies with other fields. For the current work, the analogue method is selected. The identification of the analogues fields includes the comparison between parameters of the target field and analogues field. The list of parameters is based on the geotechnical, engineering and reservoir-development data. The analysis of different papers shows, that it is possible to highlight the most common features for the appropriate selection of the analogues field. First of all, fields should have a similar formation, geological structure, and sedimentary environment. In addition, there is a list of the key factors determining the selection of the field analog [26]:

1. Porosity
2. Permeability
3. Permeability distribution
4. Net thickness
5. Continuity
6. Hydrocarbon saturation

Kaigansko-Vasyukanskoe-more field is divided into three deposits: Pela Lache, Udachnaya and South-Vasukanskaya [27]. All calculations in this part are devoted to the Pela Lache deposit. Pela Lache is considered to be the main deposit for Kaigansko-Vasyukankoe-more. Next reservoir properties of Pela Lache deposit are known [28, 29]: Effective porosity — 0,23; Permeability — 170-700 mD; Net oil-bearing thickness — 20-30 m (producing depth varies between 2510-2540 m); Initial oil saturation — 0,8. Oil density in standard conditions — 870 kg/m^3. Oil formation volume factor — 1,452. Sea depth — 110-120 m. Also, there is a primary gas cap in the reservoir.

In 2012 several geological research papers regarding the shelf of Sakhalin Island were published. One of them is dedicated to the sequence stratigraphy of Kaigansko-Vasyukansky area, especially the Pela Lache deposit [29]. The nature of the formation is studied by the parallel comparison between Pela Lache and Odoptu-more (Northern dome) field structures. As can be seen in Figure 10, these two fields are located geographically close to each other.

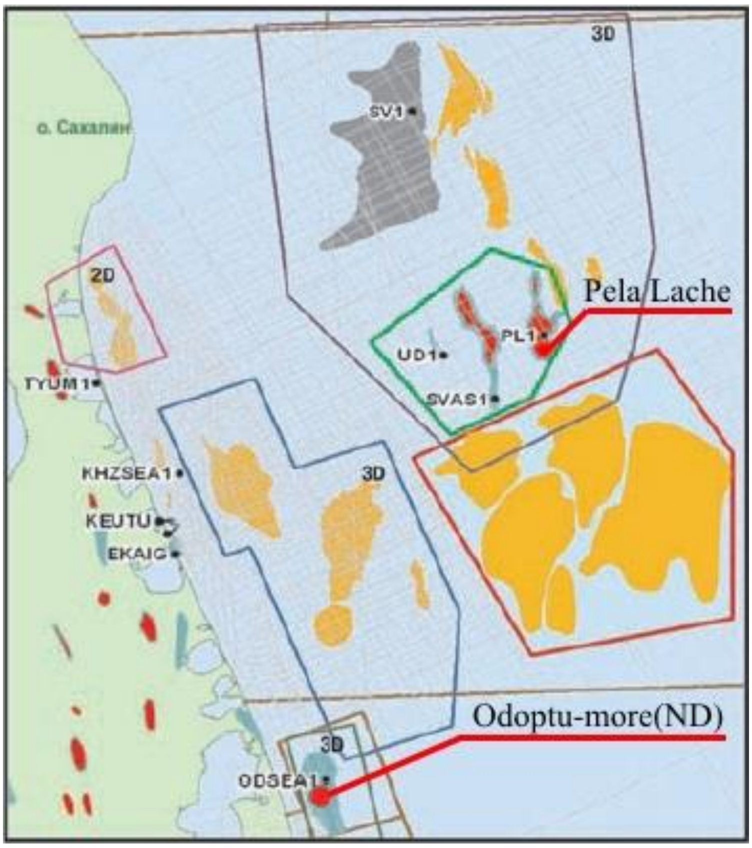

Figure 10. Kaigansky-Vasyukansky area (adapted from [29]).

Tkacheva (2012) used in her survey all available 2D and 3D seismic reflection data, which were collected during the last years [29]. The obtained data allowed to create sequence stratigraphy model. The information received during drilling was used to clarify characteristic features. The data were collected from the next wells: inshore Odoptu-more and Hanguza-more, offshore 1 Pela Lache, 1 South-Vasyukanskaya, 1 Udachnaya, 1 Savickaya. In the paper, Tkacheva (2012) states that the XX_2 formation is a typical example of the geological structure for the Odoptu-more (northern dome) due to the fact, that the most part of deposits belongs with Lowstand system tract. Formations of Kaigansko-Vasyukansky area also belongs to this kind of system tract. There are presented seismic and geophysical log characteristics of the formation, where the similarity of the geological structures for Odoptu-more (northern dome) field and Pela Lache, KVM field, can be seen in Figure 11-A. In Figure 11-B the map of the time sequence thickness map.

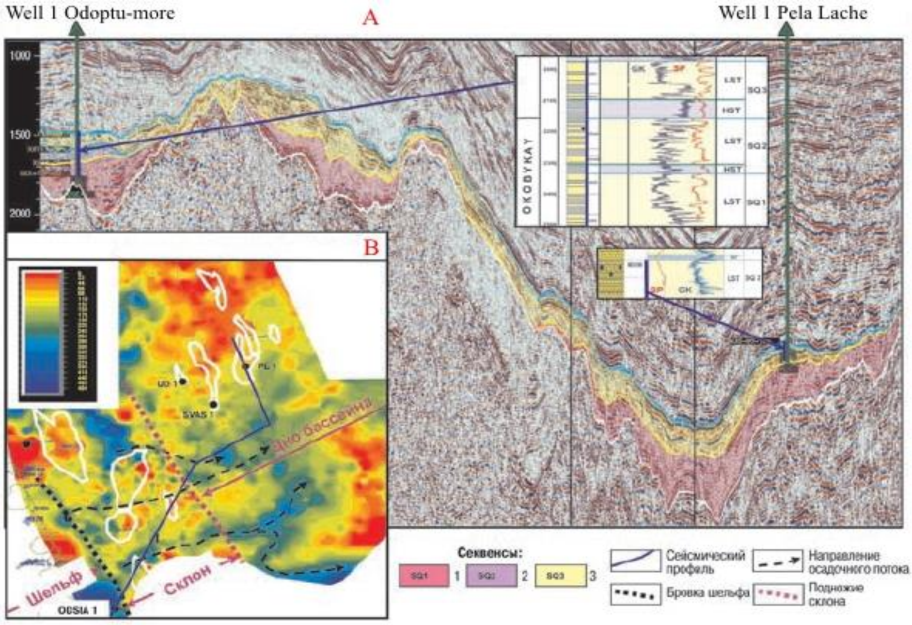

Figure 11. Seismic and geophysical log characteristics (A) and time sequence thickness map (B) [29].

Odoptu-more (Northern dome) or Odoptu-sea (Northern dome) field is one the first offshore fields in Russia. Production was started in 1998. The operator of the project is LLC RN-Sakhalinmorneftegaz, the affiliated company of Rosneft Oil Company. The production is conducted by horizontal wells from the shore of the island. In total 40 extended reach production wells were drilled. At the start of 2018 35 wells were in operation. Among them: 28 oil production and 7 injection wells. Actual production in 2017 was 371 thousand tonnes of oil and 128 mmcm of natural [30]. The field is located about 6 km from the shore of Sakhalin Island, northeast.

The stratigraphic column of the field is composed of next sediments (from bottom to top) [31]: Cretaceous; Machegarsky horizon (Oligocene sediments); Daekhuri horizon (Oligocene sediments); Uinin-Dagi-Okobykay horizon (upper-lower Miocene); Nutov horizon (upper Neocene-Miocene); quaternary rocks. Main oil-bearing formations are confined to lower Nutov sediments, where the thickness of the sand and silt reservoirs varies between 10-60m.

According to the report by T.L. Stytsenko and V.I. Igumnov [32], in 2006 the data was updated regarding the XX_2 formation. Next reservoir properties are known: Effective porosity — 0,2252; Permeability — 115mD; Net oil-bearing thickness — 20-25m; Initial oil saturation — 0,54.

As can be seen, Pela Lache(KVM) and XX_2 (Odoptu-more(ND)) reservoirs have relatively similar geological-and-physical characteristics. That leads to the possibility of applying analogue method for Kaigansko-Vasyukankoe more field analysis.

2.5 Calculations

The Kaigansko-Vasyukankoe-more field is in the early stage of design development that is why there is a lack of data on which calculations should be based on. But there are methodologies which allow conducting calculations in such case. One of them is the analog method. Nevertheless, there are limitations which affect the accuracy of the calculations. According to the Kharisov et al. (2018) [33], during research, they distinguished that data from fields, which are in the early stage of development, cannot be used for other field forecasts. It explains by the significant errors occurred in results and comparison with actual field data. In the Kharisov et al. (2018) research it is proven, that the analogue method, based on the displacement characteristics, can be used with satisfactory results only with the rate of the water-cut above 60%. The higher rate of water-cut at analog-field, the more accurate the assessment result will be.

It is identified that the XX_2 deposit can be used as an analog for the reserves and production profile calculations of Pela Lache deposit. As of 01.01.2009 for XX_2 formation was distinguished in accordance C2 estimation category: resources — 10412 thousand tonnes of oil and reserves — 2603 thousand tonnes of oil [34]. There is no any information regarding the resources and reserves for the Pela Lache reservoir. Still, it is possible to estimate it using the data received from different sources of information [28, 29]. The area of the Pela Lache formation is distinguished by using Figures 3, 10, 12 and the "Google maps" service. The estimated area of Pela Lache reservoir is 9-10 km^2. In further calculations the area is taken as 9 km^2, with approximate coordinates: 53°51'00.0"N, 143°40'00.0"E.

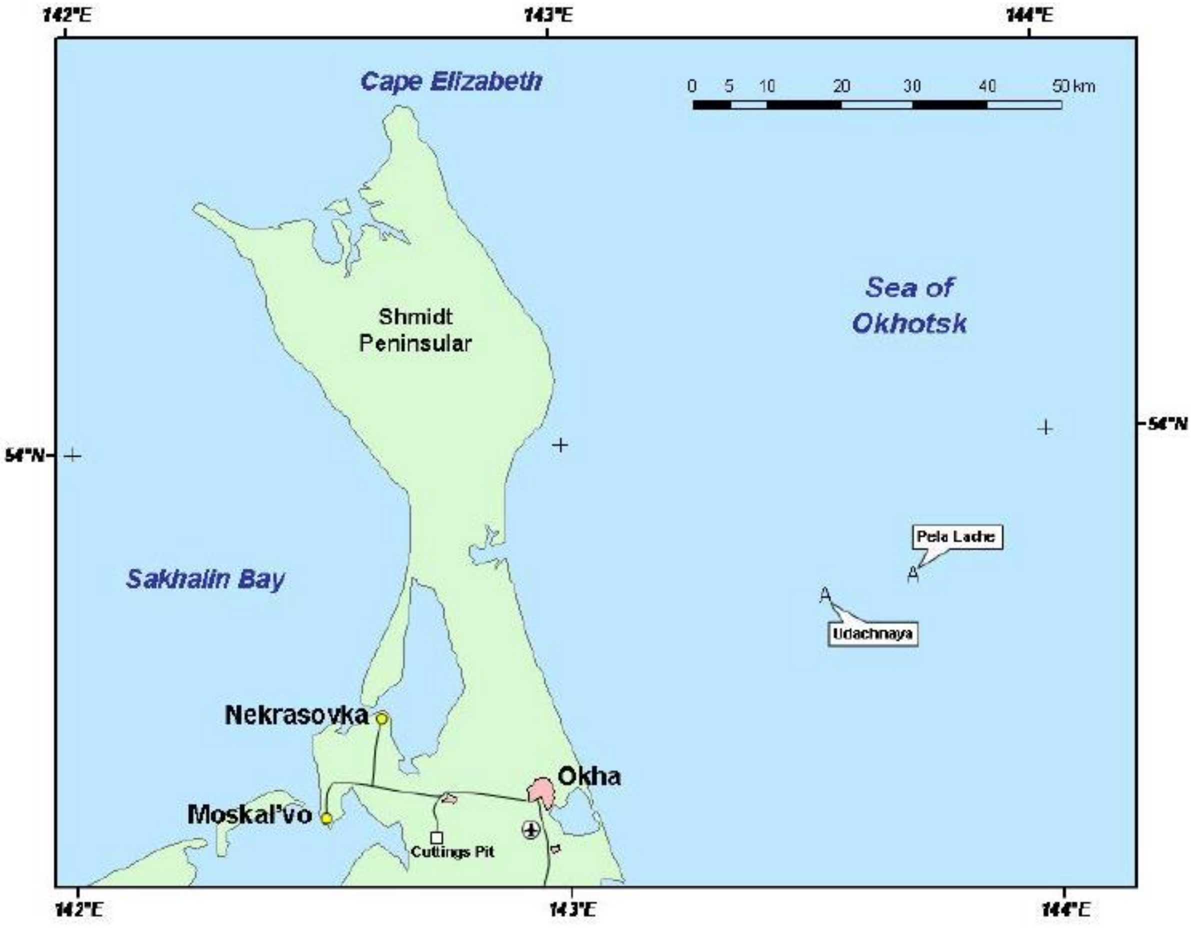

Figure 12. Pela Lache wells location [35].

Obtained parameters are enough to estimate the Pela Lache oil resources using Formula 3 and 4. It is decided to carry out calculations using the deterministic approach. Parameters and assumptions: oil saturated area (A) — 9 km^2; thickness of oil-saturated layer (h_o) is taken as — 20 m; oil saturation factor (S_o) — 0,8; effective porosity (φ) — 0,23; oil density in standard conditions (ρ) — 870 kg/m^3; oil formation volume factor — 1,452 m^3/m^3; it is assumed pressure maintenance mechanisms are the same or the difference between them is neglected; only oil is produced.

$$Oil\, resources = V_{os} \times S_o \times \varphi \times \rho \times \theta = \\ = 9 \cdot 10^6 \mathrm{m}^2 \times 20\mathrm{m} \times 0{,}8 \times 0{,}23 \times 870 \frac{\mathrm{kg}}{\mathrm{m}^3} \times \frac{1}{1{,}452} = 19{,}845 \text{ million tonnes} \quad (9)$$

Recoverable oil reserves are estimated by using Formula 6. The recovery factor according to the Lapotnikov and Savenok (2018) [34] is 0,25. It should be noted, that the analog field (Odoptu-more(ND)) has the same recovery factor, which can be calculated out of the presented oil resources and reserves. Recoverable oil reserves are calculated in the next equation:

$$Recoverable\ oil\ reserves = 19{,}845\ million\ tonnes \times 0{,}25 = 4{,}96\ million\ tonnes \quad (10)$$

According to the [36], the water-cut of produced liquid for the XX_2 reservoir as of August 2018 is about 62%. Therefore all vital requirements to make a prediction of oil-field performance, based on the displacement characteristics of the analog field, are satisfied.

There is the case when there is no information regarding oil production flow rate of the wells at the start of the development for Pela Lache reservoir. This flow rate is identified from the analysis of five XX_2 production wells from the source [36]. For each well, the average monthly decrease in oil-production rate is calculated. The results can be seen in Table 5.

Table 5. Average monthly change and start oil-production for 5 wells of XX_2 reservoir.

Well	Average monthly change in oil-production, %	Oil-production at the start, tonnes/day
1	-2,35	640,26
2	-2,37	364,57
3	-2,02	279,56
4	-2,34	566,02
5	-1,66	501,43
Avg.	**-2,14**	**470,37**

From further analysis of all wells of XX_2 reservoir, the values of oil and liquid flow rates; produced oil and liquid are found for the whole lifetime of development; the production profile and water-cut are presented in Appendix A, Figure A-1. Calculations are conducted in Microsoft Excel. After that recovery ratio and rate of increase of water-cut against time are calculated, the dimension of both rates is a unit fraction. Their ratio describes the characteristic of oil displacement. This relation is illustrated in Figure 13. The red dot in the graph is the moment when the water-cut becomes 0,98 (98%) and production stops, all recoverable reserves are produced. This dot is needed to make a trend to distinguish displacement characteristic in future steps. For 2018, the water-cut is approximately 62% with about 65% recovery rate. The formula of the trend is also presented in Figure 13. The trend demonstrates good coherence with Figure 14, presented by Dake (2001) [37], where f_{ws} is a water-cut (fractional flow of water) and N_p/N is the ratio between cumulative produced oil and initial reservoir oil in place.

It is assumed that Pela Lache has the same ratio between f_{ws} vs N_p/N as the XX_2. The oil flow rate is assumed to be the average from 5 known wells of XX_2 reservoir — 470,37 tonnes/day with an average monthly decrease in production 2,14%. The average monthly oil production rate is calculated as the average between the oil production rates on the first date of current and next month. The quantity of production wells for Pela Lache is assumed to be 8 due to the fact that this number of wells is considered to be drilled according to the RN-Sakhalinmorneftegaz drilling program [38]. It is also assumed that every year two wells are starting production, all wells have the same oil flow rates at the start, and the average monthly decrease is also the same, the interference of wells is neglected. The monthly production is estimated with the assumption that there are 30,4 days in the month; the operation factor is 0,95 [39]. The production profile for each well, accumulated oil and liquid are presented in Appendix A, Table A-2.

