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Abstract

The Arctic shelf of Russia is an area of great interests. The process of hydrocarbons offloading is the most significant challenge for the Arctic projects, mostly because of the harsh environmental conditions and lack of experience in operations on the Russian Arctic shelf. Study of this problem, in particular the conditions of the Pechora Sea was carried out in this report. Development of a method of oil offloading that would minimize the risks of oil spills, delay of oil supply and provide synergy effect is a primary aim of the Master thesis. Oil offloading by an ice-resistant terminal is considered to be the best solution.

Chapter 1 is dedicated to the environmental conditions in the Pechora Sea. Chapters 2 and 3 are devoted to the current Arctic and sub-Arctic projects and implemented offloading technologies. Based on the world experience, analysis of the possible oil transportation scheme and fields arrangement in the Pechora Sea was carried out in Chapter 4. Also, Chapter 4 contains the mathematical description of a way to find the best location of the terminal using the principle of Multiple Criteria Decision-Making (MCDM). Environmental loads estimation and risk analysis were done in Chapter 5. Chapter 6 is devoted to the economic efficiency of the offloading terminal construction and exploitation.

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Content

Abbreviations

MCDM – Multiple Criteria Decision-Making;

GBS – Gravity Based Structure;

GIR – Group Individual Risk;

FAR – Fatal Accident Rate;

FPSO – Floating, Production, Storage And Offloading;

FOIROT – Fixed Offshore Ice-Resistant Offloading Terminal;

IR – Individual Risk;

IRPA – Individual Risk Per Annum;

IRR – Internal Rate Of Return;

NPV – Net Present Value;

OET – Oil Export Terminal;

OLS – Offshore Loading Systems;

SALM – Single Anchor Leg Mooring;

SPM – Subsea Production Modules;

SPMT – Single point Mooring Tower;

STL – Submerged Turret Loading;

SYMS – Soft Yoke Mooring System;

TAPS – Trans-Alaska Pipeline System;

TLU – Tanker Loading Unit;

USGS – United States Geological Survey.

Introduction

The Pechora Sea is the South-Eastern part of the Barents Sea. The Shelf of the Pechora Sea contains vast reserves of oil and gas. The biggest fields are Prirazlomnoye, Dolginskoye, Varandey-more, Medyn-more and Kolokomorskoye oil fields, Severo-Gulyaevskoye oil-gas-condensate field and Pomorskoye gas-condensate field (Zolotukhin & Gavrilov, 2011). To our mind, in the nearest future the Pechora Sea will become an area of great interest for Russian companies. There are two main reasons for this:

1) Vast reserves of oil and gas;

2) Pryrazlomnoye oil field is in production stage now and this is the only Arctic project in Russia. All the knowledge obtained from the Pryrazlomnoye project will be valuable for the further development of oil and gas fields in this region.

The Pechora Sea is a new oil region. Technological decisions, implemented in the existing projects are not well-proven technologies. Many problems will probably show themselves in the nearest future.

Current production rates of the onshore fields guarantee a sufficient amount of oil for the internal market. So, oil from the Pechora Sea as well as from the other offshore fields will be transported to the foreign countries, e.g., like Germany, France, Belgium, etc.

Severe conditions, lack of infrastructure and technologies force hydrocarbon producing companies to forget about the traditional approach to the fields development. The Complex or “cluster” development of the Pechora Sea resources is the only way of the Arctic conquest. This work introduces an approach to the problem of oil transportation year- round from the fields in the Pechora Sea, based on the existing experience of petroleum production.

1. Environmental conditions in the Pechora Sea

Environmental conditions of the Pechora Sea are defined by the high North geographical position and air masses from the North Atlantic. The environmental and climatic conditions are extremely harsh and would have a great influence on the development, production and transportation processes. Companies' interest to the Pechora Sea rises from year to year, stimulating more exploration activity.

Precise examination of the environmental conditions is crucial for the design of offshore structures. Several meteorological stations in the Barents and Pechora Seas have been gathering metocean data. This chapter deals with the most important physical conditions of the Pechora Sea, which results in the external loads on marine structures and may put restrictions on some projects.

1.1 Wind

Wind direction highly varies from season to season. Large amount of data has been gathered for the last 30 years. These are shown in Table 1. There is no prevailing direction of the winds in different seasons. The storm duration doesn't exceed 12 hours for 80-85 % from the total amount of the storms. The average wind speed is 6,6 m/sec in summer and 9,5 m/sec in winter. Loads from wind and tilt moment should be estimated in the design stage.

Table 1- Wind conditions in the Pechora Sea (Gudmestad et al., 1999, p.113).

Month	Wind Parameter	Wind direction							
		N	NE	E	SE	S	SW	W	NW
January	U	10	9	9,9	8,5	8,8	10,1	9,4	10,5
	σ	5,5	4,6	4,6	4,4	5,2	5,2	5	5,4
	n	7	11	11	15	31	32	11	8
May	U	7,5	7,4	8,1	8,2	7,1	7,2	6,5	7,2
	σ	4,3	3,9	4,3	4,6	3,8	3,6	3,4	4,1
	n	17	15	16	10	10	17	19	20
July	U	7,2	6,1	6,4	6,7	6,6	7	6	6,9
	σ	4,1	3,5	3,4	3,4	3,5	3,5	3,1	3,8
	n	2,1	17	18	14	11	10	14	19
October	U	10,8	10,3	9,3	7,9	6,9	7,7	7,9	10,4
	σ	5,6	4,9	4,9	4,4	4,3	4,4	4,1	5
	n	16	14	9	16	21	22	12	14

1.2 Air temperature

The period of negative temperature lasts for 230 days in a year. A substantial decrease of the temperature from the east part of the sea to the west is revealed. The annual mean temperature varies from -2,9^{0}C to -5,5^{0}C. "*February is the coldest month with a mean temperature of -18,3^{0}C and an absolute minimum observed temperature of -48^{0}C, both at Varandey (USSR,1986)*" (Gudmestad et al., 1999, p.113). The average temperature varies from -17,4^{0}C in February to +6,5^{0}C in July.

1.3 Hydrological characteristics

During the tide, the water mass goes from the south-east to the north-west. Direction of the flow is reversed in the ebb. Tides are semidiurnal. The velocity of tidal currents is up to 40 cm/sec. The average velocity of the current caused by cyclones might be 60-70 cm/sec. The data concerning the wind currents are shown in Table 2. Table 3 represents water level fluctuations in the Pechora Sea.

Table 2 – Wind currents in the Barents Sea (Terzieva, Girduka, Zykovoy, Dzhenuka, 1990, p.231)

Region	Maximum velocity of the current (cm/sec), years				
	1	5	25	50	100
Central part of the Barents sea	60-70	65-75	70-80	70-80	75-85
South-East part of the Barents sea (Pechora Sea)	45-50	50-55	50-60	55-65	60-65

Table 3 – Water level fluctuations in the Pechora Sea (Gudmestad et al., 1999, p.114)

Water level	Water level +-(m), Rp years			
	1	5	20	50
Circular tide	0,9	1,15	1,2	1,25
Unperiodic storm surge	1,3	1,85	2,75	3,35

The average wave height is 2-3 meters. The storm season begins in October. In summer season the waves are usually not more than 3-4 m. The average wavelength doesn't exceed 150-180 m. "*The wave regime is substantially influenced by the bordering shorelines, the region is fully protected from the north, east and south, and the water depth is relatively small. The highest waves enter from the NW the intensity falls from west to east*" (Gudmestad et al., 1999, p.114).

The Pechora Sea is protected from all directions, accept the west. Big waves come from the north-west and propagate to the east. Table 4 contains data about the wave period and probability of exceeding.

Table 4 – Calculated parameters of design waves in the Pechora Sea according to SNIP (1996) waves at 1% prob. of exceedance; $H_{0,1\%}$- height of waves at 0,1 % prob. of exceedance; λ_m - average wave period; λ_p- peak wave period; τ_m, τ_p - wave lengths corresponding to λ_m, λ_p (Gudmestad et al., 1999, p.117)

Depth, m	H_s, m	$H_{1\%}$, m	$H_{0,1\%}$, m	λ_m, s	λ_p, s	τ_m, m	τ_p, m
R_p=5 years							
10	4,3	6,9	8,2	7,9	9,5	75	94
15	5,1	7,3	8,8	8,1	9,7	87	111
20	5,2	7,6	9,1	8,2	9,8	94	123
25	5,3	7,8	9,4	8,3	10	100	133
50	5,7	8,4	10,2	8,6	10,3	114	159
R_p=25 years							
10	5,7	8,1	8,4	8,5	10,2	82	102
15	6	8,6	10,3	8,7	10,4	95	121
20	6,2	8,9	10,8	8,8	10,6	105	134
25	6,3	9,2	11,1	8,9	10,7	112	146
50	6,7	9,9	12,1	9,2	11	130	179
R_p=50 years							
10	6,1	8,4	8,4	8,7	10,4	84	105
15	6,4	9,1	10,9	8,9	10,7	98	124
20	6,5	9,4	11,3	9	10,8	108	138
25	6,7	9,7	11,7	9,1	10,9	116	150
50	7,1	10,5	12,7	9,4	11,2	135	185
R_p=100 years							
10	6,4	8,4	8,4	8,9	10,7	86	107
15	6,7	9,5	11,4	9,1	10,9	101	127
20	6,9	9,9	11,9	9,1	11	111	141
25	7	10,2	12,3	9,2	11,1	119	154
50	7,5	11	13,4	9,5	11,5	139	190

For the design of marine structures, the loads from currents and waves estimation should be very confident and consistent. Moreover, tide currents and wind can sharply change the ice drift direction by 90° angles and even more. (Karulin & Karulina, 2010).

1.4 Ice conditions

The presence of first year ice is the greatest challenges in the Pechora Sea. The ice period starts in the end of October or middle November and lasts for 185 days in the western part of the Pechora sea and 240 in the eastern part. Generally the ice season lasts until the end of July or early August. In March and April almost all the sea surface is covered with ice. The ice concentration in March 2012 is shown in Figure 1. The average ice-free period for the Prirazlomnoye field is 110 days.

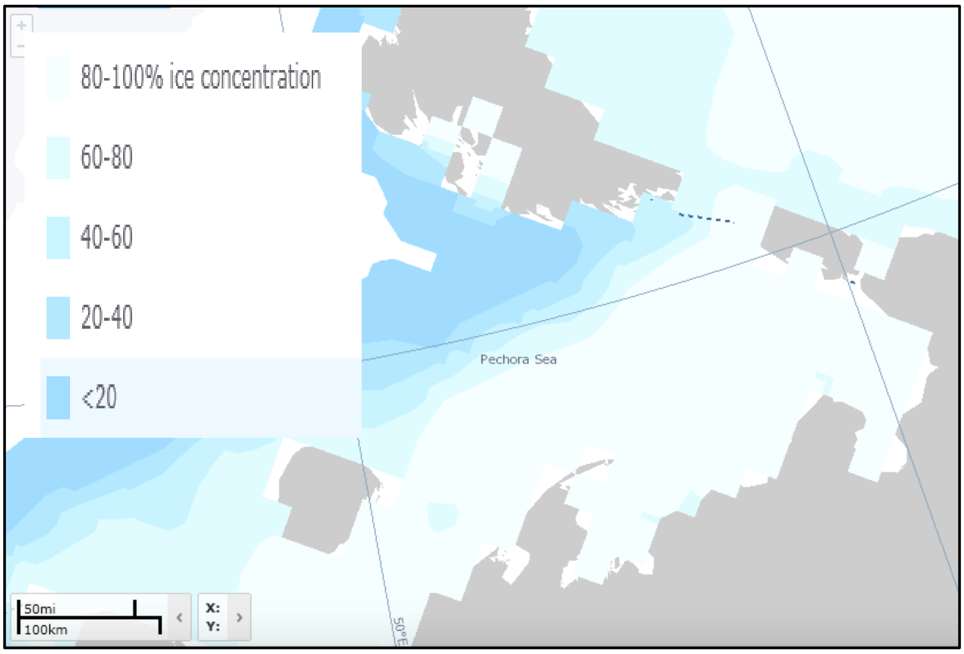


Figure 1 – Ice concentration in March 2012 (BarentsPortal, 2014)

During the winter fast ice is easily subjected to fracturing. "*This may lead to the formation of hummock fields with as much as 60-80% of the sea covered by ridges*" (Gudmestad et al., 1999, p.128). Average ice thickness reaches 0,8-1,1 m. Higher thickness of ice (up to 2,5 meters) is considered to be possible but probability of it is still very low. The main ice drift direction in winter is from the north, but in the spring ice mostly drifts from the west and south-west. Table 5 contains information about the ice drift speeds in the Pechora Sea. The average uniaxial strength is 1,37 MPa. The probability of hummock and stamuchas formation is high.

Table 5 – Ice drift speed in the Pechora Sea (Gudmestad et al., 1999, p.125)

Region	Ice drift speed due to wind (m/s)	
	Average	Maximum
East	0,09	0,6
West	0,15	1

Ice loads on the structures may become the largest component among other factors forming the total external load. Global and local ice loads should be distinguished. Both components determine the horizontal stability, local and overall strength of the structure.

1.5 Soil conditions

Soil conditions play a great role for the construction of offshore structures and marine pipelines. In order to make a good model of soil conditions much work should be done. Geological data, seismic survey and soil boring results are required. Dynamic loads (waves, wind and etc.) acting on the structure are transferred to the underlying soils. Thus, a proper estimation must be done in design stage. This part gives a brief summary of soil analysis in the Pechora Sea.

According to (Bellendir & Toropov, 2000, p.2), the authors of the article made their own classification of the soils in the Pechora sea. Their classification is based on the following criteria:

- Presence of weak clay macro porous soils;
- Depth of occurrence;
- Properties of the soils.

Thus, four types of soils might be distinguished. "*Type 1 is characterized by the absence of weak macroporous clays in the section, the whole thickness of the foundation is composed of soils with high strength parameters. Such type of section is characteristic of Severo-Gulyaevskoye and Medynskoye oil fields.*

The second type of soil conditions is characterized by the fact that strong surface soils are underlain by weak clays or silts of up to 8m thickness. This type is characteristic for Vostochno-Gulyaevskoye and Varandei-more sites, along with the first type.

The third type of soil conditions (Prirazlomnoye, Alekseevskoye, Severo-Dolginskoye) is composed of macroporous weak clay soils of 10-15m total thickness underlying the layer of dense hard sands of 4-5m thickness.

At the Polyarnoye site weak macroporuos clays and silts as well as loamy loose sands are occurring from the surface and the layers are 20-25m thick (4th type section)" (Bellendir & Toropov, 2000).

This classification doesn't contradict to the data at website www.barentsportal.com. On the picture below one can see the areas of hard and soft bottom sediments in the Pechora Sea. Information about the soil is of great importance, as some types of oil terminals should be grounded on the bottom of the sea. Regarding the soil classification, only Type I and III are suitable for the installation of any structures. The presence of the hard rocks makes the construction of such type of terminal possible.

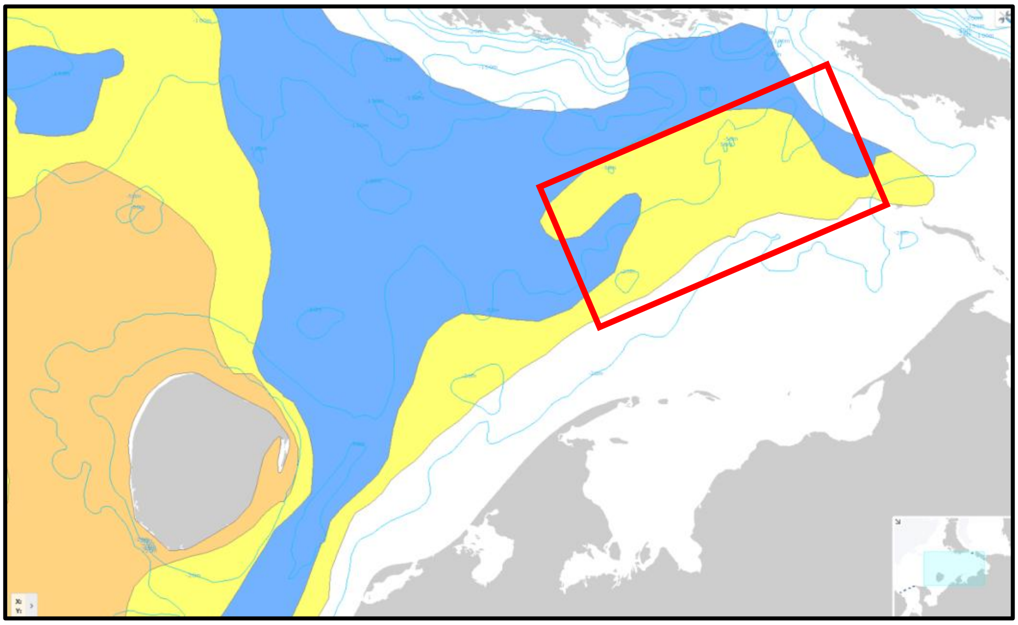


Figure 2 –Soil conditions in the Pechora Sea (yellow – hard sediments, blue –soft sediments) (BarentsPortal, 2014)

1.6 Preliminary conclusion

Analysis of the environmental conditions has revealed that the Pechora Sea is an area of really harsh conditions. The semi-closed Pechora Sea is rather shallow and covered with the first-year ice during the most time of the year. High concentration of the ice with rather big thickness, strong winds and rapidly changing currents are the greatest challenges for the development of oil and gas fields in the Pechora Sea

Nevertheless, these conditions are not unique and can be found in the other parts of the world, especially within the Arctic region. In order to pick out projects, developed within the same conditions as in the Pechora Sea, experience of the hydrocarbons production in the Arctic will be gathered and scrutinized in the following chapters.

2. Experience of oil and gas production in the Arctic

It is a well-known fact that the Arctic region hides vast amounts of minerals. According to some estimation, about 20% of the world's undiscovered resources of oil and gas are concentrated in the Arctic region, despite The Arctic region occupies only 6% of the Earth.

The Arctic border is not determined precisely. There are at least three points of view:

1. The Polar Cycle determines the Arctic region;
2. July isotherm $<10^{o}C$ defines the Arctic region;
3. Area with no trees.

For simplicity, let’s limit ourselves only by the first definition. In some parts of the world, environmental conditions are very similar to the Arctic ones, especially in winter season. Offshore projects, realized in these areas are also valuable for the analysis. These regions include Sakhalin Island (Russia) and the northern part of the Caspian Sea (Russia and Kazakhstan). Starting now, the term Arctic in this report will combine the "real Arctic" and "areas of interest”.

Two-thirds of the Arctic is covered by water. Half of this territory is the continental shelf. Arctic Council responsible for development of the Arctic area include 8 arctic states: Norway, Finland, Sweden, Russia, Canada, USA, Denmark/Greenland, and Iceland (Figure 3). Sweden and Finland cannot put any claims on the Arctic continental shelf as they don't have a marine border towards Arctic Seas. In addition, Iceland is located below the Arctic circle. Thus, only five coastal states can be involved in the Arctic marine development of hydrocarbons. This is necessary to realize for a more comprehensive further analysis of the offshore experience and formation of a modern concept for the development of new Arctic regions with emphasis on the Pechora Sea.

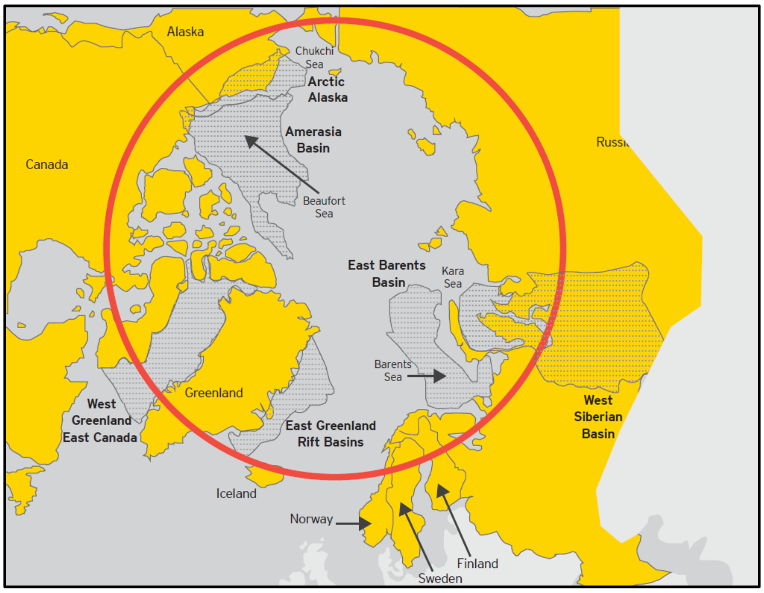


Figure 3 – The Arctic Region (Eurasia group, 2014)

The USGS reported that "90 billion barrels of oil, 1,669 trillion cubic feet of gas and 44 billion barrels of Natural Gas Liquids are recoverable in the whole Arctic" (EY's Global Oil & Gas Center, 2013). Russian participation in the Arctic offshore hydrocarbon production is unavoidable as about 43 of 61 oil and gas fields discovered in the Arctic are located in the Russian Zone. Share of hydrocarbon potential among the coastal states in the Arctic is shown in Figure 4.

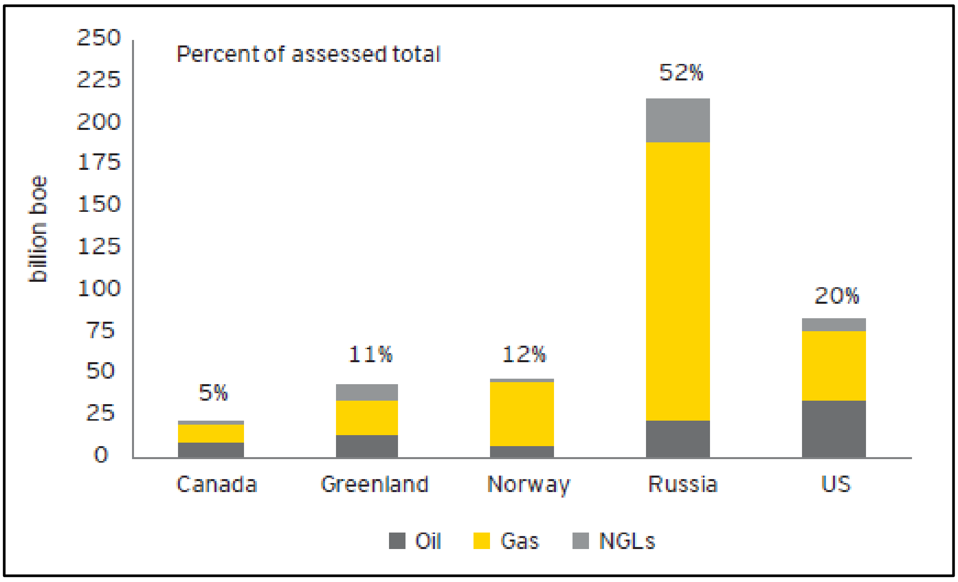


Figure 4- Distribution of the hydrocarbon potential among the countries within the Arctic (Eurasia group, 2014).

One can see that all these countries have a stable policy and follow the laws and international agreements. This fact essentially reduces the political risk and secures an access of the national companies to the Arctic.

All arctic coastal states have already started exploration and production activities. Physical and environmental conditions in the Arctic region are not similar, and varies from place to place, resulting in specific challenges for offshore oil and gas industry.

2.1 Russia

Modern Russia has intensified its efforts in the development of the offshore oil and gas sector. The area of the Russian Continental Shelf is about 6,2 mill km^2. Approximately two-thirds of this area belongs to the Arctic. The territory of the Russian Arctic shelf is split into twenty hydrocarbon provinces, and 10 of them have proved oil and gas reserves.

At present there are only two companies operating at the Russian Arctic Shelf zone: Gazprom and Rosneft. Current licensees for the offshore exploration and production activities are mostly located in the Barents, Kara and Okhotsk seas. Offshore oil and gas production in the Russian waters is concentrated on the shelves of Sakhalin Island, Pechora and Caspian seas.

<u>Sakhalin-1</u>

Sakhalin 1 is both an offshore and onshore project. There are three fields in this project: Chayvo, Odoptu, and Arkutun-Dagi. All three fields are located offshore Sakhalin Island in the Russian Far East.

Deployment of the Sakhalin-1 project began with the Chayvo oil field, located 11 km far from the coast of the Sakhalin Island (Rigzone, 2015). Chaivo field development is based into two drilling centers. The Orlan platform is used for the offshore drilling and oil production and installed in a water depth of 14 meters. Orlan is a reinforced gravity based structure that can operate in harsh ice conditions and withstand great loads. Oil production at the Orlan platform began in 2005. The picture of Orlan platform is shown in Figure 5.

Figure 5 – Orlan platform (Wikimapia, 2007)

Next to the Chayvo oil field is the Odoptu oil field, which is developed from the shore. The technology of the extended reach drilling makes it possible to produce hydrocarbons from the field, lying beneath the water and transfer it directly to the shore.

Arkutun-Dagi field is the third part of the Sakhalin-1 project. It is located 25 km from the coast of the Sakhalin Island. At this part of the Okhotsk Sea the average water depth is 40 meters. The Arkutun-Dagi field is developed by a GBS with column foundation, called “Berkut”. Production at the field started in January 2015 with the peak production rate of 31,1 million barrels tons of oil per year (Rosneft, 2015).

Figure 6 – Berkut platform (Rosneft, 2015)

Sakhalin-2

Sakhalin2 is one of the biggest offshore projects in the world with the peak hydrocarbon production of 395 thousand barrels of oil equivalent per day. The project includes Piltun-Astokhskoye oil field and the Lunskoye gas field. The main challenges for the project were the lack of infrastructure and sub-arctic conditions as it is located offshore Sakhalin Island.

Ice-class platform Moliqpaq or PA-A (Figure 7, a) was the first platform, installed at Piltun-Astokhskoye field and the first one offshore Russia. The platform enables the operator to produce 90 thousand barrels of oil per day. Piltun-Astokhskoye field is 16 km away from the east coast of Sakhalin Island, where the water depth is about 30 meters. Oil production started at PA-A in 1999.

PA-B became the second platform installed at Piltun-Astokhskoye field (Figure 7,b). This is a GBS platform with column foundation. PA-B comprises production, processing and drilling facilities with a total daily production of 70 thousand barrels of oil.

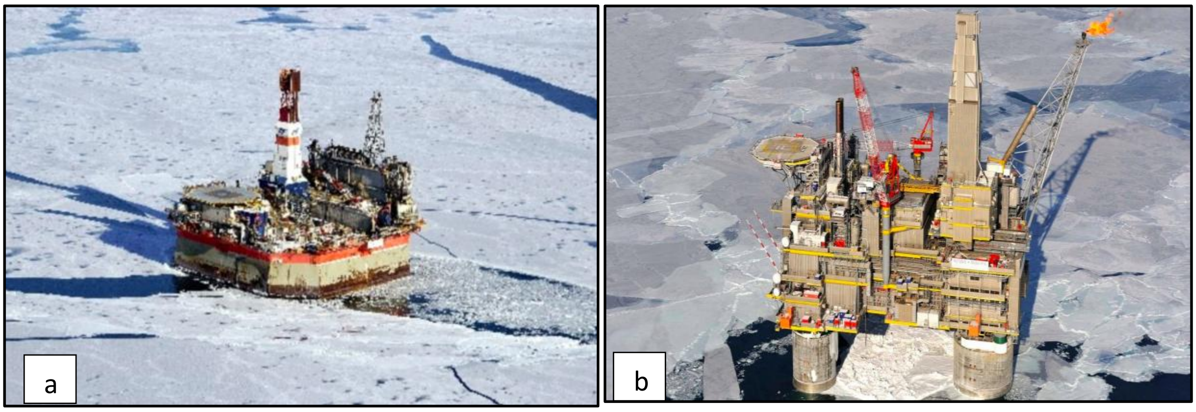


Figure 7 – PA-A (a) and PA-B (b) platforms (Subsea IQ Offshore field development, 2015)

<u>Prirazlomnoye field</u>

Prirazlomoye oilfield is located in the Pechora Sea, 60 km from the shoreline in thewater depth of 19 meters. Although it has been discovered in 1989, the oil production started only in 2013. Prirazlomnoye field is a pioneer offshore oil project in the Pechora Sea. The infrastructure of the Pechora Sea remains at a low level.

Oil reserves of the field are about 610 million barrels. All production, processing, storage and offloading facilities are carried out at one GBS referred as "Prirazlomnaya". Prirazlomnaya platform is shown in Figure 8. The maximum annual production is 45,6 million barrels of oil.

Figure 8 – Prirazlomnaya platform (Offshore energy Today.com, 2013)

Varandey terminal

The Russian company “LUKOIL” has constructed a gravity-based ice-resistant offloading terminal “Varandey” in the Pechora Sea, 22 km off the settlement of Varandey (see Figure 9). Average water depth in the area of installation is 17 meters. This terminal has a capacity of 83,6 mln. barrels per year and offloading rate of 8000 m^3/h (ArcticInfo, 2015). Oil from the different fields of the Timan-Pechora province goes to the onshore storage base. Then oil is pumped to the terminal through the pipelines (they are trenched into the sea floor to a depth of 1,5 m). The quality of oil is high, even higher than the “Urals Brent”. Then, oil is exported by three double acting Arctic tankers: Vasily Dinkov, Timofey Guzhenko and Kapitan Gotsky. The deadweight of each tanker is about 70,000 tons with a draft 12m. They can operate in the ice-covered areas with ice thickness up to 1,5 m.

Figure 9 – Varandey terminal (Bogoyavlensky, 2013)

Yuri Korchagin

North sector of the Caspian Sea in the winter season is very similar to the Arctic area. Russian company "LUKOIL" is a license holder for the development of the Yuri Korchagin field. This field is 180 km far from the Astrakhan city. Water depth is shallow, about 14 meters. Field’s reserves are estimated to be 570 million barrels of oil equivalent.

The Oil producing and gathering facilities are placed at one ice-resistant platform LSP-1, shown in Figure 10.

Figure 10 - LSP-1 with living quarter LSP-2 (Fotin & Kulikov, 2014)

2.2 Canada

Canada takes the fifth place among oil-producing countries in the world (Petroleum production in Canada, 2015). Exploration and production activities prevail above midstream and downstream operations. The greatest exploration activity on the Canadian Continental Shelf took place in 1970s and 1980s. Nowadays, there are two large offshore regions with offshore projects.

1) Beaufort Sea

Beaufort Sea is the first one. Individual exploration wells were drilled there. Nevertheless, no oil producing projects are there nowadays.

2) Newfoundland Island

This area is the heart of the offshore oil production in Canada. Exploration wells were drilled at the end of Cabot Strait and the coast of Nova Scotia. There are four significant offshore oil projects in the eastern Canada.

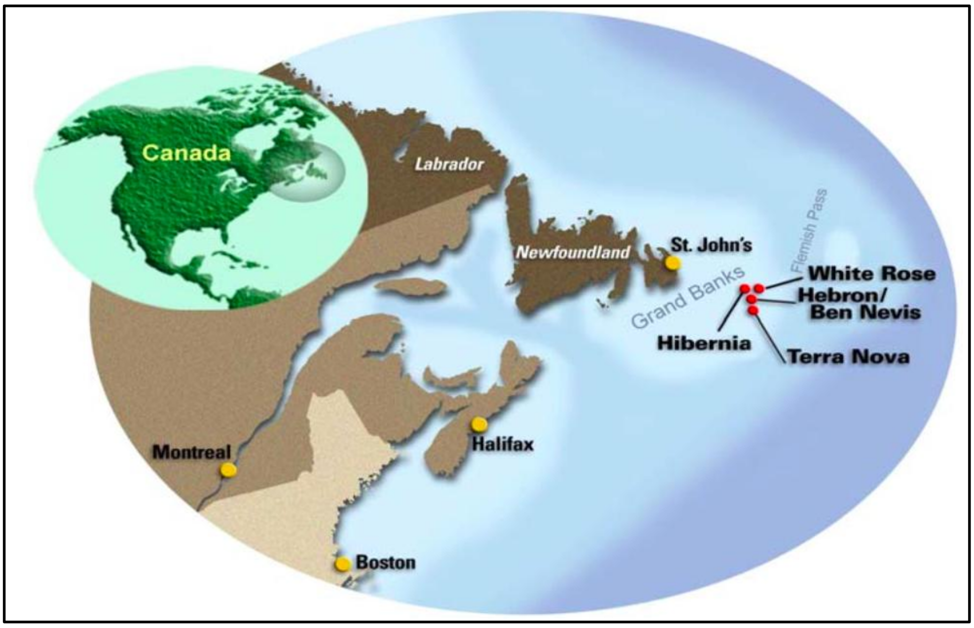


Figure 11 – Grand Banks, Canada (Norman, Lochte, & Hurley, 2008)

Terra Nova

The recoverable reserves of the Terra Nova oilfield are estimated to be 400 million barrels of oil. The oilfield is 350 km far off St. John's, Newfoundland and 90 km from the Hibernia to the south-east. The average water depth is 90 meters. The first oil was produced in 2002.