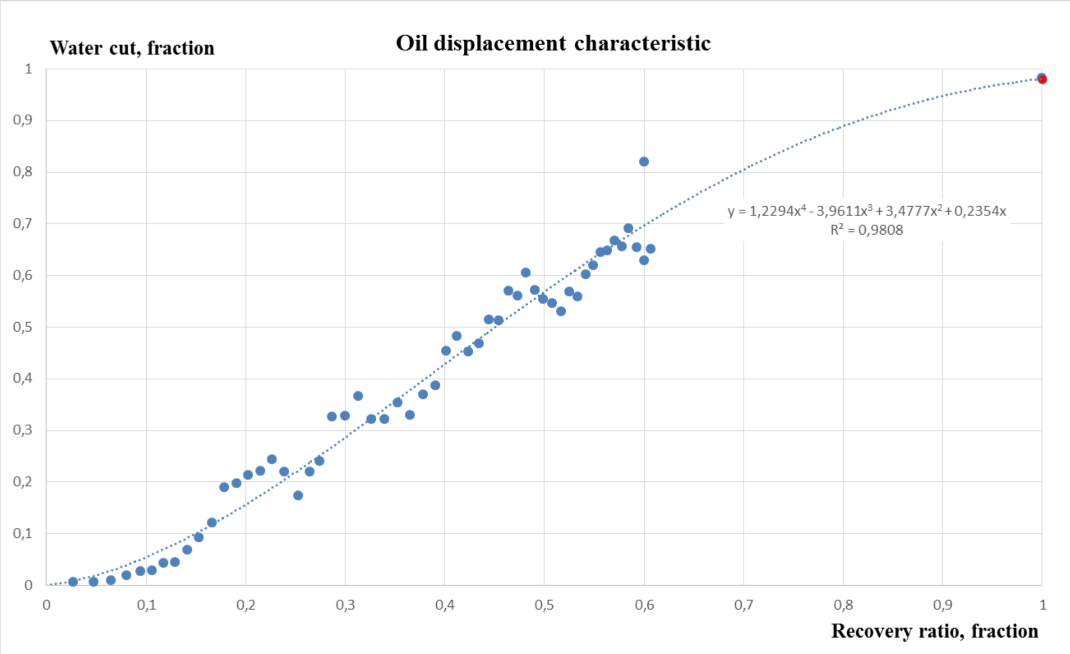

Figure 13. Oil displacement characteristic of XX_2 reservoir.

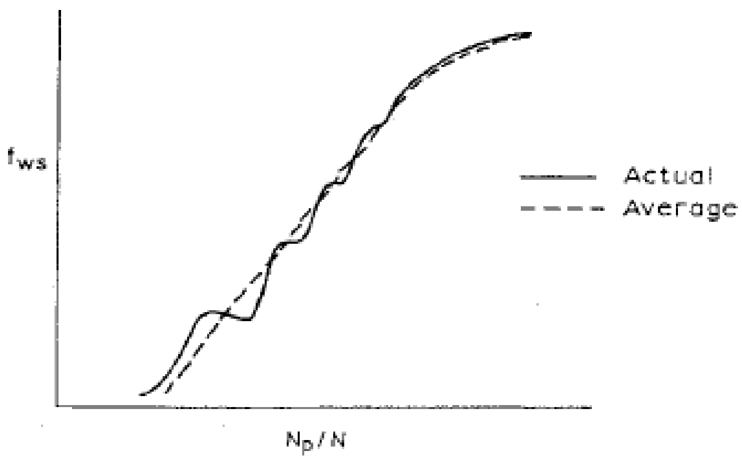

Figure 14. Actual and average displacement characteristics [37].

The well oil production flow rate produced oil and N_p/N ratio are calculated for every month along the entire development lifetime. The mass of initial recoverable reserves is taken from Formula 10. The water-cut is calculated using the trend of oil displacement characteristic, which is obtained from analog field and N_p/N ratio. That allows to estimate liquid and water production rates. When the water-cut reaches 98% the well production is stopped. In result, after 15 years of development, all wells reach 98% water-cut. The total produced oil is 4,78 mln. tonnes, it is 96,4 % of all recoverable reserves of the reservoir. The difference in 3,6% percentage can be explained by the imperfection of the trend due to the lack of data. The main trends for Pela Lache development are illustrated in Figure 15.

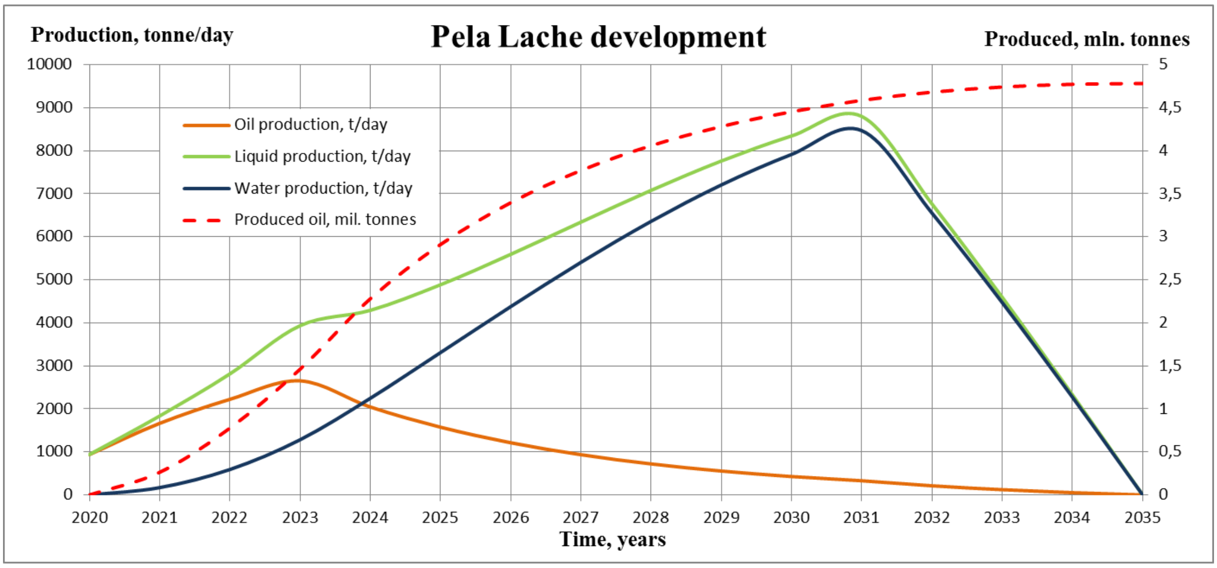

Figure 15. Estimated Pela Lache development trends.

The full calculation of indicators by year is presented in Appendix A, Table A-3.

2.6 Discussion and recommendations

Using obtained data from the Odoptu-more (ND) analog field, the resources and reserves of Pela Lache reservoir are estimated, as well as the development trends of the Pela Lache reservoir. It was determined that after 15 years of development 96,4% of the initial recoverable reserves will be produced, with a water-cut of 98%. The difference in 3,6% of the obtained percentage of produced initial recoverable reserves is explained by the imperfection of the trend due to the lack of data for obtaining proper oil displacement characteristic. The water-cut of XX_2 reservoir is only about 62%, it is enough for conducting assessments, but the greater value of the water-cut would give better estimation result. The decrease in the growth rate of fluid production in 2023 is explained by the end of the period of drilling wells because all wells are in production. There is the same reason why oil production starts to decrease after 2023. The decline in liquid and water production, which is observed between 2031-2035 years, can be explained due to the sequential shutdown of wells due to their reach of 98% water-cut.

Due to the fact, that there is a gas cap in this reservoir, the gas drive mechanism is recommended.

Chapter 3. Analysis of Subsea Production units

There is a rich world experience in the offshore production of oil and gas. Still, this knowledge doesn't fully cover all challenges faced during fields' development, which are located in arctic and subarctic zones, especially in Russia. That can be explained due to the fact that the most part of projects has been conducting in seas with mild meteorological and climate conditions free of ice. Unfortunately, for some cases, there is no possibility to implement well-known technologies for development fields with the use of objects which are located on the water surface, such as floating production storage and offloading (FPSO), gravity-based platforms, semi-submersible platforms, etc. due to harsh meteorological and ice conditions.

Based on that, the implementation of these methods is not feasible due to [40]:

- significant distance from field to shore;
- sea depths vary in values from 30 to 600 m;
- extremely cold and long winter period;
- year-round icebergs and glacier presence.

Most part of these points is applicable for KVM field, except for the presence of the icebergs and glaciers. Then, one of the options to avoid these problems is to implement subsea production systems. This technology includes implementation of subsea well completion design when the well-head is located on the seabed. Well production is extracted and transported to an onshore facility under the water surface (and under ice cover). All required equipment for production is located on the seabed. That allows to avoid negative effects of the extreme climate and ice conditions.

Russian experience in this technology is very limited; only one field is under development. Development of the Kirinskoe field, which is located in the sea of Okhotsk in 28 km from the shore, is carrying out with the implementation of the subsea production system by Gazprom PJSC. The depth of the sea is 90 m. The produced gas is collected and transported to onshore facilities by pipeline. The seismic activity of the Sakhalin region is taken into account that is why all objects are believed to withstand the earthquake with 9 point magnitude [40].

According to the Technical scope of work (2014) [41], for the Pela Lache reservoir, it is planned to drill 8 production oil wells. The technology of production is a subsea production system with two four-slot well template subsea production modules. Next chapter describes the main features of such a subsea production system, identifies feasibility, and estimates the cost of its implementation.

3.1 Subsea production system

Subsea production system for Pela Lache development is considered to include two four-slot well template subsea production modules. It is taken into account that the number of wells is constant and equals to 8. Basically, there are several options on how to group these wells:

- satellite wells;
- clustered satellite wells;
- production well templates.

In order to achieve an appropriate well location plan the groups of reservoir and drilling engineering should work together in early steps of field development. First of all, reservoir engineers distinguish the borders of the reservoir, the number, and type of wells. After that, location optimization can be started. From this moment both groups of engineers are faced with the problem of balance between the cost for wells' drilling, construction, and maintenance versus the best petroleum recovery rate. There is also a cost tradeoff consideration.

The first kind of well layout is satellite wells. The satellite wells term is used for an individual subsea well. Generally, satellite wells are broadly used for small fields, where few wells are located in comparative significant distance between each other. From each well fluids produced from the reservoir are transported by a single flowline to a subsea manifold. If there is a requirement, that a big number of wells should be, this type of field layout causes significant costs due to quantity and length of flowlines and umbilical, their installation, maintenance and assurance issues [42].

The second type of well layout is Clustered Satellite Wells. Wells locate near each other and connect to a subsea manifold, which is also located not far from them. This kind of layout is less cost-intensive in comparison with wells, which are located far from each other.

The main function of subsea production manifold is to collect and distribute production through an arrangement of piping and valves. Also, there are some specific functions [42]:

- to gather the production from individual satellite wells into a production header and manage the transport production to a field production gathering flowline;
- to gather the flow from other production gathering flowlines and transport this flow to a larger export pipeline;
- to provide access for Remotely Operated Vehicle or installation tool for installation of flowlines, chokes, pig launchers/receivers and etc.

Figure 16. Example of a 4-Well Subsea Manifold [42].

Figure 16 illustrates an example of a 4-Well Subsea Manifold [42].

The main reason for this point is that relatively low cost due to savings from the decrease in the flowlines and umbilical length. In case, when the satellite wells are in a close distance to each other, a separate production manifold can be constructed next to them to collect the production from these wells and transport it by the flow line [42]. Figure 17 shows a field layout, where three satellite wells are clustered. The production is collected in the manifold. There are single production flowline and single umbilical. The distance between wells varies and depends mostly from reservoir engineers' decision and safety well drilling without any risk to damage the well/wells nearby [42]. UTA is an Umbilical Termination Assembly.

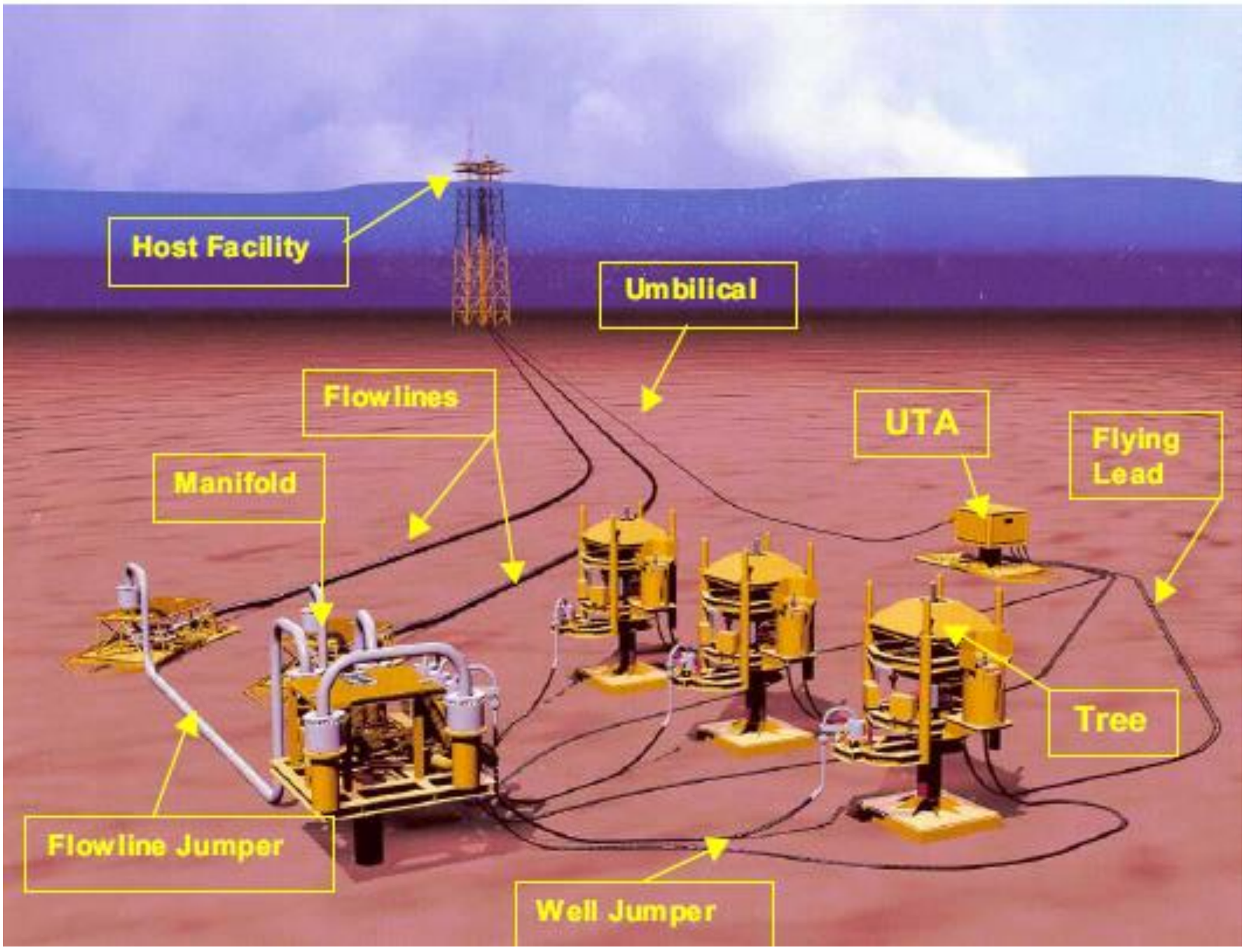

Figure 17. Typical well cluster [42].

The third way for well layout is subsea Production Well Templates. It is another option for wells' clustering. Here, a subsea template (subsea production unit/SPU) is a structure, which combines the functions of a subsea template and a subsea manifold, all in one integral assembly. The main function of this structure is to provide guidance for wells' positioning and to control their locations relative to each other [42]. The example of a template as a separated structure is shown in Figure 18.

Specific functions of the subsea template:

- to provide guiding and positioning the well conductor during installation;
- to control the space between well conductors, which are located nearby;
- to provide support for well completion equipment.

Figure 18. The template as a separated structure [42].

The template is a weldment structure, where wells have a close position to each other. Templates can be constructed for two or more wells. The number of wells, which template can support may be more than 12 [42]. The number of wells in the template is limited only by the weight and dimension of the well template which the installation vessel can handle. Small well templates can be installed by the drilling rig, but for larger ones, there is a need of special installation vessel, which could withstand required loads. The example of a subsea template is shown in Figure 19.

Figure 19. Five slot subsea template [42].

There is a list of benefits of production wells templates in comparison with clustered satellite wells [42]:

- accurate wells location;
- possibility to include the manifold and valves;
- piping and umbilical jumpers, which connect the trees and manifolds, can be pre-fabricated, tested and modified to satisfy required characteristics before offshore installation;
- cost of piping and umbilical is less;
- most part of the equipment is modules, which leads to a decrease in installation time;
- less problems connected with flow assurance due to shorter flowline piping distances
- less need for extensive pipe insulation
- template structure takes the horizontal load and supports wells.

Disadvantages:

- design and fabrication time in some cases can be much longer due to complexity;
- risk of emergency situations due to the time parallel production and drilling activities;
- less flexibility in wellhead location determination;
- less experience and fewer qualified manufacturers, suppliers and contractors;
- Remotely Operated Vehicle access may be limited due to lack of space.

For Pela Lache reservoir, where are considered to be 8 production wells, it is possible to implement all ways for field development, which are shown for 4 wells in Figure 20.