Environmental conditions are enormously harsh. Water temperature at the bottom remains constant all over the year -1,7^{o}C, while at the surfaces the temperature varies from -1,7 to 15,7 ^{o}C. The freezing point of liquids is controlled. The seasonal presence of ice is another challenge. The average ice concentration is 3/10 with ice thickness ranging from 0,3 to 1,5 m. Besides the ice present, icebergs are frequently observed at Grand Banks. Thus, the development concept here is based on an ice-resistant double-hulled FPSO and subsea wells are located in open glory holes to eliminate the risk of damage from scouring (Figure 12). The FPSO is able to withstand 100 thousand tone icebergs. The peak oil production is 150 thousand barrels per day with a storage capacity of the FPSO 900 thousand barrels (Lever, Dunsmore & Kean, 2001).

Figure 12 – Terra Nova Development concept (Lever, Dunsmore & Kean, 2001)

White Rose

White Rose project is very similar to the Terra Nova from the point of the development concept. Oil reserves and production rates are lower: 230 million barrels in place and 120 thousand barrels production per day.

The White Rose field is located only 50 km from the Terra Nova, so environmental conditions are very similar. The first oil was produced in 2005.

Figure 13 – White Rose FPSO (Offshore Technology.com, 2015, d)

Hibernia

The Hibernia oil field was discovered in 1979, 315 km off St. John's Newfoundland in 80 meters depth water. Recoverable reserves of the field are 1,200 million barrels of oil. Production began in 1997 and the peak production rate of 126 thousand barrels per day was reached in 2009.

As it was said above, Newfoundland is characterized by harsh conditions. For the Hibernia project, a GBS was used for the field development (Figure 14). The GBS is design to withstand an impact of six million tones iceberg. The caisson height is 105,5 meters with wall's thickness of 1,4 meters to transmit the ice loads. The GBS also acts as a storage tank with a capacity of 1,3 million barrels of oil (Offshore Technology.com, 2015).

Figure 14 – Hibernia Platform (Offshore Technology.com, 2015)

2.3 Greenland

Despite the geographical location of the Greenland, this Iceland is a part of Europe, Denmark. Greenland, especially the north-east part of it, is considered to be the last biggest province of undiscovered hydrocarbon potential. The latest estimation of the USGS estimated the potential to be approximately 31,4 billion boe (U.S. Geological survey, 2007). At the same time, the expenditures for the exploration activity is high: the price for one exploration well is about $ 100 million and 7 billion for the development of the whole field (Scheid, 2014). Despite the big costs, big international companies are engaged in the exploration process. About 15 oil wells have been drilled since the 1970s.

Greenland’s government is interested in the exploration activity, as this is an excellent opportunity to get independency from Denmark Nevertheless, offshore oil production hasn’t started here and is unlikely to originate in the nearest future.

2.4 Iceland

Icelandic shelf had not been involved in the exploration activity before the recent years. First exploration licenses were awarded to a UK-Based consortiums (Offshore Technology.com, 2015, a). Seabed samples gained in the Dreki area of the continental shelf showed high prerequisites for an active oil and gas system in the region. Hydrocarbon production has not started here yet.

2.5 USA

Oil potential of the USA Arctic continental shelf is estimated to be 50 billion barrels of oil equivalent (BOEM, 2011) . Alaska is one of the offshore production area and the only one located in the Arctic. Great reserves of oil and gas are hidden beneath The Beaufort Sea. The Shelf of the Beaufort and Chukchi Seas may contain 23 billion boe and 108 trillion cubic feet of natural gas. Offshore drilling started here in 1972. Since that great projects have been realized (Ebinger, Banks, & Schackmann, 2014, p.13-16).

Endicott

Endicott became the first production project to be organized in the Beaufort Sea. The construction of the artificial island began in 1985 by Sohio Alaska Petroleum Company. Nowadays, the project comprises two artificial islands (Production and Drilling) and a causeway which connects two islands with each other and the mainland. The Endicott Island is 4 km far offshore and 24 km from the Prudhoe Bay. The water depth in this area varies from 3 to 4 meters. The peak production rate was approximately 20 thousand barrels of oil per day. After the processing oil is sent to the TAPS via a 24-mile pipeline (Endicott Island, 2015).

Figure 15 - Endicott Island (Leidersdorf, Gadd, Hearon, Hall, & Perry, 2008)

North Star

North Star artificial island was selected as the most suitable alternative for the development of the Northstar Oil pool with estimated reserves in-place of 247 million barrels and 280 bcf of gas (Zolotukhin, 2013). The island was constructed in 2000 by BP company. Detailed examination of the area revealed that the wave and ice loads are higher than at the Endicott project and pack ice formation may happen every year. Only artificial island covered with concrete mats could guarantee the year-round oil production and protection in such conditions. The island is located far from the shore: 10 km north from the Alaska coast. Peak production of oil was 65 thousand barrels of oil per day (Hydrocarbons-Technology.com, 2015).

Oooguruk

Oooguruk is the third offshore production project and the eighteenth artificial island in the Beaufort Sea. The island was constructed within nine months in 2006. This island is referred as the “Offshore Drillsite” and located in shallow waters with a depth of 1,35 meters in the East Channel of the Colville River, five miles from the Harrison Bay. Figure 16 shows the Oooguruk Island (Leidersdorf et. al., 2008). Oooguruk Island faces with less severe ice conditions than two previous projects due to smaller water depth.

Figure 16 - Oooguruk Island (Leidersdorf et. al., 2008)

Peak oil production is about 15-20 thousand barrels of oil per day (Offshore Technology.com, 2015, c). The project is divided into three blocks:

- artificial island (drilling site),
- pipelines and supply flow lines
- onshore processing facilities.

Nakaitehuq

In 2011, Eni started production at the Nakaitehuq oil field with recoverable reserves of 220 million barrels of oil. A peak production of 28 thousand barrels of oil per day is expected. Eni is going to drill 52 wells, including 30 offshore wells. These wells were drilled from the artificial island (Spy Island) located 4,5 km far from the Harrison Bay. Water depth in the area of the island does not exceed 3 meters.

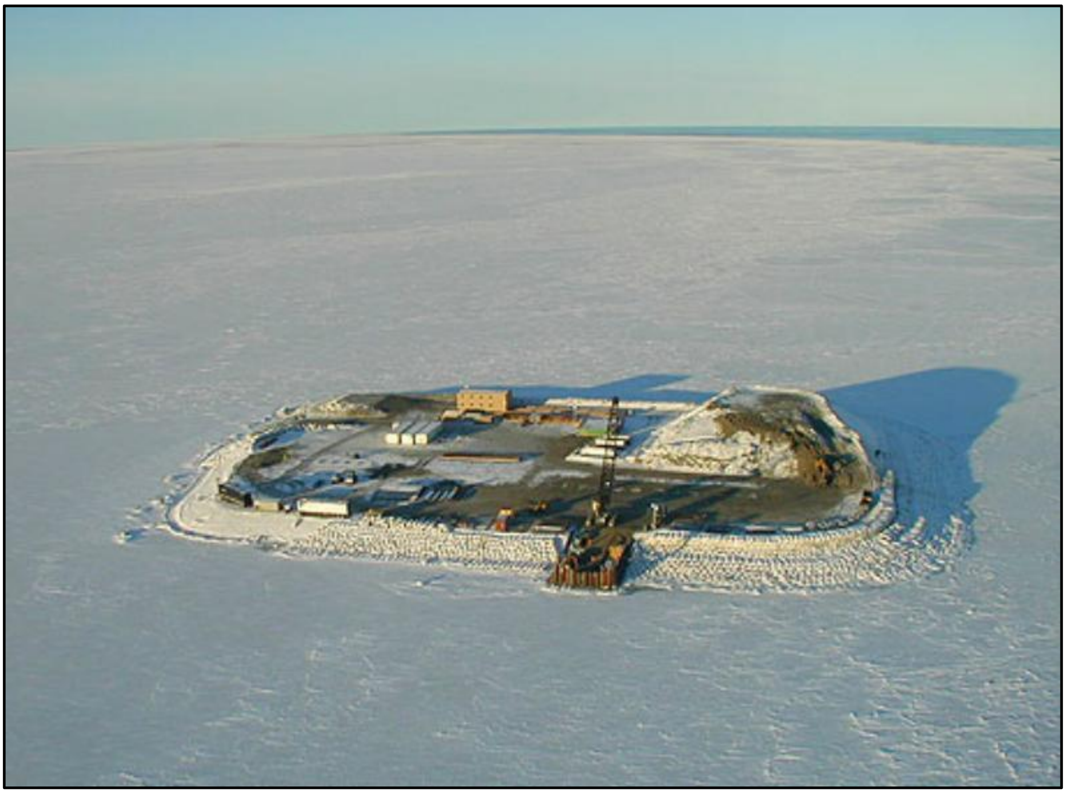


Figure 17 - Spy Island (Offshore Technology.com, 2015, b)

2.6 Norway

Norway keeps the position between the top five oil producers. Offshore sector of Norway can be spitted into two big parts:

1) North and Norwegian Seas – well-known areas with significant experience
2) Barents Sea and the north part of the Norwegian Sea – New areas with the lack of infrastructure and technical challenges.

"*USGS survey estimated that the mean undiscovered, recoverable petroleum resources in the Barents Sea Shelf to include 11 billion barrels of oil, 380 trillion cubic feet of natural gas, and two billion barrels of natural gas liquids*" (Ebinger, Banks, & Schackmann, 2014, p.8).

Norwegian and Barents Seas are the parts of the Arctic Region. In the Norwegian Sea the number of projects is huge. The main projects are Draugen, Heidrun, Njord, Skarv, Urd, and Asgard. In the Barents Sea, only Snøhvit gas field is involved into production. The next stage of hydrocarbons production in the

Barents Sea will be Goliat oil field. Currently, Oil from the Norwegian Sea is transported only by tankers.

2.7 Preliminary conclusion

In this chapter, based on the particular characteristics of the Pechora Sea, central regions of the offshore hydrocarbon production in the Arctic were considered. Depending on the geographical position, each country developed its approach for hydrocarbons offloading and transportation.

As one of the greatest challenges for the Pechora Sea is the presence of ice, Norwegian projects will be not considered further, because they are all developed in the ice-free waters. Oil transportation philosophy, implemented at Russian, Canadian and USA projects, will be examined in the next chapter in order to choose the most suitable way of the hydrocarbons transport in the Pechora Sea.

3. Oil transportation technologies in the Arctic

Central regions of the offshore hydrocarbon production and projects were listed in the previous chapter. Knowing these regions and projects, further analysis can be done. The methods that were implemented in the Arctic projects are under investigation in this chapter.

Knowing the organization of hydrocarbon transportation, why the particular method was chosen instead another one, what problems were revealed and their solutions will lead to the thought-out arrangement of the transportation system in the Pechora Sea.

Loading technologies for some of the projects are described very poorly. Comparing some of the descriptions one can see that they had different directions and were dedicated to the various specific features. The chapter forms a representation of the oil loading process in each case.

3.1 Sakhalin-1

The Dekastri oil loading terminal is placed in Ulchi District of Khabarovsk Region. The terminal is used to transfer oil from the production facilities of the Sakhalin-1 project to the tankers through a 226 km pipeline. The terminal has already offloaded more than 51 million tons of Sakhalin-1 oil (Exxon Neftegas Limited, 2012, p.1).

The Dekasti oil terminal is an Arctic TLU, built in 2005 by Bluewater company. This is a fixed piled structure with a rotating head (Figure 18). Due to the bearing system, the head can rotate relative to the tower and provide continuous oil loading, holding the tanker in the smallest total resistance zone (Bluewater Company, 2009, p.1).

TLU provides year-round oil transfer to the Aframax (110 000 DWT) class tankers even when the air temperature is lower than -35^{0}C. The bow loading is used during the winter period while midship loading takes place in summer. Both mooring and loading processes are remotely controlled from the tanker or the shore base

Figure 18 – Dekastri oil export terminal (Bluewater Company, 2009)

The terminal stays on a special foundation, as the seabed is very soft and do not provide enough stability. Moreover, this foundation enables to withstand earthquakes, which are possible in the area of Sakhalin Island.

3.2 Sakhalin-2

The Sakhalin-2 project was not only the first offshore project in modern Russia, but also one of the biggest marine campaigns in the world, with the purpose of year-round oil and gas production, hydrocarbons transportation from three platforms via the Island, construction of the first LNG plant in Russia and an oil export terminal. This is an enormous volume of work, and realization of the Sakhalin-2 project was spitted into two phases. The general sketch of the transportation system is shown in Figure 19.

Figure 19 - The Sakhalin Island

3.2.1 Phase 1

Phase 1 started in 1996 with the development of Piltun-Astokhskoye field using only one platform Molikpaq, enabling hydrocarbon production. By 1999, there was no infrastructure to organize year-round oil transportation to the consumers. Moreover, Sakhalin Island was a new area for oil producing companies. Thus, it was decided to organize seasonal oil production six month per year.

Due to the lack of infrastructure, the Vityaz production complex was developed. The complex consisted of Molikpaq platform, a SALM, offshore pipeline and the FSO Okha. The artistic impression of the complex is shown below (Figure 20). The first Phase of the project gave a new brand of oil called Vityaz. The cumulative oil production had reached 13,2 million tons of oil by the end of 2008.

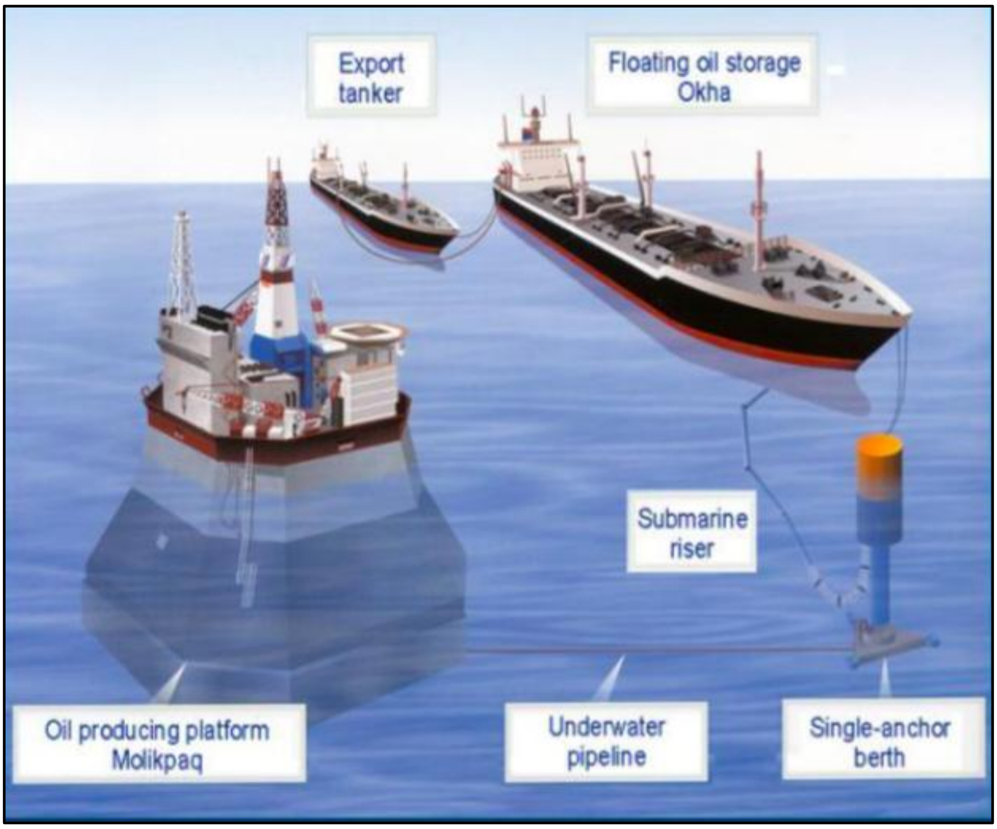


Figure 20 – Phase 1, Vityaz complex (Reed, 2014)

The SALM buoy floated to the surface in summer. It received oil from the platform and sent it to the FSO. FSO Okha was an ice class floating oil storage with additional modifications to meet the demands of the Sakhalin conditions. The export hose was always supported out of the water by a hose reel on the FSO to prevent the hose icing.

In order to supply the platform, year-round support vessels were used. Even operating in 1,5 meters ice thickness, these ships could move with a speed of 1,5 knots. The most interesting feature of the vessels is the Aquamaster propulsion system. This system was able to rotate the vessel by 180 degrees within 90 seconds and create an escort channel of 70 meters (Reed, 2014, p.20). Excellent ice management let to the continuous hydrocarbon production and transportation until the ice thickness exceeded 30 cm. Supply vessels, operating in pre-broken ice could make a wake for the FSO and SALM by the Aquamaster system. The beginning of the production season was the most difficult due to heavy ice. Icebreaker Krasin was used to eliminate the risk to the SALM and FSO damage by ice ridges and thick ice layers.

Vityaz complex was used from 1999 to 2008. In 2008, oil transportation was changed, and the complex was decommissioned

3.2.2 Phase 2

Phase 2 began with the installation of Lun-A platform and PA-B in 2006-2007. Within the bounds of Sakhalin-2, the first Russian LNG plant was created, but in this report the gas "bench" is not considered. Since that time, the oil transportation scheme of the Sakhalin 2 project has changed entirely.

Nowadays, a long network of offshore and onshore pipelines connects the PA-A and PA-B platforms with an oil terminal and loading unit at the south part of the Sakhalin Island. Environmental conditions in the south of the Iceland make it possible to transport the produced oil by conventional tankers.

Implementation of the Phase 2 resulted in a year-round oil transportation chain, comprising of four main elements:

1) Oil producing platforms

2) Pipeline system;

3) OET;

4) TLU;

Platforms

Produced oil from the PA-B platform is processed and transported to the PA-A platform via two branches of 14’’ subsea pipelines. Another 30" subsea pipeline goes to the OET from the PA-A. The total length of the pipeline is 46,6 km. Due to the challengeable shore approach, it was decided to put the pipe into 10-190 m wide trenches.

OET

There are three crude oil storage tanks with a normal capacity of 95,000 m^3. All the tanks are surrounded by an earth dike to contain oil in case of any damage or destruction of the storage facilities. Tanks are interconnected with each other by pipes (Sakhalin Energy, 2011 a, p. 67). Tanks are equipped with an alarm system to inform the staff when the level in tanks reaches maximum fill point.

Four electric centrifugal loading pumps are used to transfer crude oil via the offshore pipeline from the storage facilities to the TLU. Generally, three pumps are enough to guarantee required tanker loading rates, one pump in reserve. Special meters are used to control the process of oil pumping.

Treatment facilities include “facilities for primary and secondary wastewater treatment, including settling tanks, degreaser skimming tanks, sand filter and sludge dewatering facility” (Sakhalin Energy, 2011 b, p. 16).

Pipeline system

From the processing plant in the north part of the Island, oil is sent through the onshore pipeline to the OET.

Offshore pipeline system consists of two parts:

1) Gathering pipeline from PA-B and Molikpaq to the onshore complex;

2) Oil export pipeline to TLU

At the design stage, there were three alternatives to the offshore pipeline route. They are shown in Figure 21. The greatest challenge was not connected with some technological problem of the pipeline installation, but with the environmental restrictions. There are feeding grounds of Gray Whales between production facilities and the coastline. After all discussions, alternative 1 (blue line) was selected as a final route.

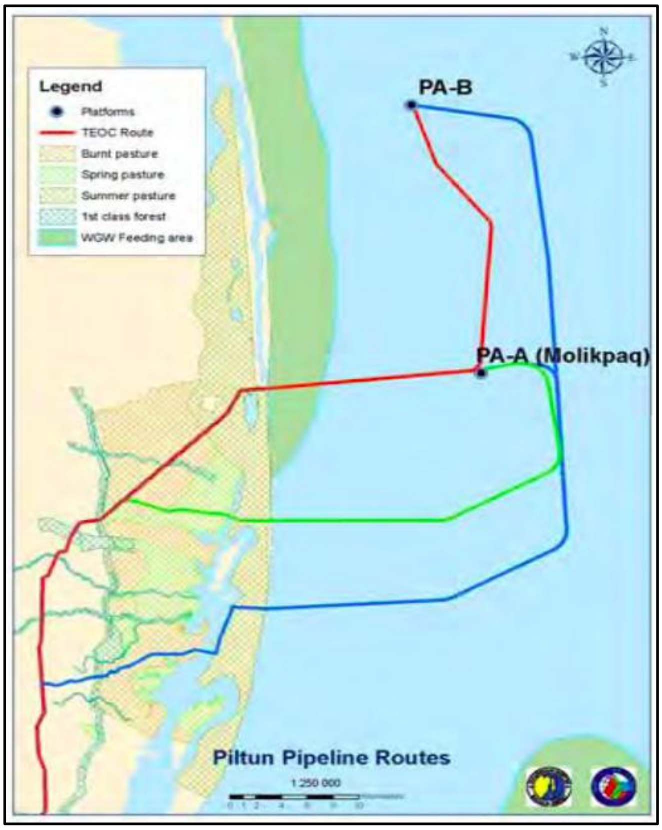


Figure 21 – Alternative pipeline routes (Sakhalin Energy, 2005)

The 5,5 km long 30’’ pipeline connects the OET and the TLU. In order to provide the TLU with electrical power a 7 cm composite cable is utilized. Communication and control signals are sent to the TLU via fibre-optic lines laid with the pipeline. Pig receiver module provides the flow assurance. Pipeline capacity is about 8000 m^3 per hour (Sakhalin Energy, 2011 b, p. 16). The pipeline is made of steel with specification 5L of API. In places with a water depth deeper than 15 m, the pipe was laid on the seabed without trenching. Both internal and external walls are covered with anticorrosion coating. A cathodic protection system also reduces the level of corrosion.

TLU

The TLU is a gravity structure of tower type with rotating crane boom. This unit is located 4.7 km south of OET in Aniva Bay. The most time in winter Aniva Bay is covered only by thin ice, but seldom there can be found thick ice. This ice drifts into the bay under the action of wind and current.

Water depth in the Aniva Bay is 28 meters, and TLU can serve tankers of different capacity: from 80 000 to 150 000 t every two or three days. About 9.8 million tons of crude oil is transferred via the TLU year-round. As the TLU and tanker are exposed to the ice loads during the winter season, support vessels are required to assist the offloading.

The main parts of the TLU are the following:

- Crane boom;
- Electric and power equipment;
- Crude oil riser boom;
- Winches;

The crane boom is able to rotate through 360^{o} following the tanker. Such design maintains the process of loading, despite the wind, current and wave loads directions. The crane suspends the loading hose, when the tanker is held by a hawser at the TLU (Hellmann, 2003).

TLU's basement has an octagonal shape and is subdivided into 17 ballast sections filled with ballast to increase the stability. Despite the TLU is unmanned structure, there is a temporary shelter on the main deck that is used in case of any emergencies. The sketch of the terminal is shown in Figure 22.

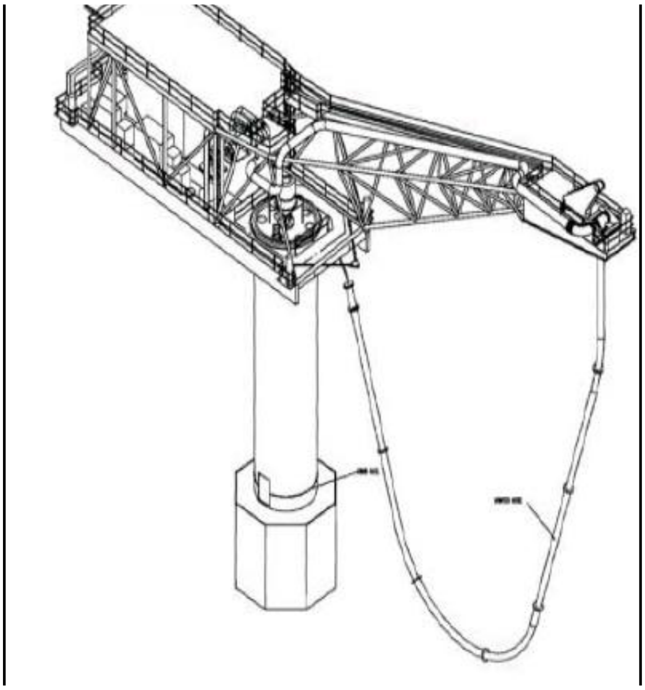


Figure 22 – Tanker Loading Unit (Sakhalin Energy, 2011, b)

The process of the TLU towing, installation and setting up were finished within three months in 2005. Great emphases were placed on the site selection. Before installation, wide preparatory work was done. 2500 m^2 of the seafloor was investigated and 0,5 m thick gravel mattress was made. The protective berm was constructed within a radius of 25 m around the TLU to prevent scouring.

During the process of offloading the hose supported by the crane boom is moved to the tanker. Tanker loading systems are located in the middle or at the bow of the ship. Depending on the season, the hose configuration can be changed. Bow loading configuration is more suitable for the ice season while central tanker loading is for the ice-free season. The process of the tanker approach to the terminal consists of the stages (Sakhalin Energy, 2011 b, p. 26):

1) An empty tanker stops at the certain distance with the bow directed to the TLU;

2) The towing line is transferred to the tanker by the means of a support vessel or line thrower;

3) The loading hose is passed to the tanker. The end of the hose is connected to the collector connection;

4) When all the previous operations are finished, and the system is ready for oil loading, personnel in the control room are informed by the “Berthing Master”.

Tanker mooring and loading generally takes 24 hours. The designed loading rate is about 8000 m^3 per hour. In order to maintain the required state of serviceability and ensure the safety of operations, the support vessel fleet is used. The list of support vessels is represented in Table 6.

Table 6 – Required support vessels (Sakhalin Energy, 2011 b, p. 27):

№	Vessel	Number	Functions
1	Icebreaker	1	Escort of tankers in winter season
2	Multipurpose Ice class tug	2	Ice breaking, assistance in mooring operations
3	Tug boat	2	
4	Tank barge	1	Repair of the loading hoses
5	Crew boat	1	Transportation of workers

Whenever the tanker is being filled with oil, a tug is used to keep the tanker in place. In ice conditions, special icebreaker tug is required. Equipped with Aquamaster propulsion system, such tugs holds the position upstream of the TLU and propellers create a wide enough free ice channel. This process is shown in Figure 23.

Figure 23 – Terminal operating in ice (Reed, 2014)

3.3 Prirazlomnoye

The Prirazlomya project follows the principal of year-round production. Even when the Pechora Sea is covered with the first-year ice, two shuttle ice-class tankers with DWT of 70 thousand tons operate and transport the produced oil to the Belokamenka FSO in the Murmansk region. Each of the tankers was specially built in Russian shipyards. They are called: Mikhail Ulyanov and Kirill Lavrov.

The Prirazlomnaya platform has two crane offloading systems on the diagonal angles of the platform. Each offloading arm can rotate 90^{o} from the diagonal. Depending on the ice drift direction, current and wind, offloading can be implemented via one of two stations. The crane transports the offloading hose to the tanker. The end of the hose is connected to the receiving facilities of the tanker.

The Arctic crane loading system is relatively new and was designed in accordance with the environmental protection rules. Each of the systems has several barriers: emergency shutdown of the pumps, protection from crane overloading, etc. The total price for two systems was NOK 90 million (AkerSolutions, 2004).

One of the functions of the platform's caisson is oil storage. The caisson is divided into 14 tanks, twelve of which are used to store the oil and has the capacity of 103 thousand tons. The sizes of the platform are 126 x 126 meters. During the winter season, platform forms a wake depending on the direction of the ice flow. At the time of offloading, tanker holds the position in this channel of ice-free water. Only this position guarantees the safety of the loading operation. When the direction of ice drift changes, deformation of the free water channel happens. At once, the edge of the ice cover begins to counteract with the tanker. Considerable ice loads can damage the tanker or result in the loading hose damage or rupture. Research of the Krylov Shipbuilding Research Institute has revealed that the ice loads on the tanker are much higher than allowable loads in mooring state. As the consequences of these events are high, offloading operations are stopped immediately when the direction of the ice floe starts to change. Moreover, some of the research has shown that the forces provided by the thrusters are smaller than the forces executed by the ice.

Besides the ice, there are several other parameters that define the possibility of offloading: wind direction, wind speed, wave height, humidity, etc. In general, 2,5 hours are required for tanker approaching and disconnection from the platform. The limited angle of rotation of the offloading cranes, amplified by the rapidly changing environmental conditions can significantly complicate the offloading process. In some cases, the design time of loading might be not enough to transfer the required volume of oil to the tanker. The likelihood of such a case has been checked by E. Subbotin.(Subbotin 2015, p. 32).

Another hazard for GBS in the Arctic conditions – formation of the rubble fields around the structure. Rubble fields can significantly reduce the ability of tanker to approach to the platform. Based on the experience of exploitation of the artificial island and GBS in the Beaufort Sea, a remote terminal was suggested as a solution to this problem (Bruce & Charpentier, 1983, p. 1-2).

3.4 Varandey terminal

Marine transportation of hydrocarbons from the Timano-Pechora province was accepted as the best way of oil supply to the international markets. Due to the shallow waters of the sea and constant alluvial currents, the idea of an onshore shipping terminal was rejected. In 2000, Lukoil company created a unique offloading complex capable to serve 20 thousand tons tankers 4 km from the Varandey settlement. The capacity of the complex was only 1.5 million tons of oil per year at it was not enough for the rapidly growing oil production in the Timan-Pechora region. Construction of a new offshore terminal was necessary.

A FOIROT was built 22 km far from the shore at a sea depth of 17,5 meters (Lukoil, offshore projects) with a capacity of 240 thousand barrels per day. The first oil from the terminal was offloaded in 2008. The terminal was created at LUKOIL-Kaliningradmarneft’s steelworks.

Figure 24 - Varandey export project (Lucoil, 2009)

The FOIROT consists of two parts:

- Octagonal shaped foundation structure with accommodation and technical facilities;
- Rotating and mooring hoist to keep the tanker in the desirable position and transfer oil to the mooring tanker.

The onshore infrastructure includes a storage base with the capacity of 235, 000 m^3, pumping station, sources of energy and other facilities. Two 820 mm diameter pipeline connects the terminal with the onshore facilities. These pipelines are combined into one loop. Between the tanker loading operations, the heated oil circulates within the interconnected branches to maintain the temperature of the pipeline. The offshore pipeline is the most vulnerable part of the project. In order to secure it from the ice scouring, 18 km section of the pipe is trenched at a depth of 2,6 meters. The scheme of Varandey export project is shown in Figure 25 (Bogoyavlensky, 2013).

The pumping units ensure transportation of 8,000 m3 of oil per hour and guarantee full loading of the tanker with DWT of 70 thousand tons within 10-12 hours (Lukoil, offshore projects). Ice class shuttle tankers transport the oil to the Belokamenka FSO in the Murmansk region, Russia. Afterward, the oil is sent to Western Europe.

During the ice season, icebreaker and ice class tugboats support all the operations. Support vessels secure maneuvering operations of the tanker next to the terminal.