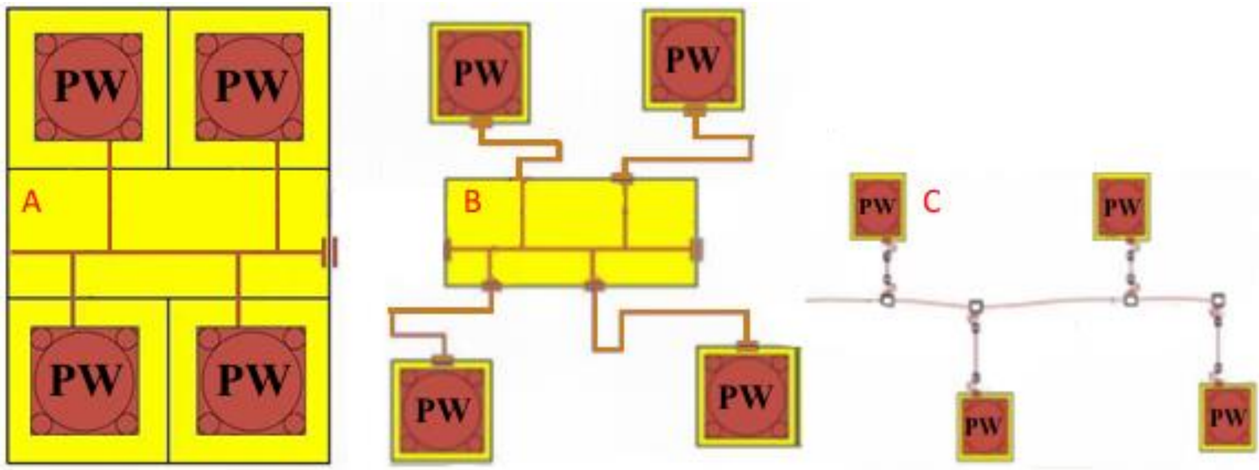

Figure 20. A - Subsea well template, B - Clustered satellite wells, C - Satellite wells. PW means production well.

3.2 Selection of optimal subsea production structures layout

As it is mentioned above, in the Technical scope of work (2014) [41] is written, that 8 production wells are grouped in two subsea four-slot well templates. In order to estimate the economic feasibility of such technical design, the comparative analysis is conducted. The comparison is carried out between two concepts: two subsea four-slot well templates and one eight-slot well template. The analysis is done based on the Grekov et al. (2007) methodology [43].

This methodology is worked out to estimate and find such field layout with subsea production templates, for which there is a minimum of capital and operating costs for the field development. It is obvious, that the capital costs for subsea production units are in the direct dependence from the number of subsea production units, which in turn depend on the number of wells. This dependence can be written in the next form, where k is a quantity of SPU and m is a number of wells in one SPU [43]:

$$C_1 = f_{SPU}(k, m) \tag{11}$$

The f_{SPU} function also takes into account the costs for installation, which depends on the k and m values. So it is possible to consider, that with an increase in the number of SPU the costs also increase. This relation is described by Function 11.

A decrease in the number of SPU and an increase in the number of wells in them lead to an increase in cost for manufacturing and installation such kind of SPU. Also, the costs will increase due to the fact that more complex and long directional (slant) wells are required. This, in turn, leads to a pressure decrease in production string, which can cause the need for additional costs for implementation technologies for pressure drop compensation. On the other hand, decrease in the number of SPU and increase in quantity of wells in them lead to the decrease in the total length of infield flowlines, umbilical, maintenance and flow assurance [43].

Basically, the finding of the rational development field layout is an extremely difficult task that may not have one unambiguous solution. That is why there is a need to make certain assumptions. Mostly the assumptions are taken not much for simplification, but for correct problem formulation, as well as the possibility to analyze the obtained results.

There are the next variable parameters:

- number of SPU and their location;
- number of wells;
- distance from the bottom of the well to the well-head projection on the production horizon;
- well design.

Also, there are some assumptions to solve the problem:

- wells' design does not change the wells' production;
- each field layout includes only one type of SPU, without combinations.

Next input data should be known or assumed to solve the problem:

- costs of SPU with different number of wells in it (including spending for transportation and installation);
- dependence of the cost of drilling a well on its length;
- dependence of infield flowlines and umbilical costs on their diameter and length.

The approximate cost of various SPU types is presented in Table 6. These values are presented for Shtokman field by Hydro Company [43]. Here, and in all following parts all costs are counted in the United States Dollar, marked as "$".

Table 6. SPU characteristics with a different number of wells [43].

Characteristic	Number of wells in SPU				
	4	6	8	10	12
Total weight, t	400 - 600	700 - 1000	1300 - 1600	1800 - 2000	2000 - 2500
Cost, mln. $	110 - 130	160 - 175	185 - 200	210 - 230	235 - 255
Installation cost, mln. $	8 - 12	8 - 12	10 - 12	10 - 12	10 - 12
Drilling rig lease, mln. $/day	0,6 - 0,8	0,6 - 0,8	0,8	0,8	0,8

The presented costs for drilling rig lease include mobilization and demobilization. From Table 6, it is possible to say, that if SPU has less number of wells then the cost is lower, as well as the installation and lease costs. But if there is a requirement of a great number of wells, this type of SPU leads to an increase in total costs for the project.

The advantages of SPU with a greater number of wells:

- less construction-and-assembling operations in the open sea;
- a shorter length of total infield flowlines and umbilical.

Disadvantages:

- need to lease more expensive vessels for construction-and-assembling operations due to the heavier weight of SPU;
- greater number of wells causes the need to drill more complicated directional wells with greater deviation, which leads to bigger costs for drilling.

It can be said in a summary, that the total costs for layout selection should include spending for SPU cost, installation, infield flowlines, umbilical, and wells drilling.

The cost of well construction depends on two main components: the drilling time and the total length of the well. For the estimated cost of field development options using various types of SPU, it is not taken into account such expense items as preparatory work for drilling, well testing, field geophysical work, etc., considering them unchanged for both options that do not affect the comparative analysis of the development options.

The spending on drilling can be expressed by the next formula [43]:

$$C_{well} = A_1 \cdot T + A_2 \cdot L \qquad (12)$$

Where:

C_{well} — well cost, mln. $;

A_1 — costs attributable to 1 hour of the work of the drilling rig (rental of the rig, the salary of the drilling crew, energy, etc.), mln. $;

T — total well construction time, days;

A_2 — costs attributable to 1 m of the length of the well tool (bits, drilling, casing, cement slurry, transportation costs, tools, etc.), mln.$/m;

L — total length of the well.

During the development, a significant part of the Equation 12 is attributable to the time of drilling (about 80%, according to Grekov et al. (2007)), since it is the rent of a drilling vessel that determines the cost of drilling at sea. Due to this point, assume that costs are attributable to 1 m length of the well (A_2) equals 0,25·A_1. So it can be expressed:

$$C_{well} = 1{,}25 \cdot A_1 \cdot \frac{L}{v_c} \qquad (13)$$

Where v_c — commercial drilling speed, which based on the world experience for an average length of the well 3500 m is 50 m/day [43].

To calculate the total length of the well there is a need to distinguish the course of the well. The trajectory of the well, selected for the analysis, is shown in Figure 21 [43].

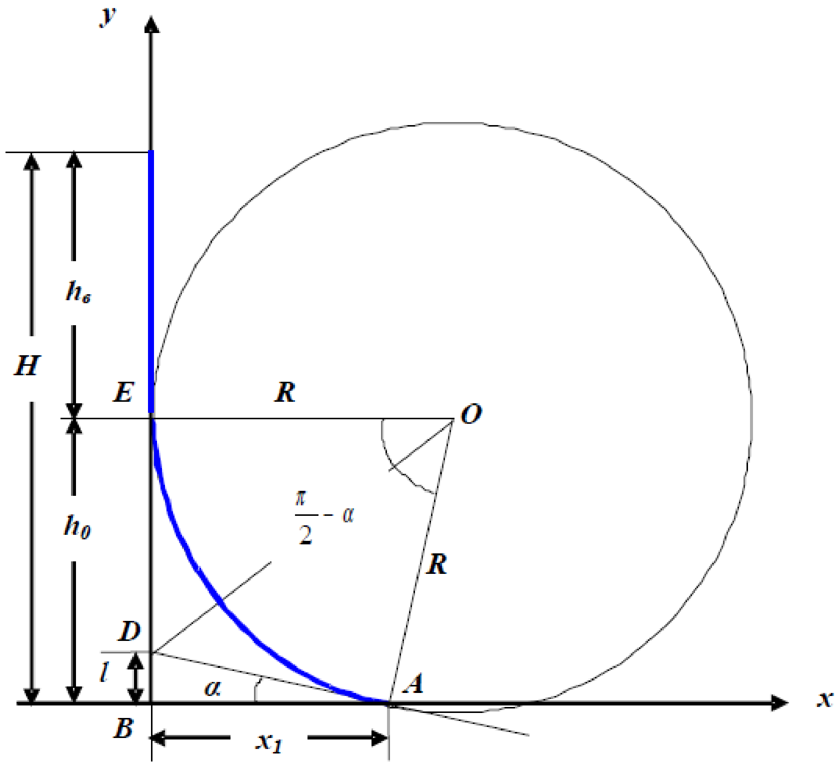

Figure 21. Well trajectory [43].

Where:

H — vertical well depth, m;

$h_в$ — vertical well section, m;

h_0 — the projection of the inclined section of the well on the y-axis, m;

x_1 — the deviation from the vertical, m;

$\frac{\pi}{2} - \alpha$ — zenith angle (inclination angle), angle degree.

From Figure 21:

$$ED = DA = \frac{x_1}{cos\alpha};\ \mathrm{R} = \frac{x_1}{cos\alpha \cdot tg(\frac{\pi}{4} - \frac{\alpha}{2})} \tag{14}$$

The total length of the well equals:

$$L = h_{\text{в}} + \frac{x_1 \cdot (\frac{\pi}{2} - \alpha)}{cos\alpha \cdot tg(\frac{\pi}{4} - \frac{\alpha}{2})}\ for\ x_1 \leq \frac{h_0 \cdot cos\alpha}{1 + sin\alpha} \tag{15}$$

It should be noted, that with an increase in the deviation of the well from the vertical, its cost increases not only by increasing the total length, but also by possible reducing the commercial drilling speed, which can lead to an increase in the well construction time, and, therefore, to additional costs for mobilization and demobilization of drilling rigs. In addition, an increase in the length of the well necessitates the use of a drilling rig of greater capacity, which in turn leads to an increase in rental costs and maintenance [43].

The cost of infield flowlines is expressed in Equation 16:

$$C_{flowlines} = f(d, L_{flowlines}, L_{umbilical}) \tag{16}$$

Where:

d — flowline diameter, inch;

$L_{flowlines}$ — total flowlines length, m;

$L_{umbilical}$ — total umbilical length, m.

The diameter of the flowlines depends on the volume of production at the SPU [43]:

$$\frac{Q}{q_i} = \left(\frac{D}{d_i}\right)^{2,6}\ where\ q_i = \frac{Q}{k} \tag{17}$$

The k parameter is a quantity of SPU and the Q value is the maximum flowrate 8971 t/day, which is calculated in Chapter 2. Also, q_i is the production rate for one SPU. Based on the world experience, the concept with two SPU the d_i is taken as 20 inches. For the option with single SPU, the d_i is calculated by Equation 17 and equals 26 inches. The dependence of the cost per meter of flowline from its diameter is shown in Figure 22 [43].

The total cost for field layout accumulates all spendings related with SPU, wells drilling, flowlines and umbilical. It can be expressed by the next equation, Equation 18:

$$C_{total} = C_{SPU} + C_{well} + C_{flowlines+umbilical} \tag{18}$$

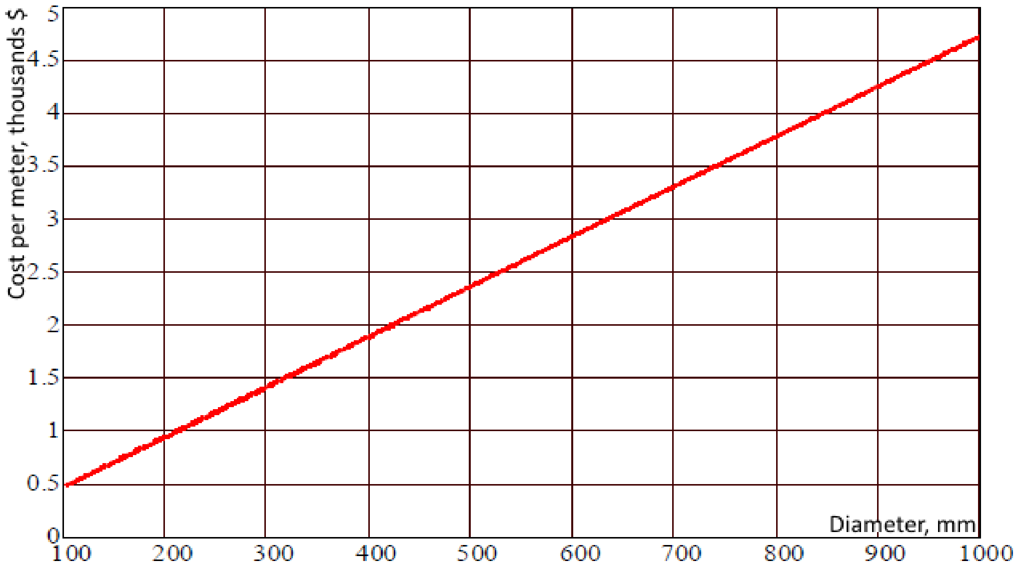

Figure 22. The dependence of the cost per meter (adapted from [43]).

The SPU position is calculated in order with the next algorithm [43]:

1. select the wells for each SPU;
2. choose the position of one well and connect it to another one. The line between them should be divided into two equal parts. New center (intermediate point) is located in the point of division.
3. connect the intermediate point with another well. Divide this line into three equal parts. The new center is located in the nearest division point to the previous intermediate point.
4. connect the intermediate point with another well. Divide this line into four equal parts. The new center is located in the nearest division point to the previous intermediate point.
5. described steps repeat in the same manner. The final intermediate point is the "center of gravity (balance)" for the system, where SPU is considered to be placed. The algorithm is used for each SPU.

The graphic illustration of this algorithm is shown in Figure 23 [43].

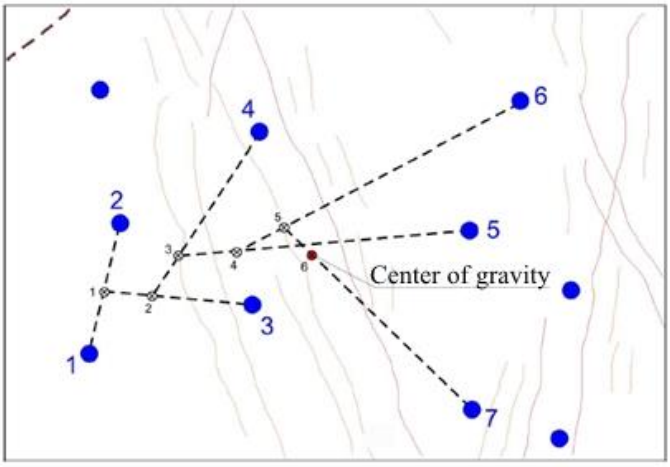

Figure 23. Graphic representation of the algorithm finding the coordinates of the SPU (adapted from [43]).

3.3 Subsea production units: estimation and analysis

To distinguish the layout and estimate its costs there is a need to know the locations of wells bottoms. As it is mentioned before, there is no information regarding it. Also, it is unknown the borders of the reservoir. In Chapter 2, the approximate area is estimated and equals 9 km^2. It is taken into the assumption, that there is a square-shape reservoir with 8 production wells (each well has its one number), Figure 24 and Figure 26 are presented for layouts with two and one SPU respectively, where blue points — locations of wells bottoms, red and green points — locations of SPU. Horizontal lines — horizontal sections of wells. Wells bottoms located in an analogical manner as the five-spot well system, where triangles — injection wells; a circle — a production well; see Figure 25 [44].

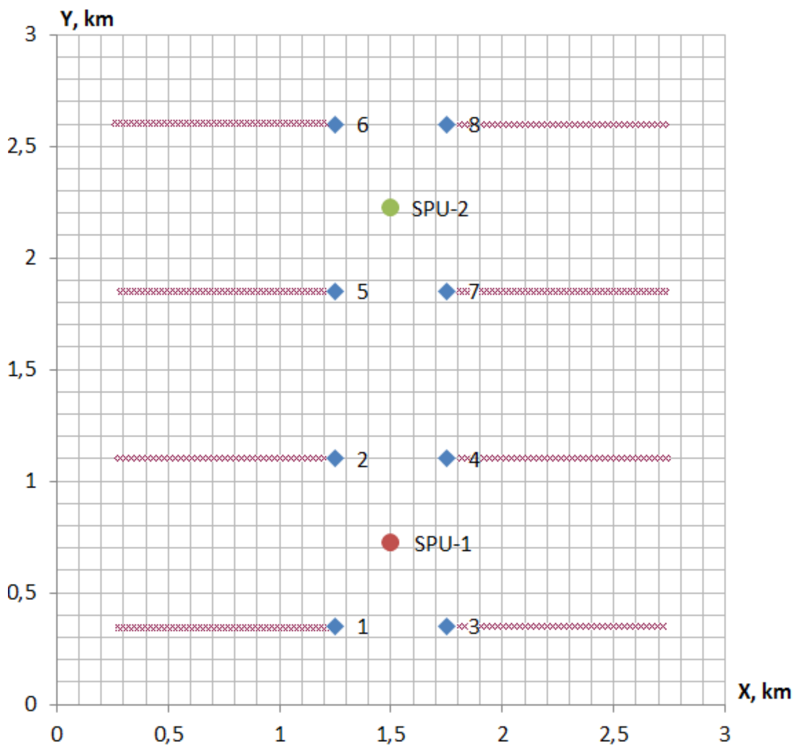

Figure 24. Field layout with two SPU.

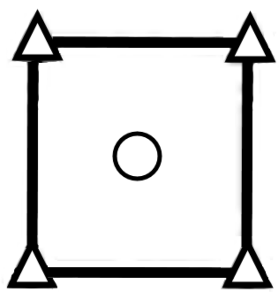

Figure 25. Five-spot well system (adapted from [44]).

The trajectory of the horizontal section of wells is directed in order to distribute proportionally the reservoir coverage of each well.

Costs for SPU are taken from Table 6 — 110 mln. $ for one four-slot SPU and 185 mln.$ for eight-slot SPU. For the first layout with two SPU, wells 1,2,3,4 are grouped to SPU-1, the rest of wells to SPU-2.

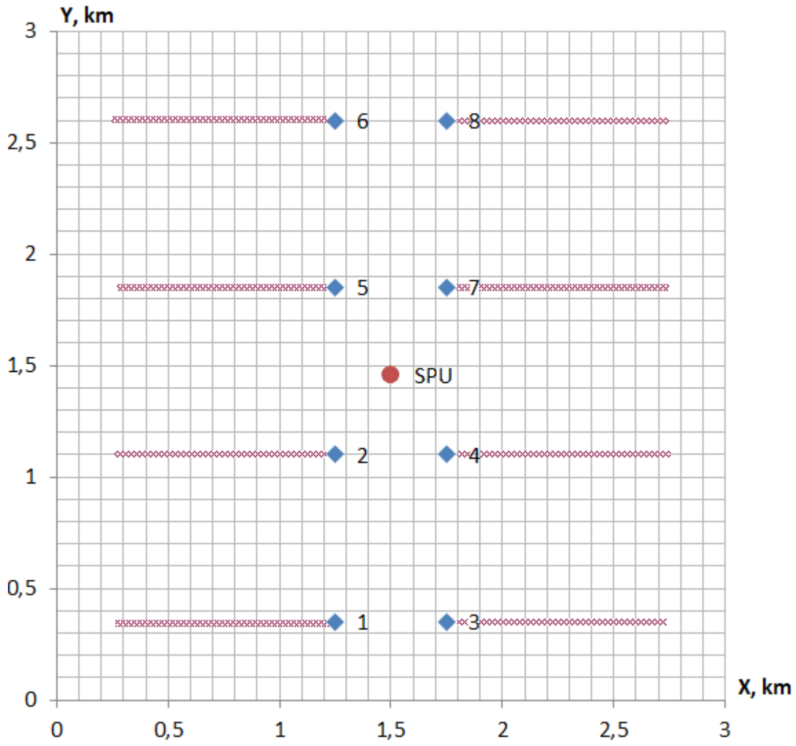

Figure 26. Field layout with one SPU.

Next step is to calculate wells construction costs. The coordinates of wells bottoms and SPU for both concepts are presented in Table 7. The locations of SPU are calculated with the use of the algorithm, described previously.

To continue calculations, next parameters are assumed: all wells are horizontal with length of horizontal part 1000 m; the minimum length of $h_{В}$ (vertical well section) is 1100 m (these two parameters are taken as typical parameters for offshore horizontal wells presented by Rosneft in April 2017) [45]; zenith angle (inclination angle) is 80° [43]; well bottom depth is the same for all wells and equals 2520 m.

Table 7. Wells bottoms and SPU coordinates for both concepts.

Wells	X-axis, km	Y-axis, km
1	1,25	0,35
2	1,25	1,1
3	1,75	0,35
4	1,75	1,1
5	1,25	1,85
6	1,25	2,6
7	1,75	1,85
8	1,75	2,6
SPU-1	1,5	0,725
SPU-2	1,5	2,225
SPU	1,5	1,475

For the first concept, Figure 24, with two SPU, the distances from all wells to SPU are the same and equals about 0,45 km — x_1. For the second concept, Figure 26, there are two lengths from SPU to wells bottoms — about 0,45 km and 1,15 km — x_1 and x_2. The calculated length of the vertical well section for x_1 is 1982,9 m, for x_2 is 1146,6 m, both satisfy the required values of the minimum vertical section of the well. The lengths of the wells from wellhead to bottom are calculated by Equation 15. The total length of the well for x_1 is 3744,4 m and for x_2 is 4093,8 m. All lengths calculations are presented in Appendix B, Table B-1.

Using Equation 13 and coefficients from Table 6 for A_1 (costs attributable to 1 hour of the work of the drilling rig) the costs for drilling are obtained. For the first concept, the A_1 coefficient is 0,6, so the total cost for drilling all wells for both SPU is 449,32 mln.$. For the second concept, the A_1 coefficient is 0,8 and the total cost for drilling all wells is 627,06 mln.$.

On the next stage of calculation, it is needed to estimate the costs of infield flowlines and umbilicals. There is also a need to make an assumption in the total length of these parameters. Assume that total length is 2 km both of them. The diameter of flowlines for the first option is 20 inches, for the second one is about 26 inches. Using Figure 22 the costs for both diameters are identified: for 20 inches — 2450 $/m and for 26 inches — 3200 $/m. The total cost of flowlines for the case with two SPU — 9,8 mln. $, for the second one, is 6,4 mln. $.

According to Grekov et al. (2007) [42], one of the most spread diameters of the umbilical is 6 inches. The cost for such diameter per meter varies between 2000 – 2500 $. The price for 1 m is taken as 2000 $. The total costs for the first case are 8 mln. $ and for the second one are 4 mln. $.

Finally, summarizing all costs for each case next numbers are obtained:

- Two four-slot production units: 687,13 mln.$;
- One eight-slot production unit: 822,46 mln.$.

All costs for both options are presented in Table 8.

Table 8. All spending on both cases.

	Case-1	Case-2
Costs section	Costs, mln.$	
SPU	220,00	185,00
Drilling	449,33	627,06
Flowlines	9,80	6,40
Umbilical	8,00	4,00
Total	687,13	822,46

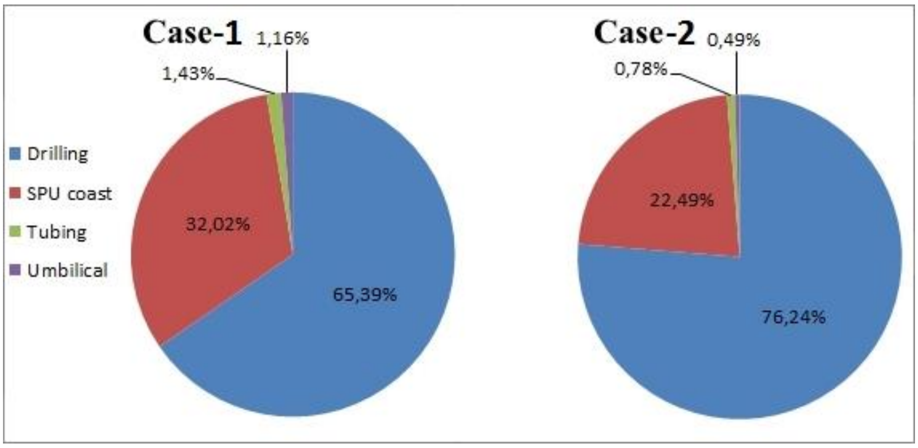

Figure 27. Costs for each case in percent.

3.4 Conclusion and recommendations

Obtained results show that the first concept with two four-slot subsea production templates is more economically effective in comparison with one eight-slot SPU. Spending on each section is presented in Figure 27 as a percentage of the total costs for each case of the layout.

As can be seen, for both layouts the main cost associated with the drilling of wells. As it was expected, the cost for option-2 is higher due to more complex trajectory and length of the wells. The SPU costs for option-1 is higher, but due to the less complex wells' trajectory, it allows to significantly decrease the costs, which in turn leads to the inexpensiveness of the project, in comparison with option-2. Despite the fact that spending on pipelines and umbilical in the first case is about 1,5 times and 2 times more from the second option, respectively, their total contribution to the costs is insignificant compared to drilling and acquiring production templates. This leads to the conclusion that for comparatively small reservoirs, like Pela Lache, the costs of satellite wells or SPU, as well as drilling wells make the greatest contribution to the total subsea production system cost. Also, comparison economic analysis between four-slot and eight-slot subsea production unit options proved that the most cost-effective is the first option, which corresponds to the choice of the company, which is presented in the Scope of Work [38].

Based on the results in this chapter and recommendation, made in Chapter 2, it is possible to propose a subsea production system layout.

Subsea production system contains equipment for collecting, extracting oil emulsion from 8 wells and transport (pipelines). Fluids from each well are directed from the reservoir through the main process equipment: well tubing, wellhead equipment, templates, field pipelines, and collected in a subsea manifold (PLET — Pipeline End Termination). From the manifold, the products are directed along the offshore pipeline route.

In order to avoid wax blockage of subsea pipelines and equipment, a wax inhibitor should be supplied to each template. The inhibitor is transported from shore by umbilical.

Umbilical serves to control and monitor subsea equipment. The umbilical system is designed to transmit high-pressure (HP) and low-pressure (LP) hydraulic fluids to the well and equipment, with a return line, there is also a line for supplying chemical reagents, well annulus control line, and an electrical signal supply line. The recommended type of umbilicals is Steel Tube Umbilicals with a 6-inch diameter, which is taken in accordance with Oceaneering umbilicals description [46] and Grekov et. al (2007) [43].

For proper umbilical usage, there is a need for a subsea distribution unit (SDU). SDU is designed to accommodate lines of umbilicals and installation of hydraulic and electrical connectors. The SDU is used to distribute hydraulic and electrical flows into SPU and gas injection well/wells.

The subsea production system includes:

- two subsea production four-slot templates;
- two flowlines with 20 inches diameter;
- two PLET;
- gas pipeline;
- umbilical and SDU ;
- one or several gas injection well/wells.

PLET is used to connect flowlines from SPU with the pipeline, which goes to the shore and to provide further circular cleaning of the pipeline by pigging.

The route of the umbilical and gas injection pipeline is laid taking into account the minimization of intersections with the production pipelines.

Also, it is recommended to transport produced products to shore facilities in two 20 inches pipelines. For later stages of field development, with lower rates of production, it is considered to use only one pipeline. Such a scheme is recommended due to the next advantages:

- possibility of repairing one pipeline without stopping production;
- providing circular cleaning of the pipeline from shore by pig launcher and receiving pig back at the shore without additional subsea equipment/constructions;
- the use of one pipeline in the period of falling production and, accordingly, the provision of high fluid velocities, which prevent wax precipitation;
- possibility of flushing the pipeline with hot prepared oil.

Figure 28 shows the recommended subsea production system layout, based on all aspects and features of the Pela Lache reservoir, which are possible to identify and analyze.

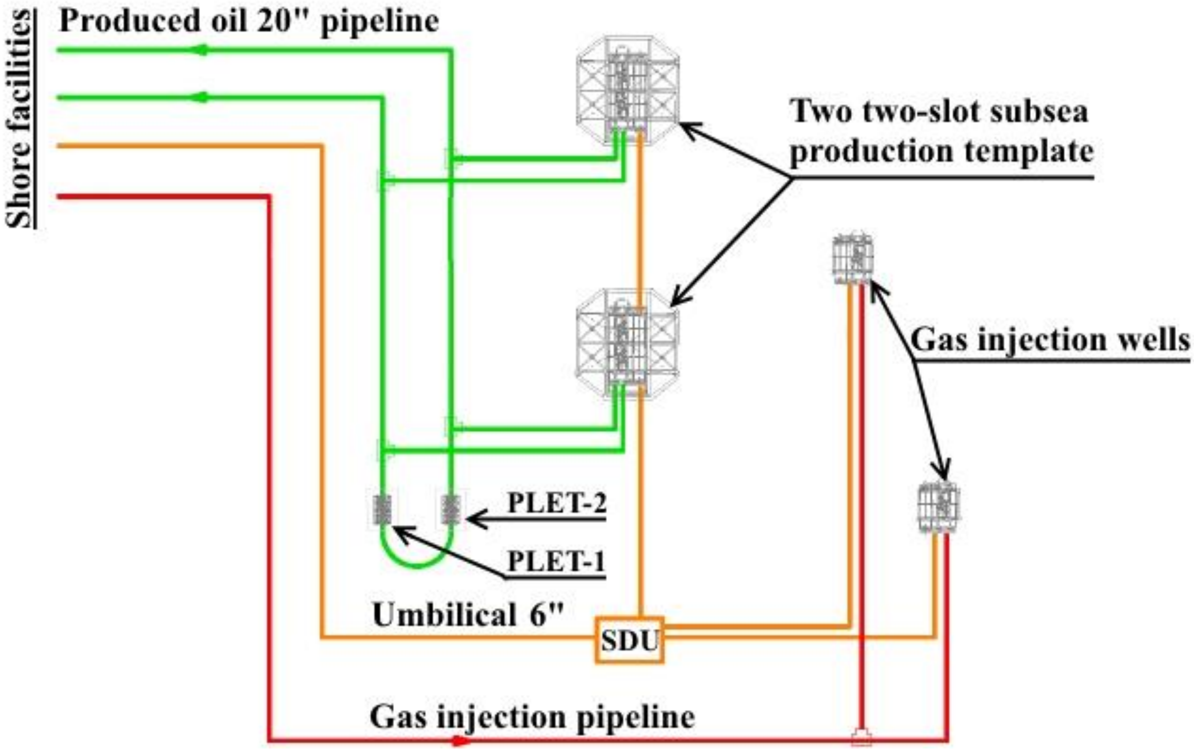

Figure 28. Proposed subsea production system layout.

Chapter 4. Economic analysis

One of the most important factors in the selection of a certain concept of field development is its economic effectiveness. Conventionally, project development costs can be divided into three main categories:

- exploration and evaluation of reserves;
- field and infrastructure development;
- operating expenses.

Capital investments in the field and infrastructure development are the most significant. Based on global experience, this category of expenses makes up approximately 60-70% of the total investments in the project. Investments in the field and infrastructure development of the project include [47]:

- drilling of wells;
- offshore facilities design and construction;
- equipment of technological processes;
- laying of infield and trunk pipelines;
- downhole equipment;
- onshore facilities and other objects.

It is taken into the assumption, that the exploration and evaluation of oil reserves have already been carried out by the company, and the contribution of these points of expenditure is insignificant. To determine the economic efficiency of project development, it is decided to evaluate the capital investments for the field and infrastructure development of the project with corresponding operating costs. The revenue, derived from the sale of oil, can be estimated using the results of oil production rates calculations, presented in Chapter 2. The main spending on field development is identified in Chapter 3. For a fuller analysis, the costs of laying pipelines and oil treatment facilities should be taken into account.

4.1 Determining the route and cost of the pipeline

There is an agreement between the Rosneft Oil Company and the companies of the Sakhalin-1 project, whereby products from the Odoptu-Sea field (northern dome) are directed to the Chayvo Onshore Processing Facility (OPF), processed and then transported via the trunk pipeline to the De-Kastri Oil Terminal. Therefore, it can be assumed that products from the Pela Lache deposit will most likely be transported in the same way. The oil trunk pipeline lies between the Chayvo OPF and De-Kastri Oil Terminal, and have enough capacity to transport oil from Pela Lache deposit [36]. All existing pipelines in the area are shown in Figure 29 [48].

Based on the coordinates of the Pela Lache reservoir, distinguished in Chapter 2, it is possible to propose pipeline route. Basically, there are two options for laying the pipeline to Chayvo OPF and further trunk pipeline to De-Kastri Oil Terminal: the first one — completely by subsea pipeline; the second — with the shortest length of the subsea part and land route. The coordinates of Chayvo OPF are founded in the “Google maps” service. The proposed ways of pipeline routes are presented in Figure 30. The Case-2, the land part of pipeline route is laid with the maximum possible use of known utility line areas. Throughout the land part of this route, the pipeline is laid in a trench and covered with soil. According to the Design code SP 36.13330-2012 [49], the pipeline should be buried down to 0,8 m.