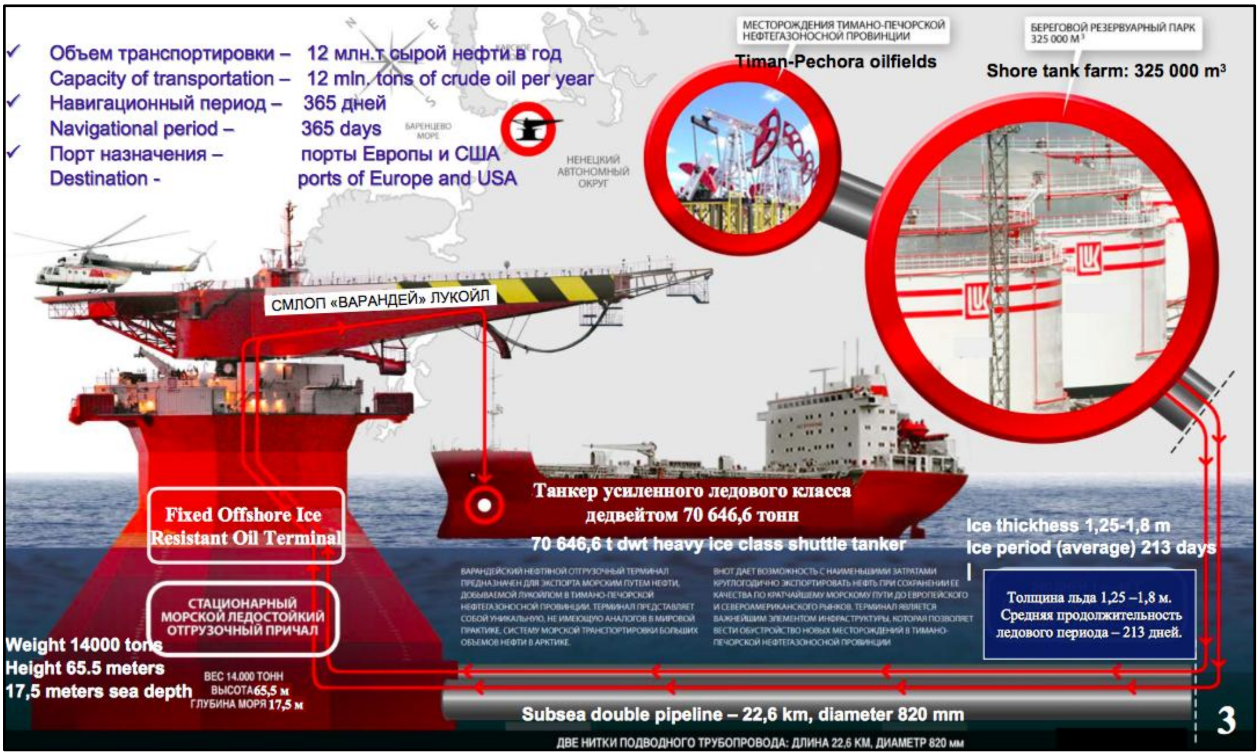


Figure 25 – Summarized description of the Varandey terminal (Lucoil, 2009)

The terminal has a design capacity of 12 million tons of oil per year. This figure is high enough to increase the export index of the Nenets autonomous area and the Russian polar region itself. Unfortunately, analysis of the current transportation rate revealed that the capacity of the terminal is not used properly (Figure 26).

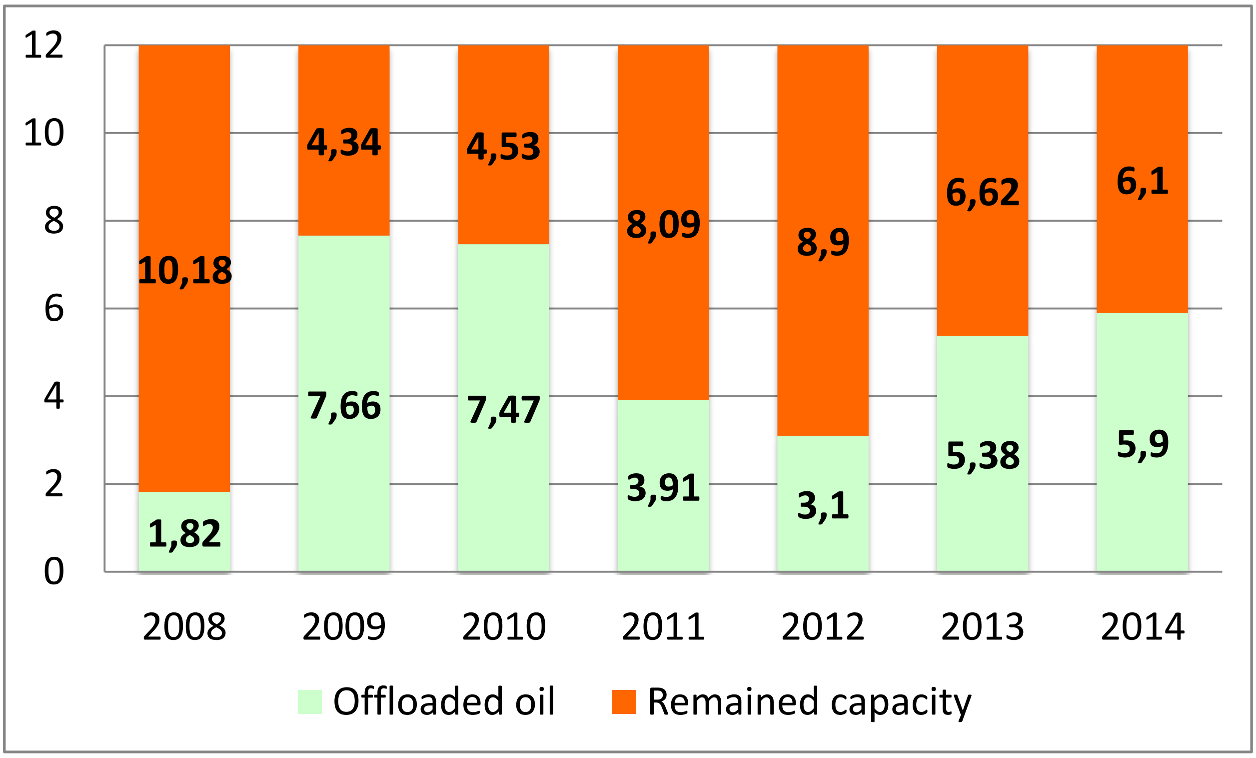


Figure 26 – Capacity of the Varandey terminal [5,43,44,59]

Timan-Pechora region of Russia contains vast resources of hydrocarbons: 1,3 billion tons of oil and 643,5 billion m^3 of gas. The region will be the most important oil producing region of Russia for many years.

The primary source of oil for the terminal is the Yuzhno-Khylchuskoye field with a peak production of 7,5 million tons of oil per year. But the reserves of the field were overestimated, and the production of oil decreased sharply in 2011 (Markov, 2010).

3.5 Yuri Korchagin field

The Shallow water area of the Yuri Korchagin field faces with heavy ice conditions, so direct loading to a tanker from the platform, using buoys couldn't been realized. Bluewater company developed and fabricated a SYMS for the Yuri Korchagin field. It was decided to lie two branches of subsea pipeline to a SPMT, located 57 km away from the production facilities in deeper waters (20,5 meters) with soft ice conditions. The general arrangement of the system is shown in Figure 27.

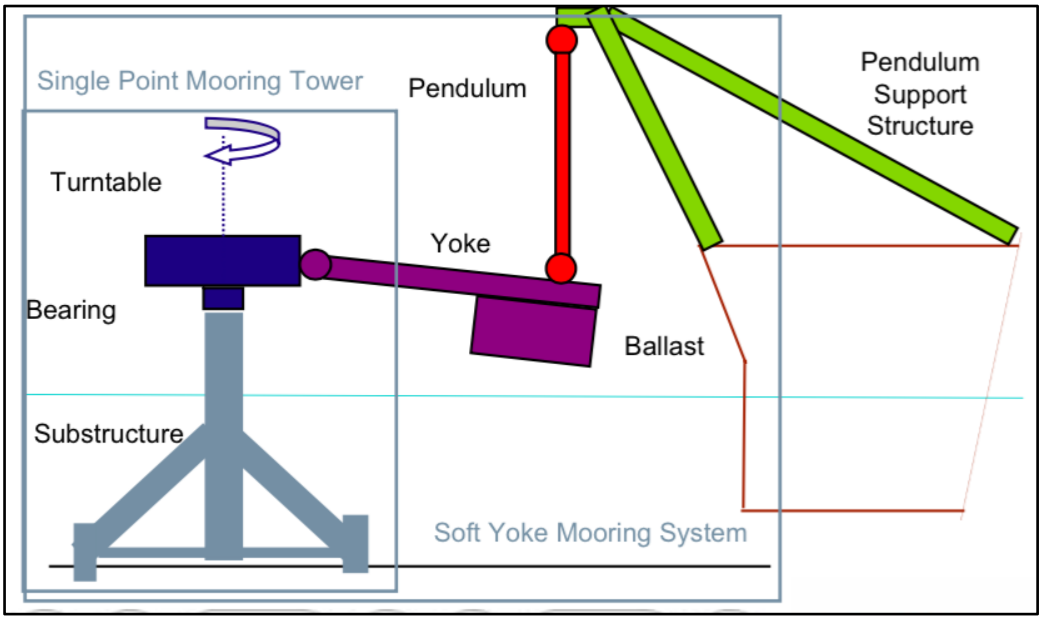


Figure 27 – Main components of the SYMS (Ottoloni, 2010)

The SYMS is constantly connected with the FSO. Oil, control signals, and power are transmitted from the fixed structure to the FSO. Shuttle takers are moored to the FSO (Figure 28). The system was designed for a 0,8 m level ice (100 years return period) with average annual ice thickness 1 cm. (Ottoloni, 2010, p. 14).

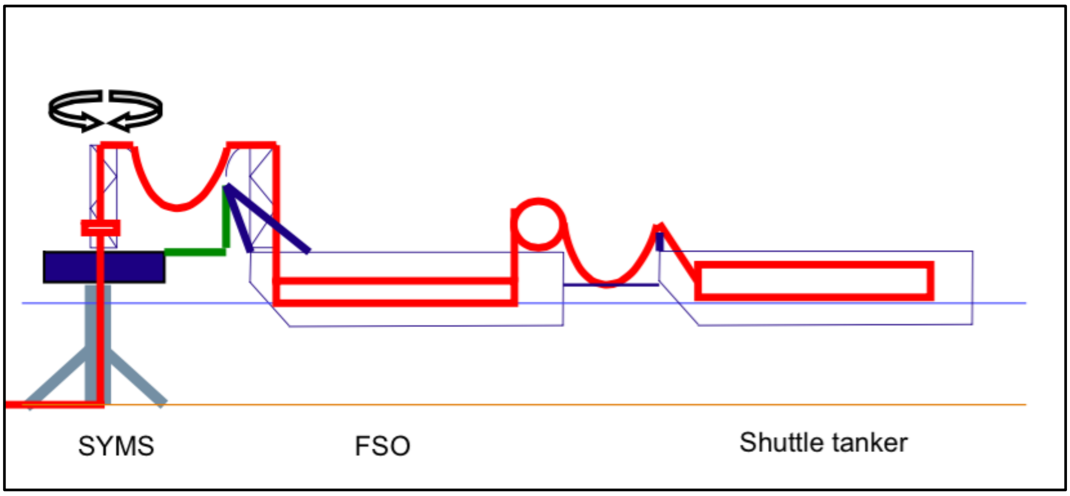


Figure 28 – Oil floating scheme (Ottoloni, 2010)

3.6 Hibernia

The loading system of the Hibernia platform consists of several components: storage tanks, two OLS and two riser assemblies. The scheme of the transportation system is shown in Figure 29. Processed oil is sent to the oil storage tanks in the basement of the platform. Every 6-7 days shuttle tankers come to take the oil away.

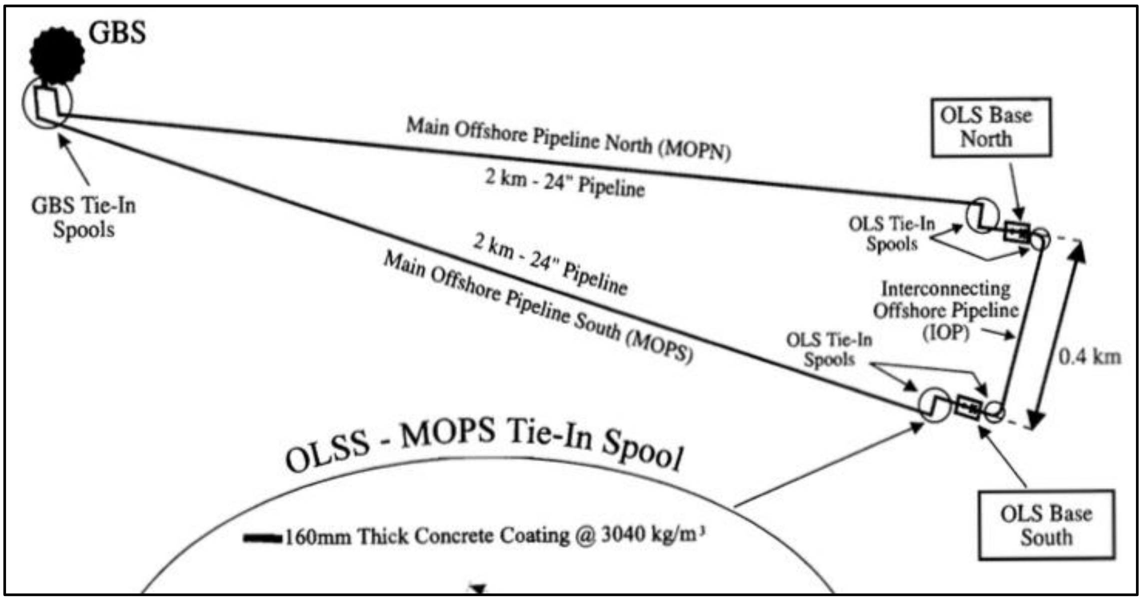


Figure 29 – General arrangement of the oil transportation scheme (Ewida, Ferrario, & Fiskerstrand, 1997)

Via two 24’’ subsea pipelines with a length of 2 km crude oil is pumped to the OLS base. Also, there is an intermediate pipeline, which connects main pipelines and the OLS bases. The OLS bases provide a reliable connection between the pipelines and risers. Both risers have a piled foundation and represented in Figure 30. After connection of the coupling head of the catenary riser to the tanker, the loading process begins.

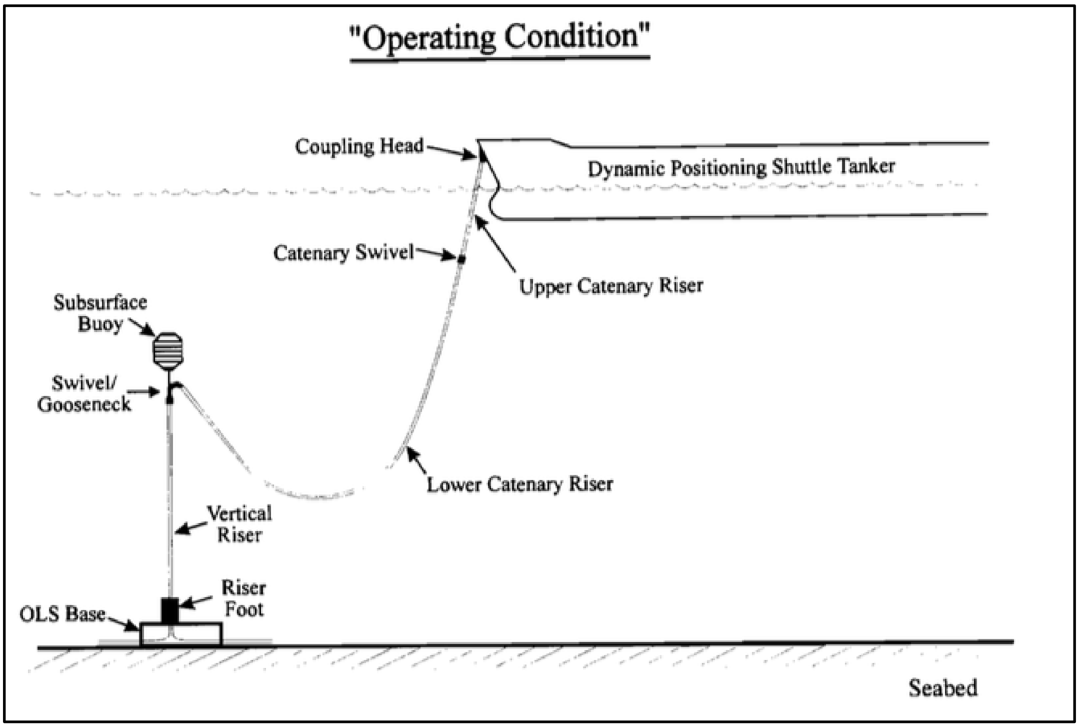


Figure 30 – Riser of the OLS (Ewida, Ferrario, & Fiskerstrand, 1997)

The great advantage of this field arrangement is redundancy. Any of the two pipeline branches can be isolated at the OLS bases. If it is necessary, one more riser can be installed at the riser base.

3.7 White Rose and Terra Nova

Two more projects realized offshore Canada, Grand Banks area. Oil loading and transportation schemes are similar to both projects. Processed oil is offloaded via the stern of the FPSO to the shuttle tankers. These tankers transfer oil to the markets.

3.8 Endicott

Endicott was a pioneer offshore field with year-round production of oil in the Arctic. At the initial stage, the project was considered as uneconomical due to the high costs and lack of the experience. Only after several re-estimations the total priced was reduced from the 3,8 billion dollars to 2 billion dollars. New estimation was connected with the number of islands, number of wells, sizes of facilities, and pipeline route.

Existing pipeline network in the Alaska region predetermined the way of oil transportation for the Endicott field as well as for all another oil fields. Oil transport via tankers was impossible because of the water depth

There were three alternative pipeline routes (Huxley, 1987, p.4):

- West Dock Marine – marine oil and gas pipelines from the offshore facilities to the Prudhoe Bay West Dock. Then oil and gas could be sent via overland pipelines to the sale points. Trans-Alaska pipeline became such point.
- Delta-Marine and Delta-Causeway – oil and gas was sent via overland pipeline through the Sag Delta to the same sales points. The only difference was in the marine part of the pipelines. The Delta-Marine marine section of the pipeline was subsea, while the other plan implements a gravel causeway for the pipelines.

Cost-benefit analyses showed that the Delta-Causeway was more preferable, and provides year-round roads and was not expensive as the water depth was 1,2 – 3,7 meters . So, now the processed oil goes through the pipelines from the Endicott Island to the Trans-Alaska Pipeline and thence to Valdez, Alaska.

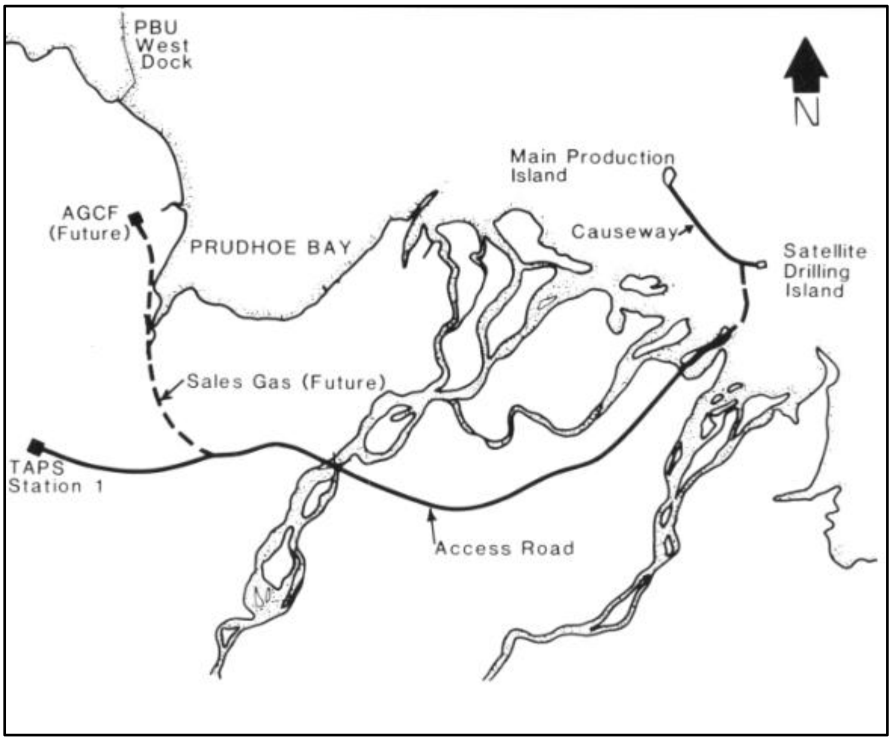


Figure 31 – Oil transportation at the Endicott field (Huxley, 1987)

3.9 Oooguruk

A pipeline became a way of the produced liquids transportation. Hydrocarbons are transported to the onshore facilities via a subsea bundle of the flowlines. Using the buried bundle of the flowlines was a significant challenge at the construction stage, as the design of this bundle was very complicated. The bundle is open, and the flowlines are strapped together, despite more traditional approach, when they are covered with one big pipe. As the result, the bundle of the pipes is less heavy. The pipeline was installed in 2007 (Offshore Technology.com, 2015). Trenching was used to protect the pipelines from ice scouring. The minimal trenching depth is 6 feet.

The 9,2 km bundle of the pipelines connects the drill site with the onshore facilities and consists of (Hall, 2008):

- 12,7’’ production multi-phase flowline;
- 8,625’’ injection line with water;
- 6,625’’ injection line with gas;
- 2,375’’ diesel transfer line;
- fibre-optic cable;

There is another trench with one more fibre-optic cable and three power cables. In order to prevent any leakages, pipe-in-pipe technology was used. This technology provides additional insulation and containment in case of a leak. At the shore, the bundle is separated into several parts and goes on the surface. All branches connect to the onshore facilities.

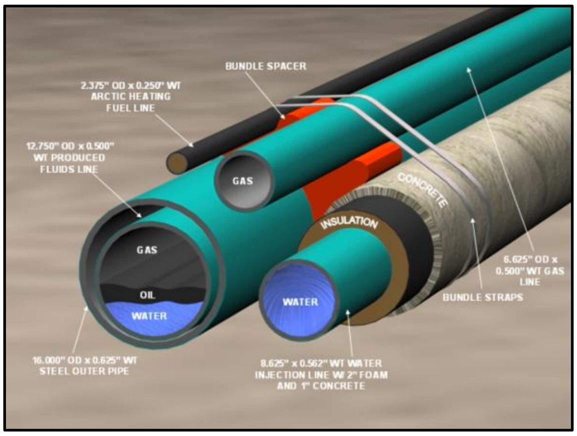


Figure 32 – Bundle of the pipelines (Huxley, 1987)

3.10 Solutions for new Arctic projects

Norwegian scientists developed the concept of the Arctic Shuttle Barge System. This system is designed for oil transportation from a sea covered with ice for the most of the year. Instead of the traditional oil loading systems, they believe that the turret-moored system would be more efficient.

In accordance with the Arctic Shuttle Barge System, the STL technique was suggested as one of the solutions for the oil loading in ice-covered waters. This technology has proven its efficiency in ice-free waters but has never been implemented in regions with the seasonal ice and ice ridges.

A Number of physical tests was carried on to check the STL technology on the ice conditions. The sketch of one of the conducted experiment is shown in Figure 33. During this tests the capability of the thrusters to keep the position was checked in level ice. The model of a tanker with the displacement of 90 DWT, length of 265,5 meters and width of 38 meters was tested in different ice conditions and speed of movement. Experiments revealed that the tanker inclination from the position above the buoy during the loading process was in the range of 1-3 meters, even when the ice thickness was 1,2 meters. In order to protect the buoy area from the ice, the vessel was equipped with a special plough at the bow and bow propellers. These propellers and the plough proved their efficiency with the level ice while they could not prevent ice appearance next to the turret in case of ice ridge present. The weakest point of the STL technique is the mooring system. Mooring lines can be damaged by the ice in the turret area (Løset, Jensen, Gudmestad, Ravndal, & Eide, 2001, p.3)

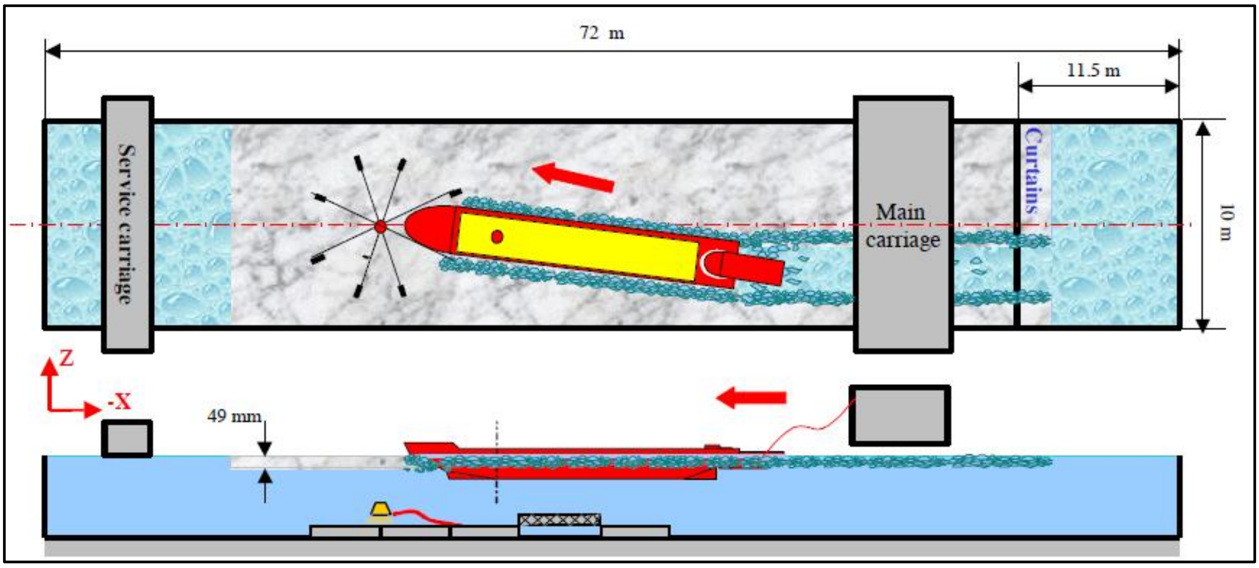


Figure 33 – Sketch of one test (Løset, Jensen & Ravndal, 2001)

Authors of the article also considered the opportunity of using the STL technique in the Pechora Sea. For the Pechora Sea, the minimal water depth should be 30 meters because of the ice scouring.

3.11 Preliminary conclusion

There are two ways of hydrocarbon transportation in the Arctic: tankers and pipelines.

Oil transportation by the pipelines can be organized only when the distance to markets does not exceed one hundred kilometers. When the region has a developed onshore transportation system, offshore pipelines can be connected to this system. USA projects are good example of pipeline transportation. Main challenges are the following: ice scouring, pipeline trenching, low surrounding temperature for the pipeline and the shore approach.

Ship transport of oil is generally used when the distance between the production area and the market is high. Depending on the environmental conditions along the tanker route, ice thickness, ice concentration and duration of the ice period, the transshipment base can be a part of the ship transportation system.

Analyses of the realized transportation systems showed that the pipeline and tanker systems could be combined. This approach was used at Yuri Korchagin and the Sakhalin-1 and -2 projects. These projects have one common feature. The production facilities are located in harsh ice conditions, while the offloading points are located in less severe conditions. The loading units and production platforms are connected via the offshore and onshore pipelines.

4. Development of the Pechora Sea

Analysis of the Pechora Sea hydrocarbon potential has revealed that the region contains significant number of potential geological structures and fields. The map of hydrocarbon resources and reserves is shown in Figure 34.

4.1 Transportation system in the Pechora Sea

The choice of a transportation system is a complex problem and requires a hard work of a group of specialists with different backgrounds. Moreover, elements of the transportation system constitute the major part of total CAPEX and OPEX. It's hard to implement any changes at the later phases of the project development. All decisions should be confident and sustainable.

Any decision regarding the transportation system should be based on three aspects:

1) Year-round production
2) Pechora Sea is an export-oriented region
3) A transshipment Terminal of oil is necessary. Convectional tankers cannot operate in the Pechora Sea. Only ice-class tankers with a small draft can serve in the harsh conditions of the Arctic. But it is very expensive to send them to the final consumer, because of the small deadweight and high power consumption.

These three clauses are the “backbone” of the oil transportation system. There are two alternative methods of oil delivery: pipeline and tanker.

A **Pipeline** delivery system can be organized in the following way: fixed platforms with oil processing facilities might be installed at large oil fields. Crude oil from the satellite fields with SPMs can be sent to the platforms for further processing. Then, the oil will be directed to the final consumer or transshipment terminal.

Figure 34 – Hydrocarbon potential of the Pechora Sea

Pipeline transportation guarantees fast and reliability of oil delivery. In the same time, the pipeline alternative brings a lot of challenges. In order to make the system stable, at least two branches of pipelines with big diameter are required. In the case of Murmansk acting like a transshipment terminal, the approximate length of the pipeline will be about 900 km only for one branch. Pipeline installation and maintenance can be done only in an ice-free period. The pipeline should be buried at some intervals because of ice ridge scouring. Moreover, a port infrastructure was designed for the oil delivery by tankers but did not have facilities to receive the oil from a pipeline. All these factors would lead to enormous CAPEX and modernization of the current infrastructure.

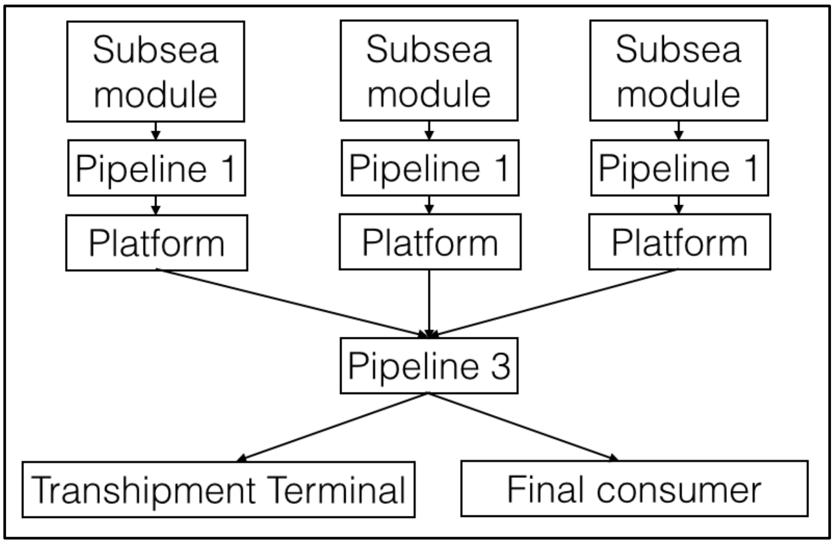


Figure 35 – Scheme of oil transportation via a pipeline

Tanker transportation system looks more promising. Oil tankers are used at the Prirazlomnoye and the Varandey projects. Several years of tankers exploitation proved their reliability and capability to operate in the Pechora Sea.