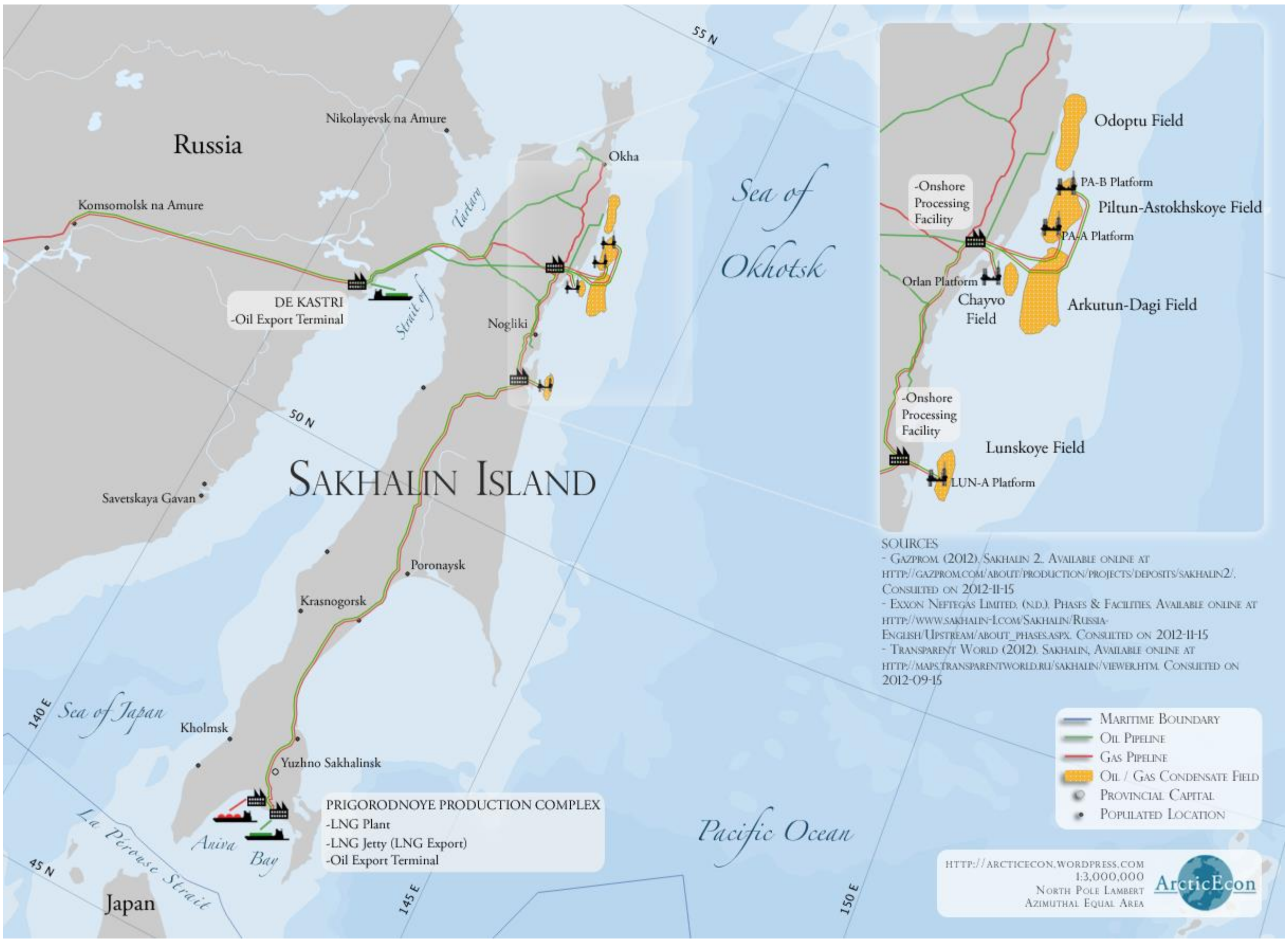

Figure 29. Sakhalin pipeline system [48].

Selection between these two cases is based on the estimated costs of both options. For the first case, there is a need to construct additional Onshore Processing Facility, marked as OPF KVM. The purpose of its construction is for oil processing and further transportation; gas separation and preparation for potential transportation back to the field. There is no information regarding the cost of such facilities in open sources. Nevertheless, in 2018 Gazprom Company put out a tender for EPCM (Engineering, Procurement, Construction, Management) project for construction OPF and Subsea production system for Kirinskoe gas-condensate field. The cost of the project is about 468 mln.$ [50]. Unfortunately, there are no separated costs but only a lump sum. For the purpose of the work, it is taken into the assumption that OPF cost is one-third of the whole project — 156,2 mln.$. The same cost is assumed for OPF KVM. The subsea pipeline includes two 20 inches flowlines from the field. The pipeline diameter for on-shore part of Case-2 is estimated at 16 inches, taking into account the maximum oil production rate and by analogy with Kirinskoe OPF. The lengths of the routes are calculated by “Google maps” service. Case-1 — 175 km; Case-2 Sea part — in total 53,4 km with 53 km to shore; Case-2 Land part — 150 km. The cost for sea parts is taken from Grekov et. al (2007) as 2,45 mln.$/km, for the land part based on the INGAA Foundation Inc. [51] and Transneft company [52] as 0,115 mln.$/km. Umbilical cost is also estimated according to Grekov et. al (2007) as 2 mln.$/km.

Estimated costs are: Case-1 — in total 1207,5 mln.$: for pipelines 857,5 mln.$ and 350 mln.$ for umbilical; Case-2 — in total 547,2 mln.$: Sea part — for pipelines 261,7 mln.$, for umbilical 106,8 mln.$, together — 368,5 mln.$; OPF KVM – 156,2 mln.$; Land part – 22,5 mln.$.

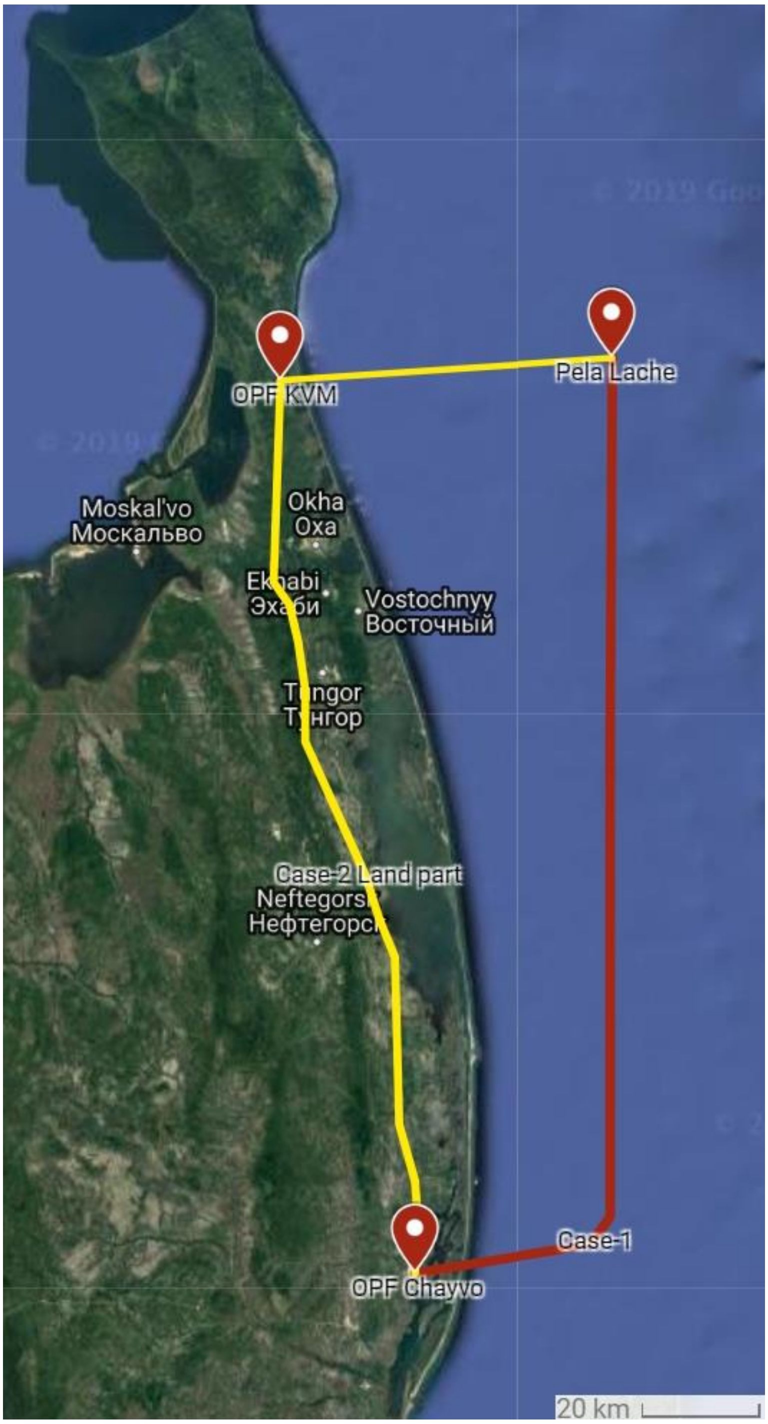

Figure 30. Two cases of pipeline route.

It should be mentioned, that such long distance of pipeline requires addition objects for pressure maintenance and activities against wax precipitation. The spending on them for the marine part is much higher in comparison with onshore analogs.

As we can see from Table 9, the Case-2 is more profitable and recommended as proposed for the potential pipeline route.

Table 9. All spending on both cases.

	Costs, mln.$	
	Case-1	Case-2
Sea		
Pipelines	857,5	261,7
Umbilical	350,0	106,8
Land		
Pipeline	-	22,5
OPF	-	156,2
	Total	
	1207,5	547,2

4.2 Economical efficiency

The capital costs required for the implementation of this project consist of the calculated costs for laying pipelines, OPF construction and the costs estimated in Chapter 3 for the field development. Taking into account the recommended most cost-effective options, the following result is obtained: the total amount of investments is 1234,3 mln.$.

To determine the feasibility of a project, a cost-benefit analysis (CBA) has been performed.

The results of the CBA-analysis are indicators of the project's economic efficiency. Economic indicators on which the result is based [53]:

1. NPV — the net present value of the project;
2. IRR — internal rate of return;
3. PBP — payback period;
4. DPB — discounted payback period;
5. BEP — break-even price;
6. PI — profitability index.

Revenue is calculated based on oil production. It is assumed that the volume of oil sold is equal to the volume of oil produced from wells.

$$Revenue = Q \times P \tag{19}$$

Where:

Q — the volume of produced hydrocarbons, barrel;

P — the price of oil, USD / 1 barrel.

The price of oil is set at 70 $ per barrel during the whole lifetime of the project.

Based on the source [54], taxes for Arctic shelf projects in Russia are divided into mineral extraction tax (5% for the first 15 years) and income tax (20%). Based on the analysis in Chapter 2, the total project development time is 15 years; therefore, the total tax is 25%.

Operating costs are assumed to be equal to the costs of oil production in the Arctic region — 30 $ per barrel of produced oil [55].

The net present value (NPV) of a project is the sum of the present values of discounted cash flows for the period of interest:

$$NPV = \sum_{i=0}^{T} \frac{Cash\ inflow_i - Cash\ outflow_i}{(1+d)^i} \tag{20}$$

Where:

$Cash\ inflow_i$ — $(Revenue_i - Depriciation_i)$;

$Cash\ outflow_i$ — a sum of capital investments, taxes, and operating expenses;

i — year number;

d — the discount rate, which is used to convert cash flows for different years into a total value. The discount rate equals 12%, which is common for oil and gas projects [55].

The IRR parameter is a criterion that determines the average annual interest rate for a project. A project is economically viable if the IRR parameter exceeds the discount rate [53]. The internal rate of return shows the discount rate of the project, where the net present value is zero:

$$NPV = \sum_{i=0}^{T} \frac{Cash\ inflow_i - Cash\ outflow_i}{(1+IRR)^i} = 0 \tag{21}$$

Discounted payback period (DPB) — the period of time required for revenue to cover investments [53].

The calculated break-even price (BEP) is 136,2326984 $ of a barrel of oil.

The profitability index is used to show the relationship between the costs and benefits of the project:

$$NPV = 1 + \frac{NPV}{CAPEX} = 0 \tag{22}$$

Where CAPEX — capital investments.

A project is cost-effective if the parameter PI > 1 [53].

Depreciation and annual fixed costs are summed up and taken as a fixed value of 6% of the capital investment for each year [53].

Input data required for conducting a CBA analysis are presented in Table 10.

Table 10. Input to CBA analysis.

Parameter	Value	Dimension
Project life cycle	15	years
Capital investments (CAPEX)	1234,3	mln.$
Oil price	70	$
Operating costs (OPEX)	30	$/barrel
Depreciation and annual fixed cost	6	% of capital investments
Taxation	25	%
Discount rate	12	%

Field development after 8 years from the start becomes unprofitable, see Figure 31; the results of the CBA analysis are presented for 8 years, where the best economic indicators are observed. Calculations are conducted in Microsoft Excel. Full calculations results by year are presented in Appendix C, Table C-1.

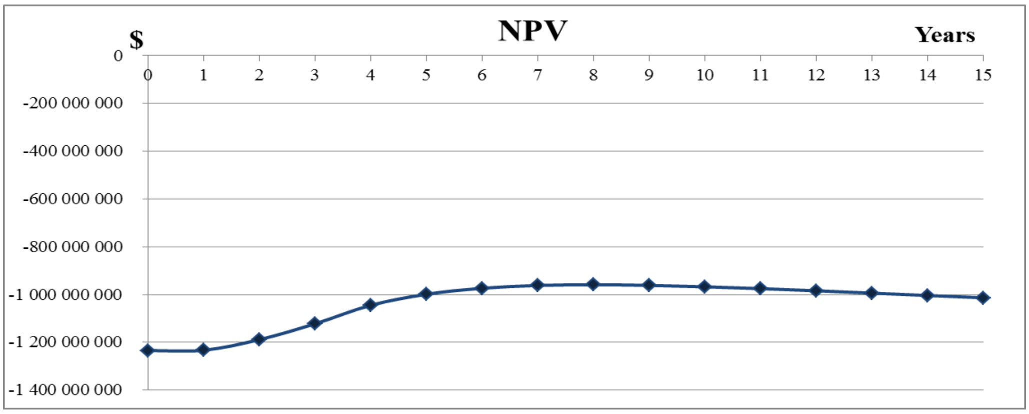

Figure 31. The net present value of the project.

Table 11. Results of CBA analysis.

NPV	-958,9 mln.$	< 0$
IRR	-21%	<12%
DPB	n/a	Year
PI	0,22	< 1

Based on the results of the CBA analysis, it can be concluded that capital investments are too high, as a result of which the project is economically inefficient. NPV of the project is negative; the profitability ratio is less than one.

4.3 Conclusions and recommendations

To determine the feasibility of the project development, an economic analysis is carried out, based on the CBA method. Capital investments, which are vital for the field and infrastructure development of the project, are analyzed, as well as operating costs. Most of the investments are calculated in Chapter 3. In the current chapter, a possible pipeline laying option is proposed, with the calculation of the required capital expenditures. Using the results of calculations of oil production rate in Chapter 2 and the total investments, an analysis of the economic efficiency of the development of the Pela Lache structures is carried out. The result of the analysis shows that the project is unprofitable.

Nevertheless, it is impossible not to take into account the fact that the constructed infrastructure for the Pela Lache deposit makes up about 44% of the total capital investments. It includes pipelines from the field, the line of the umbilical cable, the onshore processing facility and the trunk pipeline through the island to inclusion into the export pipeline. The Pela Lache deposit is one of the three for the Kaigansko-Vasyukanskoe-more field; therefore the infrastructure built can be used for two other structures, as well as fields located in the neighborhood. The onshore processing facility can also service products from several fields simultaneously, similar to Chayvo OPF, which receives products from four fields at the same time. It can be clearly seen in Figure 29. It should be taken into account, that there are no processing facilities in the northern part of Sakhalin Island, which leads to the need for their construction. Using the example of a comparative analysis of pipeline laying options, it is revealed that laying up on the seabed to an already existing OPF is significantly more expensive and complicated. Based on all the above positions, it can be summed up that the project to develop the Pela Lache structure in the proposed way is economically inefficient, while the infrastructure created for this project can be used for other projects, which can significantly reduce their capital costs.

Chapter 5. Influence on the environment

As discussed in Chapter 1, the environment in the area of interest is one the most unaffected by human and petroleum activities from the ecological point of view for the Sakhalin Shelf. There is a significant challenge for Operator Company to safe natural conditions. Based on the experience of Sakhalin-1 and Sakhalin-3 projects, with onshore processing facilities and subsea production system construction, laying marine and land pipelines, production activities, it could be declared, that it is possible to develop the proposed project without any significant influence on the environment. This part of the work is devoted to the most possible kinds of reasons, which effect on the ecological conditions and their consequences.

There are two main periods for the project: construction and exploration. That is why it is logical to consider all kinds of influence factors during these periods.

5.1 Physical impact, waste, and emissions

Physical impact

During the construction period, the main sources of physical impact (noise) are excavators, bulldozers, loaders, and vehicles. The noise level of 45 dBA is observed already at a distance of about 350-360 m from the working area of the trench engineering equipment [56].

During the operation period of the objects in question, there are no permanent sources of noise.

Waste

During construction and installation works in the water area of the Sea of Okhotsk and during the construction of the onshore section of the pipeline and onshore facilities, the following types of waste will be generated:

- residues and stubs of steel welding electrodes;
- crushed stone;
- sand;
- unsorted ferrous metal scrap (sheet piles and deformed pipe ends);
- waste from the operation of construction equipment and mechanisms;
- municipal solid waste;
- sediment from the installation of washing the wheels of vehicles;
- food waste;
- residues and stubs of steel welding electrodes;
- waste of insulated wires and cables;
- bilge water from ships;

• wiping material contaminated with oils.

Waste generated during the construction period belongs to the II, III, IV, and V hazard classes [56].

During the operation period, these kinds of waste possibly will be generated during potential repair operations.

The construction period of the field development includes the following stages:

• SPU installation and drilling;

• pipelines laying;

• umbilical laying;

• OPF construction.

Pollutions

The main pollutants into the atmospheric air during construction: in the sea area of the Sea of Okhotsk are — the exhaust gases of power plants of vessels; on the land — construction equipment and mechanisms.

The main sources of air pollution during the construction of the projected objects on land are excavators, bulldozers, loaders, welding units, vehicles, vessels for deep-water pipelines, auxiliary vessels and maintenance vessels.

In case of the trouble-free operation period of the facilities of the subsea production, offshore and onshore pipelines and emissions of pollutants into the atmosphere will not be produced, with the exception of some operations at OPF and repair operations.

5.2 Anthropogenic impact

Land resources

During the construction period, the impact on land resources is a negative effect on the relief, the movement of soil cover, as well as the withdrawal of land for long-term and short-term use.

During construction, the main factor leading to soil degradation during the construction period will be the construction of the SPU, the construction of the OPF, and the transfer of the soil during the laying of pipelines on land.

Geomechanical impact on the soil is in the formation of trenches and road construction.

When laying pipelines and developing trenches, backfilling will be carried out in the reverse order of the development of the pipeline. The soil excavation material is placed back into the trench to a level that fully corresponds to the initial ground level.