Review of the oil loading technologies in Chapter 3 made it clear that only few layouts are possible in the ice-covered area:

Option 1 - Loading from one TLU to conventional tankers (Figure 36);

Option 2 - Loading from each TLU to ice-class tankers (Figure 37);

Option 3 - Loading from one TLU to ice-class tankers (Figure 38);

Option 4 - Loading from one TLU + Processing facility to ice-class tankers (Figure 39);

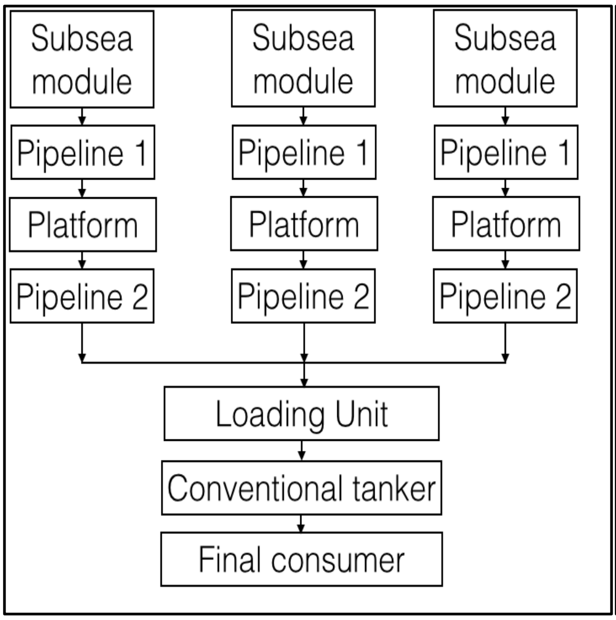


Figure 36 – Option 1

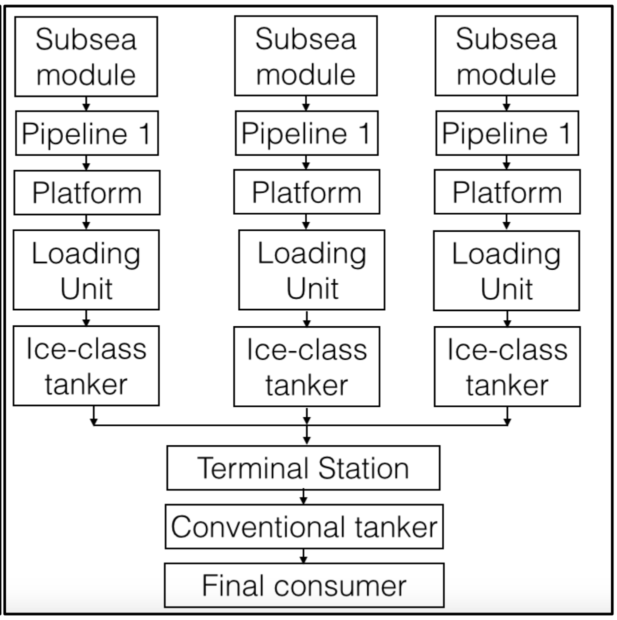


Figure 37 – Option 2

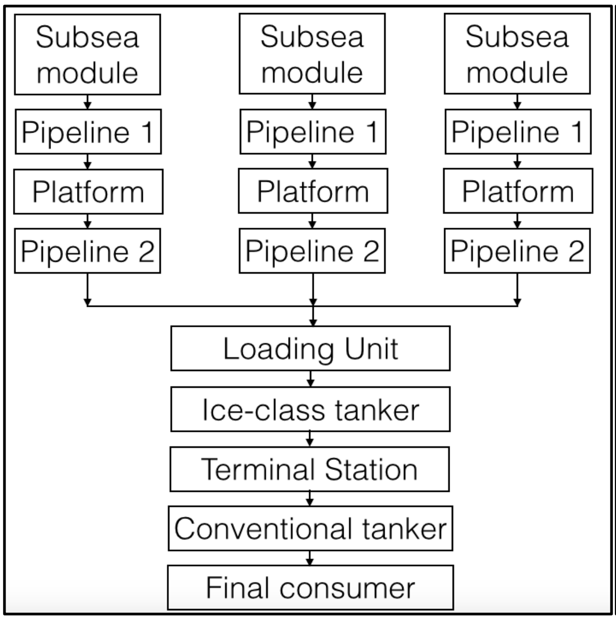


Figure 38 – Option 3

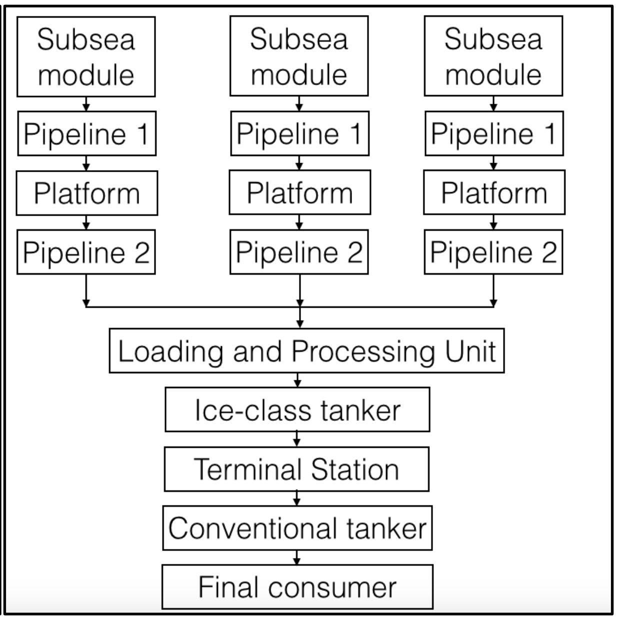


Figure 39 – Option 4

Option 1 can hardly be realized, as the ice cover area spread deeply into the Pechora Sea, and the most shallow water depth in the ice-free area is about 100-120 meters. The ice-free area is very far from the current oil fields and prospective structures in the Pechora Sea. This is shown on Figure 47. Thus, Option 1 can hardly be realized.

Option 2 requires offloading facilities at each platform. As TLUs, such systems as SALM, CALM and crane systems with hoses can be used. SALM and CALM systems are out of competition as they not providing year-round oil production. At the Prirazlomnoye project oil offloading is implemented via a system of hoses supported by special cranes. Among the other ways of oil loading, direct oil transfer to the tanker via hoses is the cheapest alternative. As it was mentioned in Chapter 1, the direction of the ice drifts changes by 180^{o} every 12 hours. Such phenomenon results in more strict requirements for the tanker type. This is imperative during the ice season when the tanker should stay in the wake behind the platform. In case of the ice drift direction changing, the tanker has to move to the opposite loading facilities accompanied by supply vessels or icebreakers. In a whole, the scheme of tanker loading from the edge of the platform is very risky, makes high demands on the tanker fleet, requires a dynamic positioning system, and can be implemented in limited environmental conditions. Experience gained at Prirazlomnoye field proves that such type of loading system can be used, but it is accompanied by a lot of challenges.

Options 3 and 4 are similar and based on the same principle. Processed oil is loaded on the ice-class tanker from one TLU common for several fields. Options 3 and 4 allows us to finish the offloading and mooring process faster than for Option 2. Risks and CAPEX are lower due to the lack of loading facilities on the platforms. On the other hand, CAPEX might be higher as an additional GBS structure, and pipeline network is required. Intermediate loading terminal should be organized in Murmansk, Russia

The efficiency of Option 2 has not been proven yet. Some apprehensions regarding this type of tanker loading exist. The disruptions of the oil delivery process due to the lack of whether windows in 2015 were estimated by Subbotin E. in his Master Thesis (Subbotin, 2015). The consequences of such events are unacceptable. Usage of individual loading facilities can be a good decision for this problem. Options 3 and 4 are recommended for further investigations. The proposed terminal geometry is a ice-resistant structure with rotating head.

4.2 Scenarios of the complex arrangement

The development of the Pechora Sea attracts a lot of attention among Russian researchers. During the last 15 years, the number of Ph.D. theses dedicated to the hydrocarbon potential of the Pechora Sea has been consistently growing. The author of this Master thesis acquainted himself with these works and gathered the data about oil fields and perspective structures in this region. Based on this information, a generalized table has been created (Table 7).

Table 7 – Hydrocarbon potential of the Pechora Sea

№	Field	Recoverable resources, mln. tonns
1	Northern part of the Dolginskoye	150
2	Southern part of the Dolginskoye	70
3	Alekseevskoye	50
4	North Gulyaevskoye	20
5	West Gulyaevskoye	15
7	Medyn-More	139,9
8	Varandey-More	41,8

Reference to Mandel, 2005, p. 149-150
Holodilov, 2006, p. 150
Rudenko, 2005, p. 10

As there is no any data about the average production rates for these fields, we may assume that the average annual production rate is equal varies within the range of 5-8 percent from the recoverable recourses (Aliev & Bondarenko, 2002, p. 476).

The number of oil fields and potential structures in the Pechora Sea is high as illustrated by Figure 34. These fields can be grouped into three clusters. Here and after, we assume that for each field only one platform will be used. The coordinates of each platform are found in accordance with Figure 34 and are listed in Table 8.

Table 8 – Average production rates and coordinates of production facilities

№	Field	Production rate, mln. tons/year	Coordinates	
			Latitude	Longitude
Cluster 1				
1	Medyn-More	6,90	58,63	69,01
2	Varandey-More	2,10	57,91	68,91
Cluster 2				
1	Northern part of the Dolginskoye	9,00	55,40	69,75
2	Southern part of the Dolginskoye	4,06	55,60	69,58
Cluster 3				
1	Alekseevskoye	3,50	56,45	69,35
2	North Gulyaevskoye	1,50	55,60	69,30
3	West Gulyaevskoye	0,84	56,60	69,15
Other				
1	Prirazlomnoye	6,60	57,34	69,25
2	Varandey terminal	---	57,60	69,01

Medyn-More and Varandey-More are in the first cluster while the rest of the fields are in the second and third ones. Cluster 1 is located in shallow waters with a depth of 12 meters, very close to the shoreline and far from Cluster 2. In Chapter 3, Varandey FOIROT was described. The terminal was designed to offload 12 million tons of oil per year. Current offloading rates are low and might remain at the same level for the next years. In order to improve the economic efficiency of the terminal, Lukoil Company may allow Gazprom to use the facility for oil loading to the tankers.

Cluster 2 consists of two GBS (Boiko, 2014). Cluster 3 comprises several fields. These fields are not big. A GBS with production and processing facilities can be installed at the Alekseevskaoye field while the other fields will be connected to this platform used as a hub.

Prirazlomnoye field is not considered in this work. There are three oil fields close to the platform: West-Polyarnoye, Polyarnoye and East-Prirazlmnoye

(Mandel, 2005, p. 149). These fields might be tied-in to the platform when the annual production rate will start to decline.

All the discussions regarding the oil fields can be summarized in the following scenarios of the complex arrangement:

Scenario 1 – Cluster 2 and Cluster 3 are tied in to the offloading terminal №1. Cluster 1 is attached to the Varandey terminal.

Scenario 2 – Cluster 2 and Cluster 3 are connected to the offloading terminal №1. Cluster 1 is linked to terminal №2.

Based on the possible production rates for Clusters 2 and 3 the following graphs of oil production can be developed (Figures 40 to 42). Here, we assume that the oil production begins in 2019. The total capacity of the terminal for Clusters 2 and 3 is 12,5 mln. tons per annum.

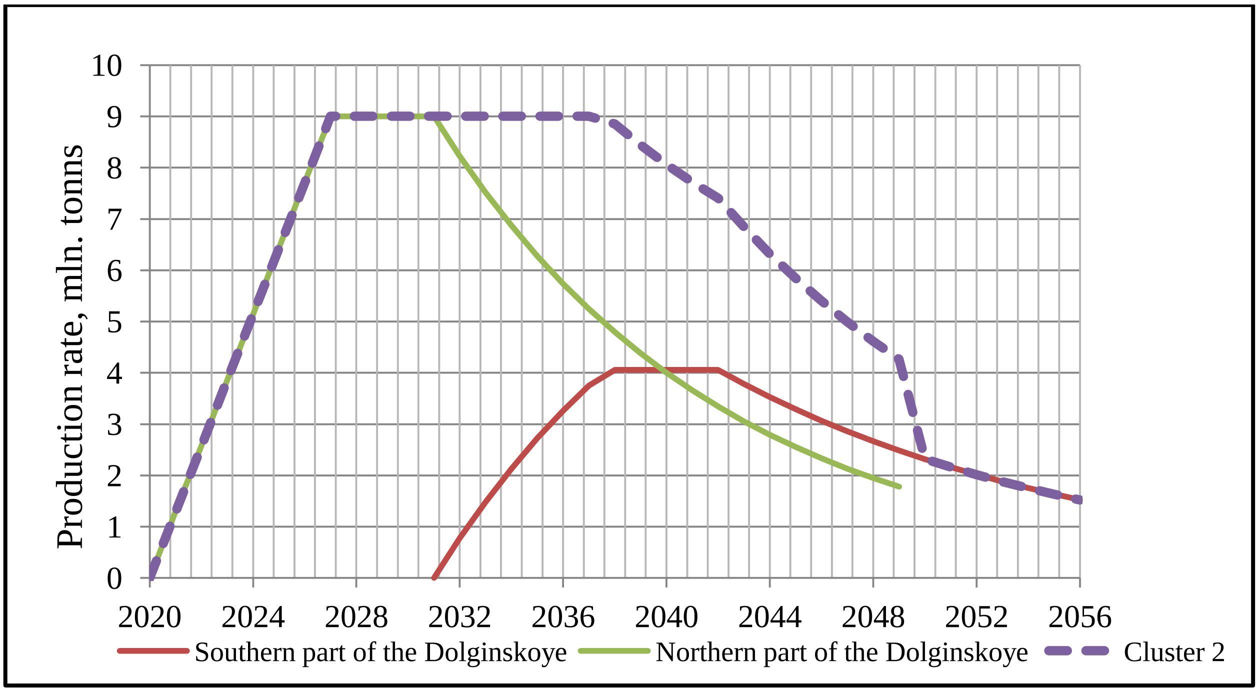


Figure 40 – Oil production rate for Cluster 2

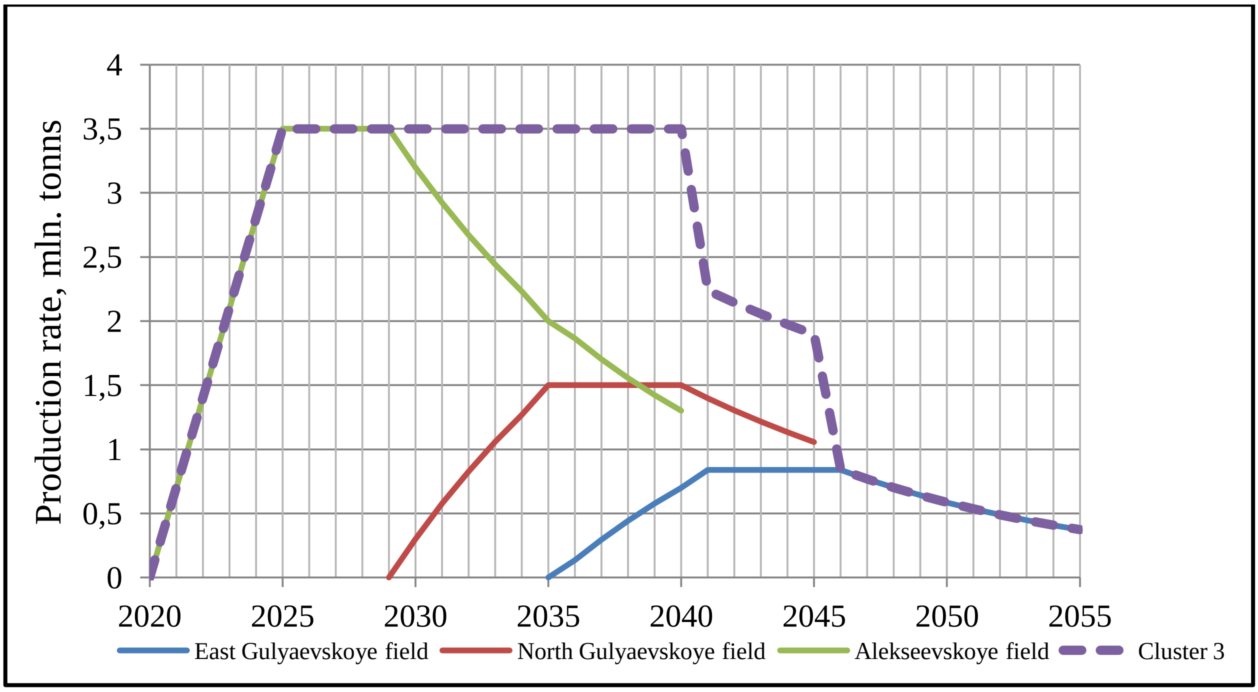


Figure 41 – Oil production rate for Cluster 3

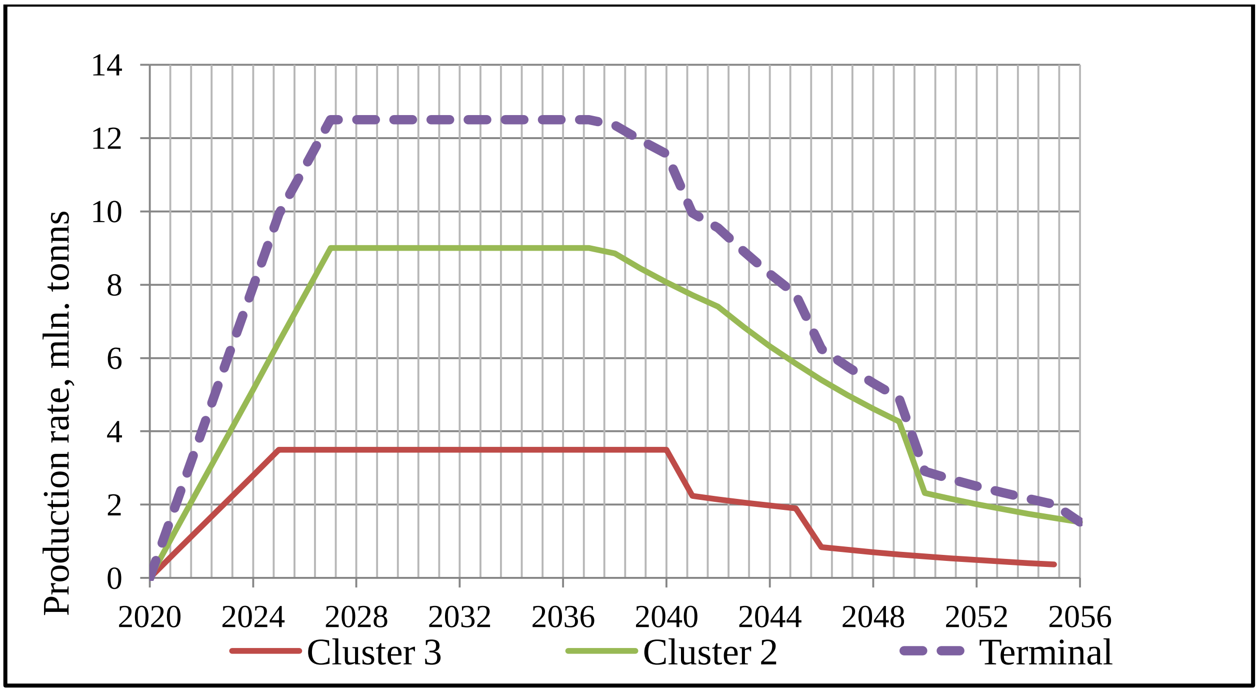


Figure 42 – Capacity of the terminal for Cluster 2 and 3

Scenario 3 – Cluster 2 and Cluster 3 are connected to the offloading terminal №1. Cluster 1 is attached to terminal №2. Varandey-More is drilled from the land (Vovk et al., 2000, p. 24-26).