During the operation of SPU, pipelines, umbilical, and OPF, the impact on land resources will not occur.

Vegetation cover (Flora)

The following main types of impacts on vegetation cover are possible during the construction period:

• destruction of natural plant communities in the area of land allocation for construction and, as a result, depletion of the species composition of vegetation and its ruderalization;

• increase the probability of fires;

• degradation of plant communities of bog complexes as a result of violations of the water regime of the territories;

• disturbance of vegetation cover in the course of water erosion of the soil, in turn, caused by disturbance of the soil cover;

• industrial pollution of natural territories.

Vegetation cover will be completely destroyed during OPF construction. The strongest impact on vegetation cover will be observed in the preparation of the territory for the construction of service facilities. There is an increased probability of fires during construction and welding, possible fuel spills, etc. Watering of areas adjacent to construction sites may occur due to the violation of the hydrological regime as a result of the construction of roads, embankments and other objects. As a result of these processes, both waterlogging and the draining of individual areas have the potential to occur.

During the operation period in the normal mode, there will be no impacts leading to a change in vegetation cover.

Fauna

The construction of any object leads to significant changes in natural complexes. When building occurs:

• direct impact on the fauna during excavation work;

• transformation, disturbance, and alienation of habitats;

• presence effect and noise from the operation of equipment;

• social factor (increased press hunting, poaching);

• pollution of territories.

The period of construction, as a rule, everywhere is accompanied by a decrease in the number and species richness. A significant number of people employed in construction will dramatically increase the load on the surrounding natural territories. This will lead to an increase in anxiety factor among animals, migrating to new places, and a decrease in their number in the area of construction.

During the operation of objects in the normal mode, the impact on the animal world will not be provided.

Water environment

During the period of construction, the main impact the water environment is the water turbidity:

• construction of a cofferdam and tidal dam on the onshore section of the pipeline route;

• dredging of a trench for pipelines and its backfilling;

• strengthening of pipelines by sprinkling with gravel and filling the gaps;

• vessels anchoring.

Also, the source of the impact on water resources is seawater intake for the needs of hydrotesting of offshore pipelines and for cooling the power equipment of vessels.

In the period of trouble-free operation impacting on water resources is not expected.

Marine flora and fauna

During the construction period, the main sources of adverse effects on marine flora and fauna are:

• the use of areas of the water area and the bottom for work on the laying of the pipelines and SPU construction;

• physical presence of artificial structures in the sea;

• potential development and backfilling of the pipeline trench;

• soil dumping along the trenches border;

• removal of soil from the temporary underwater dump for backfilling of the trench.

The main factors causing adverse effects on flora and fauna are:

• mechanical destruction and changes in the structure of the soil lining the bottom;

• increased water turbidity;

• the effects of noise from working mechanisms;

• water withdrawal for technical needs;

• changes in the chemical composition of water;

• human presence and associated factors.

Mechanical disruption of the bottom structure, removal, movement, and dumping of the soil, during dredging, causes the destruction of the existing communities of benthic organisms. As a result, the complete or partial dying of the inhabitants of the bottom layer of the water column is possible.

The impact on benthic organisms is aggravated by the fact that most of them lead a sedentary lifestyle and, unlike adult fish, they cannot leave the zone of the negative impact of work. In general, the degree of impact on these organisms depends on the duration of the negative factors, and the time required for their recovery (naturally or with the help of special events).

Increased water turbidity is a factor inevitable in the performance of all the above-mentioned types of hydraulic works, which has a negative impact on all levels of the organization of living ecosystems in the area involved in the work. In this regard, in the construction zone, partial or complete dying of fish, marine mammals and other kinds of animals is possible but unlikely.

Sounds spreading in the water are extremely important for the communication of marine mammals and for them to obtain information about their habitat. Avoiding marine mammals of areas of high noise levels may result in a change in their migration paths, feeding areas, and, finally, affect the general state of populations.

During the period of regular operation of the offshore facilities of the Kaigansko-Vasyukanskoe-more field, there is no negative impact on aquatic biota, as well as the release of pollutants into the aquatic environment.

5.3 Conclusion

The work identified the main negative impacts during the development of the Pela Lache field on the ecology in the areas of interest. The potential consequences of these negative factors are revealed. Based on the information received, it can be said that the most harmful period in the development of the project is the construction stage. However, the impact of negative consequences is insignificant, while adherence to all regulatory documents. During the operating stage, the influence is negligible in case of trouble-free operations.

Conclusion

Analysis of the meteorological and oceanographic conditions shows that one of the main features of the Sakhalin Island shelf is the fact that it belongs to the subarctic region. In the cold months, ice completely covers the sea, so that the duration of offshore operations in the open sea is very limited. In general, the territory is characterized by high seismic activity, which leads to additional costs to achieve the required level of industrial safety and reliability of facilities.

Using volumetric method, initial recoverable oil reserves are calculated for one structure of Kaigansko-Vasyukanskoe-more field, Pela Lache deposit. Due to the great lack of information regarding the main parameters and characteristics of Pela Lache deposit, the calculation of main trends of field development is conducted using analogue-method. The analog-field is identified with the most possible similarity of the main characteristics, which are necessary for the implementation of the method with the most accurate result.

Based on world experience in the field development of deep-water deposits located in the Arctic region, it has been determined that the field layout with the implementation of subsea production modules has the greatest technical and economic efficiency. As a result of comparative analysis between the two most probable designs, the design with two 4-slot subsea production modules is selected.

A possible pipeline route is proposed with the calculation of all the necessary expenses for its laying, as well as the cost for the construction of the onshore processing facility. An economic analysis of the project is carried out, on the basis of the capital expenditures required for the field development. The analysis demonstrates that the development of the project as a separate unit is unprofitable. Nevertheless, almost half of all capital investments are spending in infrastructure, which can be used for other fields of the Sakhalin-4 and Sakhalin-5 projects and provide a significant synergistic effect by analogy with the Sakhalin-1 fields.

The proposed field layout, onshore processing facility, and pipelines do not have a significant impact on the environment. The greatest influence on the environment is expected during construction works. During operation activities in case of trouble-free mode, the influence is negligible.

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Appendix A

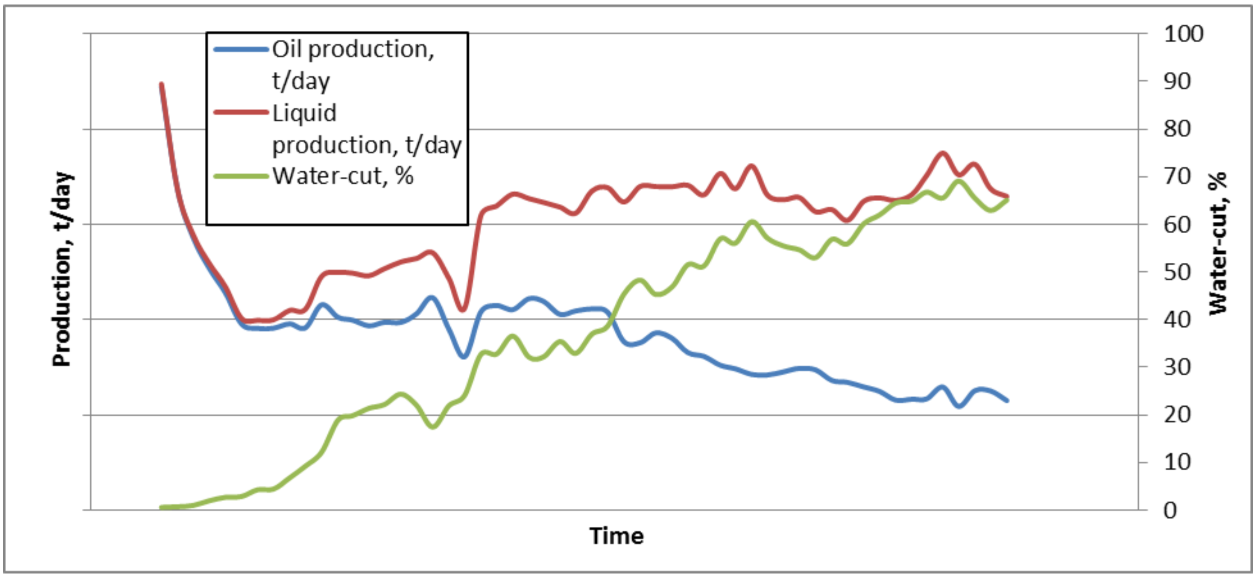

Figure A-1. XX_2 oil and liquid production rates, water-cut.

Table A-2. Excel Sheet (Part 1) — Production profile for each well; accumulated oil and liquid.

Date	Oil,t/day	Liquid, t/day	Oil,t/day	Liquid, t/day	Oil,t/day	Liquid, t/day	Oil,t/day	Liquid, t/day	Oil,t/day	Liquid, t/day	Oil,t/day	Liquid, t/day	Oil,t/day	Liquid, t/day	Oil,t/day	Liquid, t/day	Accumulated Oil ,ths.t	Accumulated Liquid, ths.t	Total oil production, t/d	Total liquid production,t/d
01.01.2020	470,000	470,000	470,000	470,000	0	0	0	0	0	0	0	0	0	0	0	0	0,000	0,000	940,000	940,000
01.02.2020	459,909	462,935	459,909	462,935	0	0	0	0	0	0	0	0	0	0	0	0	26,564	26,739	919,819	925,870
01.03.2020	450,035	457,938	450,035	457,938	0	0	0	0	0	0	0	0	0	0	0	0	52,558	53,190	900,070	915,875
01.04.2020	440,373	453,637	440,373	453,637	0	0	0	0	0	0	0	0	0	0	0	0	77,994	79,392	880,746	907,273
01.05.2020	430,919	450,296	430,919	450,296	0	0	0	0	0	0	0	0	0	0	0	0	102,884	105,401	861,837	900,593
01.06.2020	421,667	447,803	421,667	447,803	0	0	0	0	0	0	0	0	0	0	0	0	127,240	131,266	843,334	895,606
01.07.2020	412,614	446,062	412,614	446,062	0	0	0	0	0	0	0	0	0	0	0	0	151,072	157,030	825,228	892,125
01.08.2020	403,755	444,995	403,755	444,995	0	0	0	0	0	0	0	0	0	0	0	0	174,393	182,733	807,510	889,991
01.09.2020	395,087	444,535	395,087	444,535	0	0	0	0	0	0	0	0	0	0	0	0	197,213	208,410	790,173	889,070
01.10.2020	386,604	444,624	386,604	444,624	0	0	0	0	0	0	0	0	0	0	0	0	219,544	234,091	773,209	889,249
01.11.2020	378,304	445,214	378,304	445,214	0	0	0	0	0	0	0	0	0	0	0	0	241,394	259,807	756,608	890,428
01.12.2020	370,182	446,263	370,182	446,263	0	0	0	0	0	0	0	0	0	0	0	0	262,776	285,583	740,364	892,525
01.01.2021	362,234	447,733	362,234	447,733	470,000	470,000	470,000	470,000	0	0	0	0	0	0	0	0	310,846	338,591	1664,469	1835,466
01.02.2021	354,457	449,593	354,457	449,593	459,909	462,935	459,909	462,935	0	0	0	0	0	0	0	0	357,884	391,299	1628,733	1825,055
01.03.2021	346,847	451,815	346,847	451,815	450,035	457,938	450,035	457,938	0	0	0	0	0	0	0	0	403,912	443,846	1593,765	1819,505
01.04.2021	339,401	454,374	339,401	454,374	440,373	453,637	440,373	453,637	0	0	0	0	0	0	0	0	448,952	496,293	1559,548	1816,021
01.05.2021	332,114	457,248	332,114	457,248	430,919	450,296	430,919	450,296	0	0	0	0	0	0	0	0	493,024	548,713	1526,065	1815,089
01.06.2021	324,984	460,418	324,984	460,418	421,667	447,803	421,667	447,803	0	0	0	0	0	0	0	0	536,151	601,171	1493,301	1816,442
01.07.2021	318,006	463,866	318,006	463,866	412,614	446,062	412,614	446,062	0	0	0	0	0	0	0	0	578,351	653,729	1461,240	1819,856
01.08.2021	311,179	467,576	311,179	467,576	403,755	444,995	403,755	444,995	0	0	0	0	0	0	0	0	619,646	706,439	1429,868	1825,142
01.09.2021	304,498	471,534	304,498	471,534	395,087	444,535	395,087	444,535	0	0	0	0	0	0	0	0	660,054	759,351	1399,169	1832,137
01.10.2021	297,960	475,727	297,960	475,727	386,604	444,624	386,604	444,624	0	0	0	0	0	0	0	0	699,594	812,510	1369,130	1840,702
01.11.2021	291,563	480,143	291,563	480,143	378,304	445,214	378,304	445,214	0	0	0	0	0	0	0	0	738,286	865,959	1339,735	1850,715
01.12.2021	285,304	484,772	285,304	484,772	370,182	446,263	370,182	446,263	0	0	0	0	0	0	0	0	776,147	919,736	1310,971	1862,069
01.01.2022	279,178	489,603	279,178	489,603	362,234	447,733	362,234	447,733	470,000	470,000	470,000	470,000	0	0	0	0	840,342	1001,023	2222,825	2814,672
01.02.2022	273,184	494,628	273,184	494,628	354,457	449,593	354,457	449,593	459,909	462,935	459,909	462,935	0	0	0	0	903,159	1082,301	2175,102	2814,311
01.03.2022	267,319	499,837	267,319	499,837	346,847	451,815	346,847	451,815	450,035	457,938	450,035	457,938	0	0	0	0	964,627	1163,719	2128,404	2819,179
01.04.2022	261,580	505,222	261,580	505,222	339,401	454,374	339,401	454,374	440,373	453,637	440,373	453,637	0	0	0	0	1024,776	1245,347	2082,708	2826,466
01.05.2022	255,964	510,777	255,964	510,777	332,114	457,248	332,114	457,248	430,919	450,296	430,919	450,296	0	0	0	0	1083,633	1327,269	2037,993	2836,643
01.06.2022	250,469	516,494	250,469	516,494	324,984	460,418	324,984	460,418	421,667	447,803	421,667	447,803	0	0	0	0	1141,227	1409,561	1994,238	2849,429
01.07.2022	245,091	522,365	245,091	522,365	318,006	463,866	318,006	463,866	412,614	446,062	412,614	446,062	0	0	0	0	1197,584	1492,290	1951,422	2864,586
01.08.2022	239,829	528,386	239,829	528,386	311,179	467,576	311,179	467,576	403,755	444,995	403,755	444,995	0	0	0	0	1252,731	1575,520	1909,526	2881,913
01.09.2022	234,680	534,549	234,680	534,549	304,498	471,534	304,498	471,534	395,087	444,535	395,087	444,535	0	0	0	0	1306,694	1659,307	1868,529	2901,235
01.10.2022	229,642	540,849	229,642	540,849	297,960	475,727	297,960	475,727	386,604	444,624	386,604	444,624	0	0	0	0	1359,499	1743,706	1828,413	2922,400
01.11.2022	224,711	547,280	224,711	547,280	291,563	480,143	291,563	480,143	378,304	445,214	378,304	445,214	0	0	0	0	1411,169	1828,766	1789,157	2945,274
01.12.2022	219,887	553,837	219,887	553,837	285,304	484,772	285,304	484,772	370,182	446,263	370,182	446,263	0	0	0	0	1461,731	1914,532	1750,745	2969,742
01.01.2023	215,166	560,514	215,166	560,514	279,178	489,603	279,178	489,603	362,234	447,733	362,234	447,733	470,000	470,000	470,000	470,000	1538,354	2028,195	2653,157	3935,700
01.02.2023	210,546	567,306	210,546	567,306	273,184	494,628	273,184	494,628	354,457	449,593	354,457	449,593	459,909	462,935	459,909	462,935	1613,332	2142,240	2596,195	3948,924
01.03.2023	206,026	574,209	206,026	574,209	267,319	499,837	267,319	499,837	346,847	451,815	346,847	451,815	450,035	457,938	450,035	457,938	1686,701	2256,824	2540,456	3967,597
01.04.2023	201,603	581,217	201,603	581,217	261,580	505,222	261,580	505,222	339,401	454,374	339,401	454,374	440,373	453,637	440,373	453,637	1758,494	2372,023	2485,913	3988,901
01.05.2023	197,274	588,326	197,274	588,326	255,964	510,777	255,964	510,777	332,114	457,248	332,114	457,248	430,919	450,296	430,919	450,296	1828,746	2487,927	2432,541	4013,295
01.06.2023	193,039	595,531	193,039	595,531	250,469	516,494	250,469	516,494	324,984	460,418	324,984	460,418	421,667	447,803	421,667	447,803	1897,489	2604,617	2380,316	4040,491
01.07.2023	188,895	602,827	188,895	602,827	245,091	522,365	245,091	522,365	318,006	463,866	318,006	463,866	412,614	446,062	412,614	446,062	1964,757	2722,165	2329,211	4070,240
01.08.2023	184,839	610,210	184,839	610,210	239,829	528,386	239,829	528,386	311,179	467,576	311,179	467,576	403,755	444,995	403,755	444,995	2030,580	2840,641	2279,204	4102,333
01.09.2023	180,871	617,675	180,871	617,675	234,680	534,549	234,680	534,549	304,498	471,534	304,498	471,534	395,087	444,535	395,087	444,535	2094,990	2960,105	2230,271	4136,585
01.10.2023	176,987	625,218	176,987	625,218	229,642	540,849	229,642	540,849	297,960	475,727	297,960	475,727	386,604	444,624	386,604	444,624	2158,018	3080,617	2182,387	4172,835
01.11.2023	173,188	632,834	173,188	632,834	224,711	547,280	224,711	547,280	291,563	480,143	291,563	480,143	378,304	445,214	378,304	445,214	2219,692	3202,229	2135,532	4210,942
01.12.2023	169,469	640,519	169,469	640,519	219,887	553,837	219,887	553,837	285,304	484,772	285,304	484,772	370,182	446,263	370,182	446,263	2280,042	3324,991	2089,683	4250,780
01.01.2024	165,831	648,268	165,831	648,268	215,166	560,514	215,166	560,514	279,178	489,603	279,178	489,603	362,234	447,733	362,234	447,733	2339,096	3448,951	2044,819	4292,237
01.02.2024	162,271	656,078	162,271	656,078	210,546	567,306	210,546	567,306	273,184	494,628	273,184	494,628	354,457	449,593	354,457	449,593	2396,883	3574,152	2000,917	4335,211
01.03.2024	158,787	663,944	158,787	663,944	206,026	574,209	206,026	574,209	267,319	499,837	267,319	499,837	346,847	451,815	346,847	451,815	2453,429	3700,635	1957,958	4379,610
01.04.2024	155,378	671,862	155,378	671,862	201,603	581,217	201,603	581,217	261,580	505,222	261,580	505,222	339,401	454,374	339,401	454,374	2508,760	3828,439	1915,922	4425,352
01.05.2024	152,042	679,827	152,042	679,827	197,274	588,326	197,274	588,326	255,964	510,777	255,964	510,777	332,114	457,248	332,114	457,248	2562,904	3957,601	1874,788	4472,357
01.06.2024	148,777	687,836	148,777	687,836	193,039	595,531	193,039	595,531	250,469	516,494	250,469	516,494	324,984	460,418	324,984	460,418	2615,886	4088,155	1834,537	4520,556
01.07.2024	145,583	695,884	145,583	695,884	188,895	602,827	188,895	602,827	245,091	522,365	245,091	522,365	318,006	463,866	318,006	463,866	2667,730	4220,133	1795,150	4569,883
01.08.2024	142,458	703,966	142,458	703,966	184,839	610,210	184,839	610,210	239,829	528,386	239,829	528,386	311,179	467,576	311,179	467,576	2718,461	4353,566	1756,609	4620,274
01.09.2024	139,399	712,079	139,399	712,079	180,871	617,675	180,871	617,675	234,680	534,549	234,680	534,549	304,498	471,534	304,498	471,534	2768,102	4488,484	1718,895	4671,673
01.10.2024	136,406	720,219	136,406	720,219	176,987	625,218	176,987	625,218	229,642	540,849	229,642	540,849	297,960	475,727	297,960	475,727	2816,678	4624,914	1681,991	4724,025
01.11.2024	133,478	728,382	133,478	728,382	173,188	632,834	173,188	632,834	224,711	547,280	224,711	547,280	291,563	480,143	291,563	480,143	2864,211	4762,882	1645,880	4777,277
01.12.2024	130,612	736,563	130,612	736,563	169,469	640,519	169,469	640,519	219,887	553,837	219,887	553,837	285,304	484,772	285,304	484,772	2910,724	4902,412	1610,543	4831,380
01.01.2025	127,808	744,758	127,808	744,758	165,831	648,268	165,831	648,268	215,166	560,514	215,166	560,514	279,178	489,603	279,178	489,603	2956,238	5043,528	1575,965	4886,287
01.02.2025	125,064	752,963	125,064	752,963	162,271	656,078	162,271	656,078	210,546	567,306	210,546	567,306	273,184	494,628	273,184	494,628	3000,774	5186,252	1542,130	4941,951
01.03.2025	122,379	761,175	122,379	761,175	158,787	663,944	158,787	663,944	206,026	574,209	206,026	574,209	267,319	499,837	267,319	499,837	3044,355	5330,603	1509,021	4998,331
01.04.2025	119,751	769,389	119,751	769,389	155,378	671,862	155,378	671,862	201,603	581,217	201,603	581,217	261,580	505,222	261,580	505,222	3087,000	5476,603	1476,623	5055,382
01.05.2025	117,180	777,601	117,180	777,601	152,042	679,827	152,042	679,827	197,274	588,326	197,274	588,326	255,964	510,777	255,964	510,777	3128,729	5624,268	1444,921	5113,064
01.06.2025	114,664	785,808	114,664	785,808	148,777	687,836	148,777	687,836	193,039	595,531	193,039	595,531	250,469	516,494	250,469	516,494	3169,562	5773,616	1413,899	5171,337
01.07.2025	112,203	794,005	112,203	794,005	145,583	695,884	145,583	695,884	188,895	602,827	188,895	602,827	245,091	522,365	245,091	522,365	3209,519	5924,663	1383,543	5230,162
01.08.2025	109,794	802,189	109,794	802,189	142,458	703,966	142,458	703,966	184,839	610,210	184,839	610,210	239,829	528,386	239,829	528,386	3248,618	6077,424	1353,839	5289,502
01.09.2025	107,436	810,356	107,436	810,356	139,399	712,079	139,399	712,079	180,871	617,675	180,871	617,675	234,680	534,549	234,680	534,549	3286,877	6231,912	1324,772	5349,318
01.10.2025	105,130	818,501	105,130	818,501	136,406	720,219	136,406	720,219	176,987	625,218	176,987	625,218	229,642	540,849	229,642	540,849	3324,315	6388,141	1296,330	5409,574
01.11.2025	102,873	826,622	102,873	826,622	133,478	728,382	133,478	728,382	173,188	632,834	173,188	632,834	224,711	547,280	224,711	547,280	3360,950	6546,121	1268,498	5470,235
01.12.2025	100,664	834,715	100,664	834,715	130,612	736,563	130,612	736,563	169,469	640,519	169,469	640,519	219,887	553,837	219,887	553,837	3396,797	6705,864	1241,264	5531,265
01.01.2026	98,503	842,775	98,503	842,775	127,808	744,758	127,808	744,758	165,831	648,268	165,831	648,268	215,166	560,514	215,166	560,514	3431,875	6867,379	1214,615	5592,629
01.02.2026	96,388	850,799	96,388	850,799	125,064	752,963	125,064	752,963	162,271	656,078	162,271	656,078	210,546	567,306	210,546	567,306	3466,200	7030,675	1188,537	5654,294
01.03.2026	94,319	858,784	94,319	858,784	122,379	761,175	122,379	761,175	158,787	663,944	158,787	663,944	206,026	574,209	206,026	574,209	3499,788	7195,760	1163,020	5716,225
01.04.2026	92,294	866,726	92,294	866,726	119,751	769,389	119,751	769,389	155,378	671,862	155,378	671,862	201,603	581,217	201,603	581,217	3532,655	7362,640	1138,050	5778,389
01.05.2026	90,312	874,622	90,312	874,622	117,180	777,601	117,180	777,601	152,042	679,827	152,042	679,827	197,274	588,326	197,274	588,326	3564,817	7531,321	1113,617	5840,753
01.06.2026	88,373	882,467	88,373	882,467	114,664	785,808	114,664	785,808	148,777	687,836	148,777	687,836	193,039	595,531	193,039	595,531	3596,287	7701,808	1089,708	5903,285

Table A-2. Excel Sheet (Part 2) — Production profile for each well; accumulated oil and liquid.

01.07.2026	86,476	890,260	86,476	890,260	112,203	794,005	112,203	794,005	145,583	695,884	145,583	695,884	188,895	602,827	188,895	602,827	3627,082	7874,104	1066,312	5965,952
01.08.2026	84,619	897,996	84,619	897,996	109,794	802,189	109,794	802,189	142,458	703,966	142,458	703,966	184,839	610,210	184,839	610,210	3657,216	8048,214	1043,419	6028,722
01.09.2026	82,803	905,672	82,803	905,672	107,436	810,356	107,436	810,356	139,399	712,079	139,399	712,079	180,871	617,675	180,871	617,675	3686,703	8224,138	1021,017	6091,565
01.10.2026	81,025	913,286	81,025	913,286	105,130	818,501	105,130	818,501	136,406	720,219	136,406	720,219	176,987	625,218	176,987	625,218	3715,557	8401,879	999,096	6154,448
01.11.2026	79,285	920,833	79,285	920,833	102,873	826,622	102,873	826,622	133,478	728,382	133,478	728,382	173,188	632,834	173,188	632,834	3743,792	8581,436	977,646	6217,341
01.12.2026	77,583	928,311	77,583	928,311	100,664	834,715	100,664	834,715	130,612	736,563	130,612	736,563	169,469	640,519	169,469	640,519	3771,420	8762,808	956,657	6280,213
01.01.2027	75,917	935,716	75,917	935,716	98,503	842,775	98,503	842,775	127,808	744,758	127,808	744,758	165,831	648,268	165,831	648,268	3798,455	8945,995	936,118	6343,034
01.02.2027	74,287	943,047	74,287	943,047	96,388	850,799	96,388	850,799	125,064	752,963	125,064	752,963	162,271	656,078	162,271	656,078	3824,910	9130,994	916,020	6405,775
01.03.2027	72,692	950,299	72,692	950,299	94,319	858,784	94,319	858,784	122,379	761,175	122,379	761,175	158,787	663,944	158,787	663,944	3850,796	9317,801	896,353	6468,404
01.04.2027	71,132	957,470	71,132	957,470	92,294	866,726	92,294	866,726	119,751	769,389	119,751	769,389	155,378	671,862	155,378	671,862	3876,127	9506,413	877,109	6530,894
01.05.2027	69,605	964,557	69,605	964,557	90,312	874,622	90,312	874,622	117,180	777,601	117,180	777,601	152,042	679,827	152,042	679,827	3900,914	9696,826	858,277	6593,216
01.06.2027	68,110	971,558	68,110	971,558	88,373	882,467	88,373	882,467	114,664	785,808	114,664	785,808	148,777	687,836	148,777	687,836	3925,169	9889,032	839,851	6655,340
01.07.2027	66,648	978,470	66,648	978,470	86,476	890,260	86,476	890,260	112,203	794,005	112,203	794,005	145,583	695,884	145,583	695,884	3948,903	10083,026	821,819	6717,238
01.08.2027	65,217	985,290	65,217	985,290	84,619	897,996	84,619	897,996	109,794	802,189	109,794	802,189	142,458	703,966	142,458	703,966	3972,128	10278,800	804,175	6778,883
01.09.2027	63,817	992,016	63,817	992,016	82,803	905,672	82,803	905,672	107,436	810,356	107,436	810,356	139,399	712,079	139,399	712,079	3994,854	10476,346	786,910	6840,248
01.10.2027	62,447	998,645	62,447	998,645	81,025	913,286	81,025	913,286	105,130	818,501	105,130	818,501	136,406	720,219	136,406	720,219	4017,092	10675,656	770,015	6901,304
01.11.2027	61,106	1005,175	61,106	1005,175	79,285	920,833	79,285	920,833	102,873	826,622	102,873	826,622	133,478	728,382	133,478	728,382	4038,852	10876,719	753,483	6962,025
01.12.2027	59,794	1011,604	59,794	1011,604	77,583	928,311	77,583	928,311	100,664	834,715	100,664	834,715	130,612	736,563	130,612	736,563	4060,146	11079,525	737,306	7022,384
01.01.2028	58,510	1017,929	58,510	1017,929	75,917	935,716	75,917	935,716	98,503	842,775	98,503	842,775	127,808	744,758	127,808	744,758	4080,982	11284,064	721,477	7082,356
01.02.2028	57,254	1024,149	57,254	1024,149	74,287	943,047	74,287	943,047	96,388	850,799	96,388	850,799	125,064	752,963	125,064	752,963	4101,371	11490,322	705,987	7141,915
01.03.2028	56,025	1030,260	56,025	1030,260	72,692	950,299	72,692	950,299	94,319	858,784	94,319	858,784	122,379	761,175	122,379	761,175	4121,322	11698,288	690,830	7201,036
01.04.2028	54,822	1036,262	54,822	1036,262	71,132	957,470	71,132	957,470	92,294	866,726	92,294	866,726	119,751	769,389	119,751	769,389	4140,845	11907,948	675,998	7259,694
01.05.2028	53,645	1042,152	53,645	1042,152	69,605	964,557	69,605	964,557	90,312	874,622	90,312	874,622	117,180	777,601	117,180	777,601	4159,949	12119,288	661,484	7317,864
01.06.2028	52,493	1047,927	52,493	1047,927	68,110	971,558	68,110	971,558	88,373	882,467	88,373	882,467	114,664	785,808	114,664	785,808	4178,642	12332,293	647,282	7375,522
01.07.2028	51,366	1053,587	51,366	1053,587	66,648	978,470	66,648	978,470	86,476	890,260	86,476	890,260	112,203	794,005	112,203	794,005	4196,934	12546,948	633,386	7432,646
01.08.2028	50,264	1059,130	50,264	1059,130	65,217	985,290	65,217	985,290	84,619	897,996	84,619	897,996	109,794	802,189	109,794	802,189	4214,834	12763,237	619,787	7489,211
01.09.2028	49,184	1064,553	49,184	1064,553	63,817	992,016	63,817	992,016	82,803	905,672	82,803	905,672	107,436	810,356	107,436	810,356	4232,349	12981,142	606,480	7545,195
01.10.2028	48,128	1069,856	48,128	1069,856	62,447	998,645	62,447	998,645	81,025	913,286	81,025	913,286	105,130	818,501	105,130	818,501	4249,488	13200,646	593,460	7600,576
01.11.2028	47,095	1075,036	47,095	1075,036	61,106	1005,175	61,106	1005,175	79,285	920,833	79,285	920,833	102,873	826,622	102,873	826,622	4266,259	13421,732	580,718	7655,333
01.12.2028	46,084	1080,092	46,084	1080,092	59,794	1011,604	59,794	1011,604	77,583	928,311	77,583	928,311	100,664	834,715	100,664	834,715	4282,670	13644,381	568,250	7709,443
01.01.2029	45,095	1085,022	45,095	1085,022	58,510	1017,929	58,510	1017,929	75,917	935,716	75,917	935,716	98,503	842,775	98,503	842,775	4298,729	13868,573	556,050	7762,886
01.02.2029	44,126	1089,826	44,126	1089,826	57,254	1024,149	57,254	1024,149	74,287	943,047	74,287	943,047	96,388	850,799	96,388	850,799	4314,443	14094,289	544,112	7815,641
01.03.2029	43,179	1094,502	43,179	1094,502	56,025	1030,260	56,025	1030,260	72,692	950,299	72,692	950,299	94,319	858,784	94,319	858,784	4329,820	14321,508	532,430	7867,689
01.04.2029	42,252	1099,047	42,252	1099,047	54,822	1036,262	54,822	1036,262	71,132	957,470	71,132	957,470	92,294	866,726	92,294	866,726	4344,866	14550,209	520,999	7919,010
01.05.2029	41,345	1103,462	41,345	1103,462	53,645	1042,152	53,645	1042,152	69,605	964,557	69,605	964,557	90,312	874,622	90,312	874,622	4359,589	14780,371	509,814	7969,586
01.06.2029	40,457	1107,746	40,457	1107,746	52,493	1047,927	52,493	1047,927	68,110	971,558	68,110	971,558	88,373	882,467	88,373	882,467	4373,997	15011,971	498,868	8019,397
01.07.2029	39,589	1111,896	39,589	1111,896	51,366	1053,587	51,366	1053,587	66,648	978,470	66,648	978,470	86,476	890,260	86,476	890,260	4388,095	15244,987	488,158	8068,426
01.08.2029	38,739	1115,912	38,739	1115,912	50,264	1059,130	50,264	1059,130	65,217	985,290	65,217	985,290	84,619	897,996	84,619	897,996	4401,890	15479,396	477,677	8116,656
01.09.2029	37,907	1119,792	37,907	1119,792	49,184	1064,553	49,184	1064,553	63,817	992,016	63,817	992,016	82,803	905,672	82,803	905,672	4415,389	15715,174	467,422	8164,068
01.10.2029	37,093	1123,537	37,093	1123,537	48,128	1069,856	48,128	1069,856	62,447	998,645	62,447	998,645	81,025	913,286	81,025	913,286	4428,598	15952,298	457,386	8210,647
01.11.2029	36,297	1127,144	36,297	1127,144	47,095	1075,036	47,095	1075,036	61,106	1005,175	61,106	1005,175	79,285	920,833	79,285	920,833	4441,524	16190,742	447,566	8256,377
01.12.2029	35,517	1130,614	35,517	1130,614	46,084	1080,092	46,084	1080,092	59,794	1011,604	59,794	1011,604	77,583	928,311	77,583	928,311	4454,172	16430,482	437,957	8301,242
01.01.2030	34,755	1133,945	34,755	1133,945	45,095	1085,022	45,095	1085,022	58,510	1017,929	58,510	1017,929	75,917	935,716	75,917	935,716	4466,549	16671,492	428,554	8345,226
01.02.2030	34,009	1137,136	34,009	1137,136	44,126	1089,826	44,126	1089,826	57,254	1024,149	57,254	1024,149	74,287	943,047	74,287	943,047	4478,660	16913,746	419,354	8388,316
01.03.2030	33,279	1140,188	33,279	1140,188	43,179	1094,502	43,179	1094,502	56,025	1030,260	56,025	1030,260	72,692	950,299	72,692	950,299	4490,511	17157,219	410,350	8430,496
01.04.2030	32,564	1143,098	32,564	1143,098	42,252	1099,047	42,252	1099,047	54,822	1036,262	54,822	1036,262	71,132	957,470	71,132	957,470	4502,107	17401,883	401,540	8471,754
01.05.2030	31,865	1145,867	31,865	1145,867	41,345	1103,462	41,345	1103,462	53,645	1042,152	53,645	1042,152	69,605	964,557	69,605	964,557	4513,455	17647,712	392,919	8512,076
01.06.2030	31,181	1148,493	31,181	1148,493	40,457	1107,746	40,457	1107,746	52,493	1047,927	52,493	1047,927	68,110	971,558	68,110	971,558	4524,559	17894,678	384,483	8551,449
01.07.2030	30,511	1150,978	30,511	1150,978	39,589	1111,896	39,589	1111,896	51,366	1053,587	51,366	1053,587	66,648	978,470	66,648	978,470	4535,424	18142,753	376,229	8589,861
01.08.2030	29,856	1153,319	29,856	1153,319	38,739	1115,912	38,739	1115,912	50,264	1059,130	50,264	1059,130	65,217	985,290	65,217	985,290	4546,056	18391,910	368,151	8627,301
01.09.2030	29,215	1155,516	29,215	1155,516	37,907	1119,792	37,907	1119,792	49,184	1064,553	49,184	1064,553	63,817	992,016	63,817	992,016	4556,460	18642,119	360,247	8663,756
01.10.2030	28,588	1157,570	28,588	1157,570	37,093	1123,537	37,093	1123,537	48,128	1069,856	48,128	1069,856	62,447	998,645	62,447	998,645	4566,641	18893,352	352,513	8699,215
01.11.2030	27,974	1159,479	27,974	1159,479	36,297	1127,144	36,297	1127,144	47,095	1075,036	47,095	1075,036	61,106	1005,175	61,106	1005,175	4576,603	19145,581	344,944	8733,669
01.12.2030	27,374	1161,244	27,374	1161,244	35,517	1130,614	35,517	1130,614	46,084	1080,092	46,084	1080,092	59,794	1011,604	59,794	1011,604	4586,351	19398,775	337,539	8767,108
01.01.2031	26,786	1162,863	26,786	1162,863	34,755	1133,945	34,755	1133,945	45,095	1085,022	45,095	1085,022	58,510	1017,929	58,510	1017,929	4595,890	19652,905	330,292	8799,520
01.02.2031	26,211	1164,338	26,211	1164,338	34,009	1137,136	34,009	1137,136	44,126	1089,826	44,126	1089,826	57,254	1024,149	57,254	1024,149	4605,224	19907,941	323,201	8830,898
01.03.2031	25,648	1165,667	25,648	1165,667	33,279	1140,188	33,279	1140,188	43,179	1094,502	43,179	1094,502	56,025	1030,260	56,025	1030,260	4614,358	20163,854	316,262	8861,233
01.04.2031	25,098	1166,851	25,098	1166,851	32,564	1143,098	32,564	1143,098	42,252	1099,047	42,252	1099,047	54,822	1036,262	54,822	1036,262	4623,295	20420,612	309,472	8890,516
01.05.2031	24,559	1167,889	24,559	1167,889	31,865	1145,867	31,865	1145,867	41,345	1103,462	41,345	1103,462	53,645	1042,152	53,645	1042,152	4632,041	20678,185	302,827	8918,739
01.06.2031	24,031	1168,781	24,031	1168,781	31,181	1148,493	31,181	1148,493	40,457	1107,746	40,457	1107,746	52,493	1047,927	52,493	1047,927	4640,599	20936,542	296,326	8945,895
01.07.2031	23,516	1169,528	23,516	1169,528	30,511	1150,978	30,511	1150,978	39,589	1111,896	39,589	1111,896	51,366	1053,587	51,366	1053,587	4648,973	21195,653	289,964	8971,977
01.08.2031	0	0	0	0	29,856	1153,319	29,856	1153,319	38,739	1115,912	38,739	1115,912	50,264	1059,130	50,264	1059,130	4655,838	21387,899	237,717	6656,720
01.09.2031	0	0	0	0	29,215	1155,516	29,215	1155,516	37,907	1119,792	37,907	1119,792	49,184	1064,553	49,184	1064,553	4662,556	21580,810	232,613	6679,723
01.10.2031	0	0	0	0	28,588	1157,570	28,588	1157,570	37,093	1123,537	37,093	1123,537	48,128	1069,856	48,128	1069,856	4669,130	21774,361	227,619	6701,925
01.11.2031	0	0	0	0	27,974	1159,479	27,974	1159,479	36,297	1127,144	36,297	1127,144	47,095	1075,036	47,095	1075,036	4675,562	21968,531	222,732	6723,318
01.12.2031	0	0	0	0	27,374	1161,244	27,374	1161,244	35,517	1130,614	35,517	1130,614	46,084	1080,092	46,084	1080,092	4681,856	22163,294	217,950	6743,899
01.01.2032	0	0	0	0	26,786	1162,863	26,786	1162,863	34,755	1133,945	34,755	1133,945	45,095	1085,022	45,095	1085,022	4688,016	22358,629	213,271	6763,661
01.02.2032	0	0	0	0	26,211	1164,338	26,211	1164,338	34,009	1137,136	34,009	1137,136	44,126	1089,826	44,126	1089,826	4694,043	22554,510	208,692	6782,601
01.03.2032	0	0	0	0	25,648	1165,667	25,648	1165,667	33,279	1140,188	33,279	1140,188	43,179	1094,502	43,179	1094,502	4699,940	22750,915	204,212	6800,712
01.04.2032	0	0	0	0	25,098	1166,851	25,098	1166,851	32,564	1143,098	32,564	1143,098	42,252	1099,047	42,252	1099,047	4705,711	22947,819	199,827	6817,992
01.05.2032	0	0	0	0	24,559	1167,889	24,559	1167,889	31,865	1145,867	31,865	1145,867	41,345	1103,462	41,345	1103,462	4711,359	23145,197	195,537	6834,436
01.06.2032	0	0	0	0	24,031	1168,781	24,031	1168,781	31,181	1148,493	31,181	1148,493	40,457	1107,746	40,457	1107,746	4716,884	23343,026	191,339	6850,041
01.07.2032	0	0	0	0	23,516	1169,528	23,516	1169,528	30,511	1150,978	30,511	1150,978	39,589	1111,896	39,589	1111,896	4722,292	23541,282	187,231	6864,802
01.08.2032	0	0	0	0	0	0	0	0	29,856	1153,319	29,856	1153,319	38,739	1115,912	38,739	1115,912	4726,254	23672,353	137,190	4538,460
01.09.2032	0	0	0	0	0	0	0	0	29,215	1155,516	29,215	1155,516	37,907	1119,792	37,907	1119,792	4730,131	23803,774	134,245	4550,617
01.10.2032	0	0	0	0	0	0	0	0	28,588	1157,570	28,588	1157,570	37,093	1123,537	37,093	1123,537	4733,924	23935,531	131,362	4562,213
01.11.2032	0	0	0	0	0	0	0	0	27,974	1159,479	27,974	1159,479	36,297	1127,144	36,297	1127,144	4737,637	24067,606	128,542	4573,247

Table A-2. Excel Sheet (part 3) — Production profile for each well; accumulated oil and liquid.

01.12.2032	0	0	0	0	0	0	0	0	27,374	1161,244	27,374	1161,244	35,517	1130,614	35,517	1130,614	4741,269	24199,984	125,782	4583,715
01.01.2033	0	0	0	0	0	0	0	0	26,786	1162,863	26,786	1162,863	34,755	1133,945	34,755	1133,945	4744,824	24332,648	123,082	4593,617
01.02.2033	0	0	0	0	0	0	0	0	26,211	1164,338	26,211	1164,338	34,009	1137,136	34,009	1137,136	4748,302	24465,581	120,439	4602,949
01.03.2033	0	0	0	0	0	0	0	0	25,648	1165,667	25,648	1165,667	33,279	1140,188	33,279	1140,188	4751,706	24598,767	117,854	4611,709
01.04.2033	0	0	0	0	0	0	0	0	25,098	1166,851	25,098	1166,851	32,564	1143,098	32,564	1143,098	4755,036	24732,190	115,323	4619,897
01.05.2033	0	0	0	0	0	0	0	0	24,559	1167,889	24,559	1167,889	31,865	1145,867	31,865	1145,867	4758,295	24865,832	112,847	4627,511
01.06.2033	0	0	0	0	0	0	0	0	24,031	1168,781	24,031	1168,781	31,181	1148,493	31,181	1148,493	4761,484	24999,678	110,425	4634,549
01.07.2033	0	0	0	0	0	0	0	0	23,516	1169,528	23,516	1169,528	30,511	1150,978	30,511	1150,978	4764,605	25133,710	108,054	4641,011
01.08.2033	0	0	0	0	0	0	0	0	0	0	0	0	29,856	1153,319	29,856	1153,319	4766,330	25200,326	59,713	2306,637
01.09.2033	0	0	0	0	0	0	0	0	0	0	0	0	29,215	1155,516	29,215	1155,516	4768,017	25267,069	58,431	2311,032
01.10.2033	0	0	0	0	0	0	0	0	0	0	0	0	28,588	1157,570	28,588	1157,570	4769,668	25333,930	57,176	2315,139
01.11.2033	0	0	0	0	0	0	0	0	0	0	0	0	27,974	1159,479	27,974	1159,479	4771,284	25400,901	55,949	2318,958
01.12.2033	0	0	0	0	0	0	0	0	0	0	0	0	27,374	1161,244	27,374	1161,244	4772,865	25467,975	54,747	2322,487
01.01.2034	0	0	0	0	0	0	0	0	0	0	0	0	26,786	1162,863	26,786	1162,863	4774,412	25535,142	53,572	2325,727
01.02.2034	0	0	0	0	0	0	0	0	0	0	0	0	26,211	1164,338	26,211	1164,338	4775,926	25602,394	52,422	2328,676
01.03.2034	0	0	0	0	0	0	0	0	0	0	0	0	25,648	1165,667	25,648	1165,667	4777,408	25669,723	51,296	2331,334
01.04.2034	0	0	0	0	0	0	0	0	0	0	0	0	25,098	1166,851	25,098	1166,851	4778,857	25737,120	50,195	2333,702
01.05.2034	0	0	0	0	0	0	0	0	0	0	0	0	24,559	1167,889	24,559	1167,889	4780,276	25804,578	49,117	2335,778
01.06.2034	0	0	0	0	0	0	0	0	0	0	0	0	24,031	1168,781	24,031	1168,781	4781,664	25872,086	48,063	2337,563
01.07.2034	0	0	0	0	0	0	0	0	0	0	0	0	23,516	1169,528	23,516	1169,528	4783,022	25939,638	47,031	2339,056
01.08.2034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4783,022	25939,638	0,000	0,000
01.09.2034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4783,022	25939,638	0,000	0,000
01.10.2034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4783,022	25939,638	0,000	0,000
01.11.2034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4783,022	25939,638	0,000	0,000
01.12.2034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4783,022	25939,638	0,000	0,000
01.01.2035	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4783,022	25939,638	0,000	0,000

Table A-3. Key field development indicators.

Year	Produced oil, mln.tonn	Initial recoverable reserves produced,%	Oil production rate, t/day	Liquid production rate, t/day	Water production rate, t/day
2020	0	0	940	940	0
2021	0,263	5,297	1664,469	1835,466	170,997
2022	0,776	15,644	2222,825	2814,672	591,847
2023	1,462	29,464	2653,157	3935,700	1282,543
2024	2,280	45,958	2044,819	4292,237	2247,418
2025	2,911	58,670	1575,965	4886,287	3310,321
2026	3,397	68,468	1214,615	5592,629	4378,014
2027	3,771	76,019	936,118	6343,034	5406,917
2028	4,060	81,839	721,477	7082,356	6360,880
2029	4,283	86,324	556,050	7762,886	7206,835
2030	4,454	89,781	428,554	8345,226	7916,672
2031	4,586	92,445	330,292	8799,520	8469,228
2032	4,682	94,370	213,271	6763,661	6550,390
2033	4,741	95,568	123,082	4593,617	4470,535
2034	4,773	96,205	53,572	2325,727	2272,155
2035	4,783	96,409	0,000	0,000	0,000

Appendix B

Table B-1. Calculation of well lengths.

Wells	X, km	Y, km	Distance, km		Wells	X, km	Y, km	Distance, km
1	1,25	0,35	0,4507		1	1,25	0,35	1,1524
2	1,25	1,1	0,4507		2	1,25	1,1	0,4507
3	1,75	0,35	0,4507		3	1,75	0,35	1,1524
4	1,75	1,1	0,4507		4	1,75	1,1	0,4507
5	1,25	1,85	0,4507		5	1,25	1,85	0,4507
6	1,25	2,6	0,4507		6	1,25	2,6	1,1524
7	1,75	1,85	0,4507		7	1,75	1,85	0,4507
8	1,75	2,6	0,4507		8	1,75	2,6	1,1524
SPU-1	1,5	0,725			SPU	1,5	1,475	
SPU-2	1,5	2,225			Calculations for "close" wells are the same as for Case-1			
All wells		$x_1 \leq \frac{h_0 \cos\alpha}{1 + \sin\alpha}$			For "far" wells		$x_1 \leq \frac{h_0 \cos\alpha}{1 + \sin\alpha}$	
Depth,m	2520	x1, m			Depth,m	2520	x1, m	
hв, m	1100	450,694	1191,521		hв, m	1420	1152,443	1191,521
h0, m	1420	$L = h_в + \frac{x_1\left(\frac{\pi}{2} - \alpha\right)}{\cos\alpha \cdot tg\left(\frac{\pi}{4} - \frac{\alpha}{2}\right)}$			h0, m	1100	$L = h_в + \frac{x_1\left(\frac{\pi}{2} - \alpha\right)}{\cos\alpha \cdot tg\left(\frac{\pi}{4} - \frac{\alpha}{2}\right)}$	
ED, m	457,647				ED, m	1170,221		
DA, m	457,647				DA, m	1170,221		
l, m	79,469	L,m	2744,409		l, m	203,207	L,m	3093,822
h0-2, m	537,116	Lhor.part,m	1000		h0-2, m	1373,428	Lhor.part,m	1000
hв-2, m	1982,884	L+Lh=	3744,409		hв-2, m	1146,572	L+Lh=	4093,822
Case-1					Case-2			

Appendix C

Table C-1. Calculation of economic development indicators.

Lifetime of the project	15	years		Oil density, kg/m3	870	OPEX, $/bbl	30
Investment (CAPEX):	1234300000	$		1 bbl=> m3	0,159	OPEX, $/tonne	216,8726957
Oil price	506036,29	$/1000t		1 bbl=> kg	138,33		
Operating expences	216872,70	$/1000t		Cost, bbl/$	70		
cost	0,06	of initial investment		Cost, $/tonne=>	506,03629		
Taxes on profit	0,25	25%		BEP, $/bbl	136,2326984		
Discount rate:	0,12	12%		BEP, $/tonne=>	984,8384183		

Year	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**
Number of the year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
OPERATING ACTIVITY																
Mass of oil production, 1000 tonnes	0	263	513	686	818	631	486	375	289	223	172	132	96	59	32	10
Revenue, $	0	132 974 289	259 784 201	346 930 437	414 095 046	319 147 828	245 970 911	189 572 618	146 105 803	112 605 427	86 786 301	66 887 203	48 329 221	30 065 058	15 988 656	5 139 812
Operating cost	0	56 988 981	111 336 086	148 684 473	177 469 306	136 777 640	105 416 105	81 245 408	62 616 773	48 259 469	37 194 129	28 665 944	20 712 523	12 885 025	6 852 281	2 202 776
Other costs	0	74 058 000	74 058 000	74 058 000	74 058 000	74 058 000	74 058 000	74 058 000	74 058 000	74 058 000	74 058 000	74 058 000	74 058 000	74 058 000	74 058 000	74 058 000
Profit	0	1 927 308	74 390 115	124 187 964	162 567 741	108 312 187	66 496 806	34 269 210	9 431 030	-9 712 042	-24 465 828	-35 836 741	-46 441 302	-56 877 967	-64 921 625	-71 120 965
Tax	0	481 827	18 597 529	31 046 991	40 641 935	27 078 047	16 624 202	8 567 303	2 357 758	-2 428 010	-6 116 457	-8 959 185	-11 610 326	-14 219 492	-16 230 406	-17 780 241
Profit after tax	0	1 445 481	55 792 586	93 140 973	121 925 806	81 234 140	49 872 605	25 701 908	7 073 273	-7 284 031	-18 349 371	-26 877 556	-34 830 977	-42 658 475	-48 691 219	-53 340 724
Operating cash flow	0	1 445 481	55 792 586	93 140 973	121 925 806	81 234 140	49 872 605	25 701 908	7 073 273	-7 284 031	-18 349 371	-26 877 556	-34 830 977	-42 658 475	-48 691 219	-53 340 724
INVESTMENT ACTIVITY																
Investment	-1 234 300 000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Project cash flow	-1 234 300 000	1 445 481	55 792 586	93 140 973	121 925 806	81 234 140	49 872 605	25 701 908	7 073 273	-7 284 031	-18 349 371	-26 877 556	-34 830 977	-42 658 475	-48 691 219	-53 340 724
PV	-1 234 300 000	1 290 608	44 477 508	66 295 905	77 486 054	46 094 433	25 267 014	11 626 238	2 856 776	-2 626 695	-5 908 006	-7 726 655	-8 940 244	-9 776 222	-9 963 188	-9 745 151
PV (sum)	-1 234 300 000	-1 233 009 392	-1 188 531 884	-1 122 235 979	-1 044 749 925	-998 655 492	-973 388 479	-961 762 241	-958 905 465	-961 532 159	-967 440 166	-975 166 821	-984 107 065	-993 883 286	-1 003 846 474	-1 013 591 625