Scenario 4 – Cluster 2 and Cluster 3 are connected to the offloading terminal №1. Prirazlomnaya platform can be tied to the terminal, in case of significant problems with the oil offloading.

4.3 Parameters of the terminal location

Geographical longitude and latitude define the location of the terminals. The location depends on different parameters, such as water depth, sea bed conditions, remoteness of the terminal, ice thickness and concentration, wind direction and speed, currents, icebergs, and environmental restrictions. As all these data is difficult to find, only four parameters are taken into account: water depth, sea bed conditions, remoteness and ice thickness.

Water depth

Current production and loading facilities in the Pechora Sea are located in shallow waters with water depth not more than 20 meters. Water depth is connected with the deadweight and draft of tankers. Tankers with deadweight of 70,000 tons are used for Prirazlomnaya and Varandey projects. According to the most of the articles and Ph.D. works dedicated to the development of the Pechora Sea, exploitation of tankers with bigger deadweight is possible (Efremkin, 2000, p.34). In the Baltic Sea during the ice season, tankers Tempera and Mastera with deadweight of 106,304 tons are used. The average draft in the summer is 15,3 meters (MT Tempera, 2015). For such type of tankers, water depth should be more than 20 meters.

The water depth map of the whole Arctic region was downloaded from the website of International Bathymetric Chart of the Arctic Ocean (IBCAO, 2014). Resolution of the map is 30x30 arc seconds. This map was processed in MATLAB R2013a to create a bathymetrical chart, Figure 43 of the Pechora Sea.

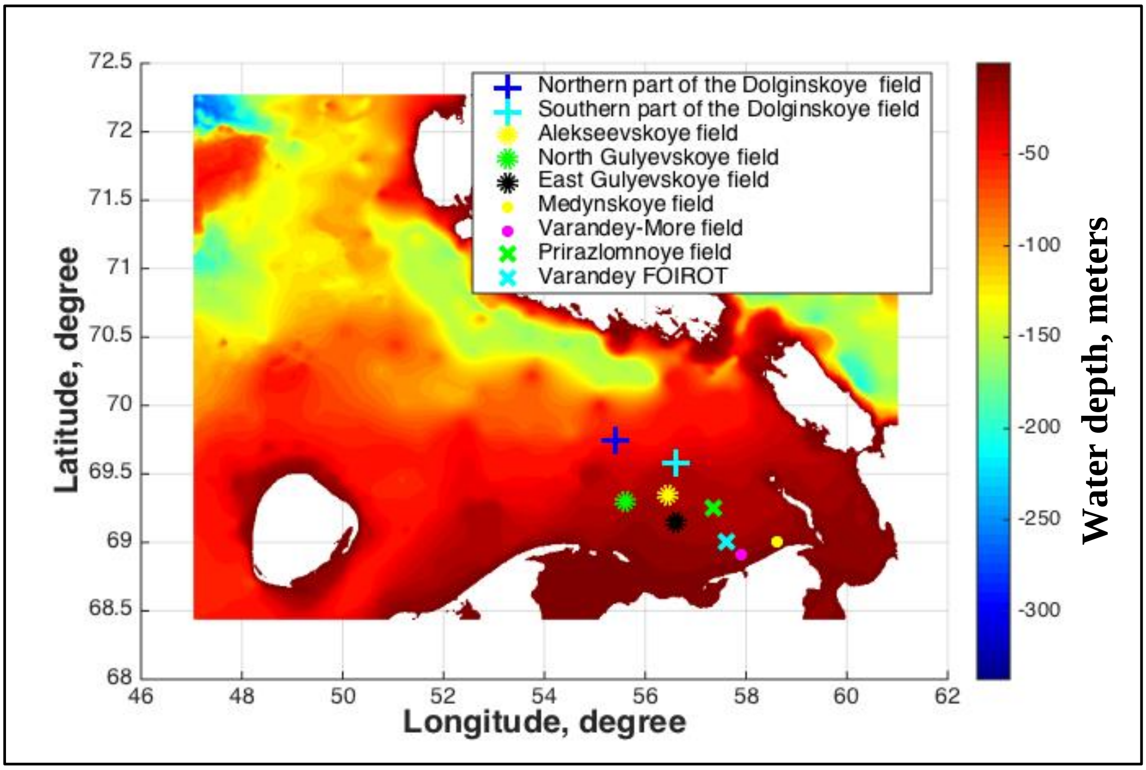


Figure 43 – Water depth in the Pechora Sea

Sea bed conditions

Bottom conditions restrictions can be changed by bottom site preparation. Preparation activities are expensive, however, so it is better to find a batter place with hard bottom layers.

Analysis of the soil conditions in Chapter 1 revealed an area with hard soils. After processing this data in MatLab2013a, the following picture (Figure 44) was obtained.

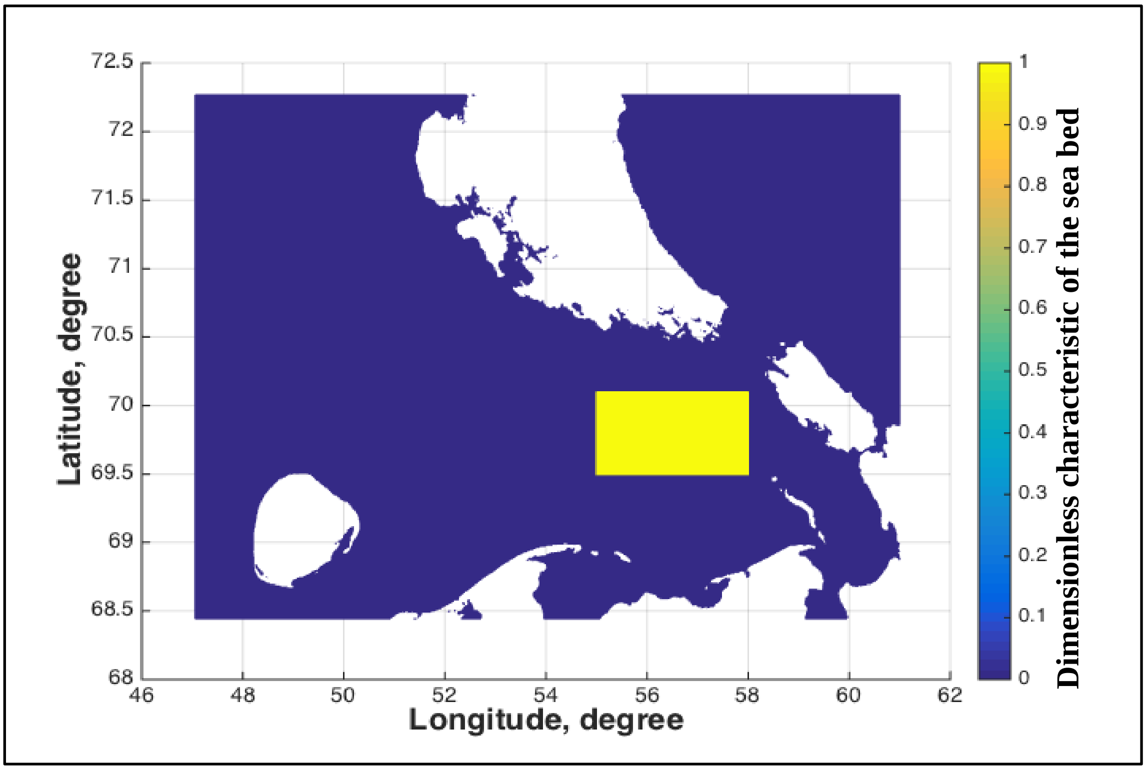


Figure 44 – Soil conditions in the Pechora Sea (yellow – hard sediments, blue – soft sediments)

Remoteness

Remoteness has implication on the total length of the pipelines from the terminal to the production or processing facilities. Depending on the field development scheme, not every offshore structure will be connected to the terminal. For example, oil from subsea wells can be firstly sent to the processing facility and only after that to the terminal.

Let's assume that l_i is the distances between the terminal and Platform №i. Moreover, we can assume that l_i is the length of the pipeline between the terminal and platforms. The sum of the length should be minimized. Hence, we should solve an optimization problem, where:

$$f(l) = \sum_{i=1}^{n} l_i \rightarrow min$$ - objective function.

The length of the pipeline must be greater than zero, so an inequality constraint should be taken into account:

$$l_i > 0;$$

Our planet has the form of the geoid. The shortest distance between two points on the Earth, following the surface is the Great-Circle distance (not a line). The following equations enable us to find the distance between two points (1 and 2) given their coordinates:

$$lat_1^{rad} = 2 * \pi * lat_1^{o}/360;$$

$$lat_2^{rad} = 2 * \pi * lat_2^{o}/360;$$

$$lon_1^{rad} = 2 * \pi * lon_1^{o}/360;$$

$$lon_2^{rad} = 2 * \pi * lon_2^{o}/360;$$

$$d_{lat} = lat_2^{rad} - lat_1^{rad};$$

$$d_{lon} = lon_2^{rad} - lon_1^{rad};$$

$$a = \sin\left(\frac{d_{lat}}{2}\right)^2 + \cos\left(lat_1^{rad}\right) * \cos\left(lat_2^{rad}\right) * \sin\left(\frac{d_{lon}}{2}\right)^2;$$

$$c = 2 * arctan\left(\frac{\sqrt{a}}{\sqrt{1-a}}\right);$$

$$l = R * c;$$

where R – the Earth radius (6371 km). For example, let's consider Clusters 2 and 3, where the Northern and Southern parts of the Dolginskoye filed together with the Alekseevskoye field are connected to one terminal. Other fields of Cluster 3 are tied-in to the platform, installed at the Alekseevskoye field. The results are represented in Figure 45.

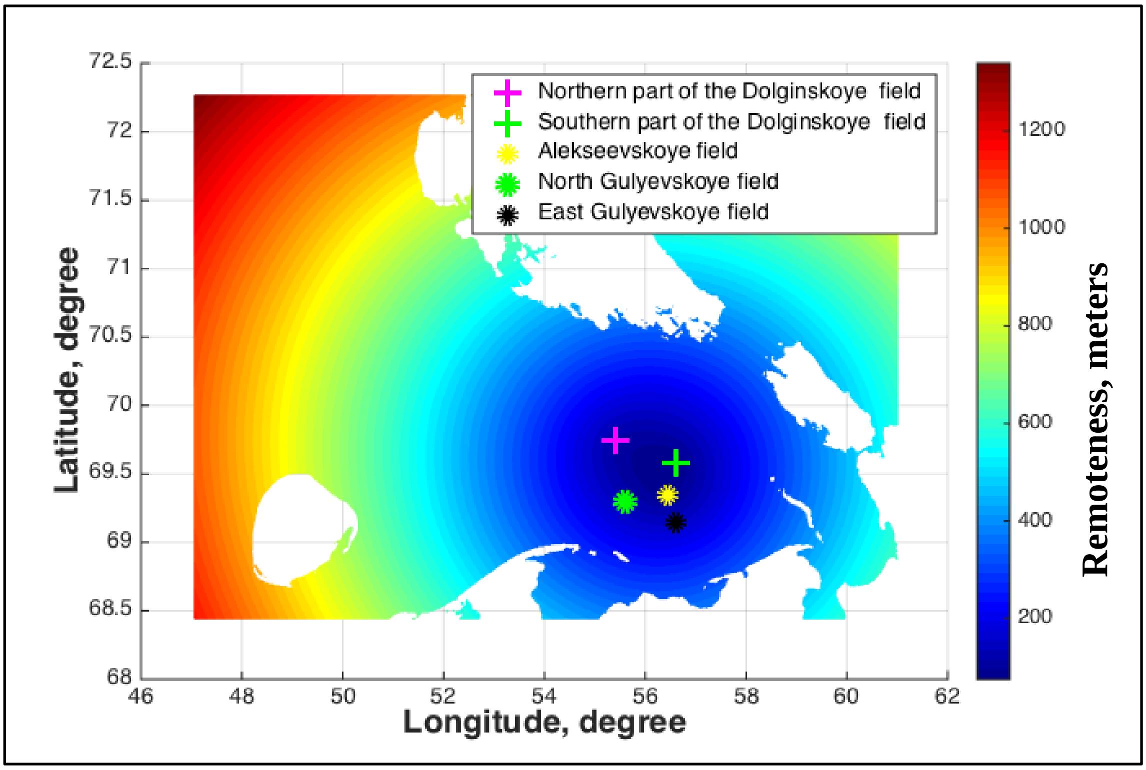


Figure 45 – Remoteness for Cluster 2 and 3

Ice thickness

Initial data was downloaded from the website of National Snow and Ice Data Center (National Snow and Ice Data Center, 2015). Ice thickness data were gathered by satellites. In contrast to other parameters, distribution of the ice thickness in the Pechora Sea changes from year to year. Six-year observations (2003-2008) were analyzed to predict the ice thickness in the sea with a return period of 10 years. This estimation was based on the Theory of Extremes. The theory is widely used to predict the frequency of rare events, such as earthquakes or water floods. In 1958 Gumbel, presented the CDF of extreme events in the following form (Leder, Smircic, & Vilibic, 1998, p. 3)

$$F(x) = e^{-e^{-y}}$$

F(x) shows the probability that all the data is lower than input *x*. The Fisher-Tripett solution can give the value of *y*:

$$y = \frac{x - A}{B}$$

The return period *T(x)* is connected with the probability *F(x)* via the following equation that shows the probability that *x* will be exceeded within any year:

$$\frac{1}{T(x)} = 1 - F(x)$$

The unknown parameters *A* and *B* can be calculated by three different methods:

- Graphic method;
- Maximum likelihood estimation
- Method of moments;

Ice thickness data has a big variation. In order to obtain maps with similar scale and execute calculations, interpolation was done (Figure 46).

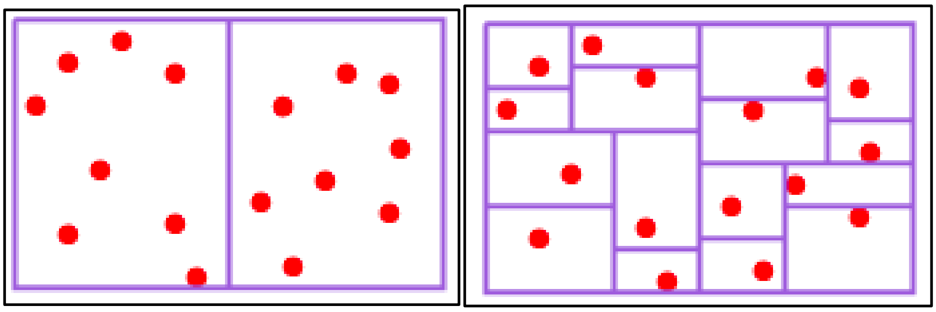


Figure 46 - Nearest neighbor interpolation (left - initial data, right – after interpolation)

As there is uncertainty regarding the ice thickness values at intermediate points (for example, the value of the ice thickness next to the shoreline could be several millimeters), it has been decided to use the nearest neighbor interpolation instead of the linear one. An illustrative example is shown in Figure 47.

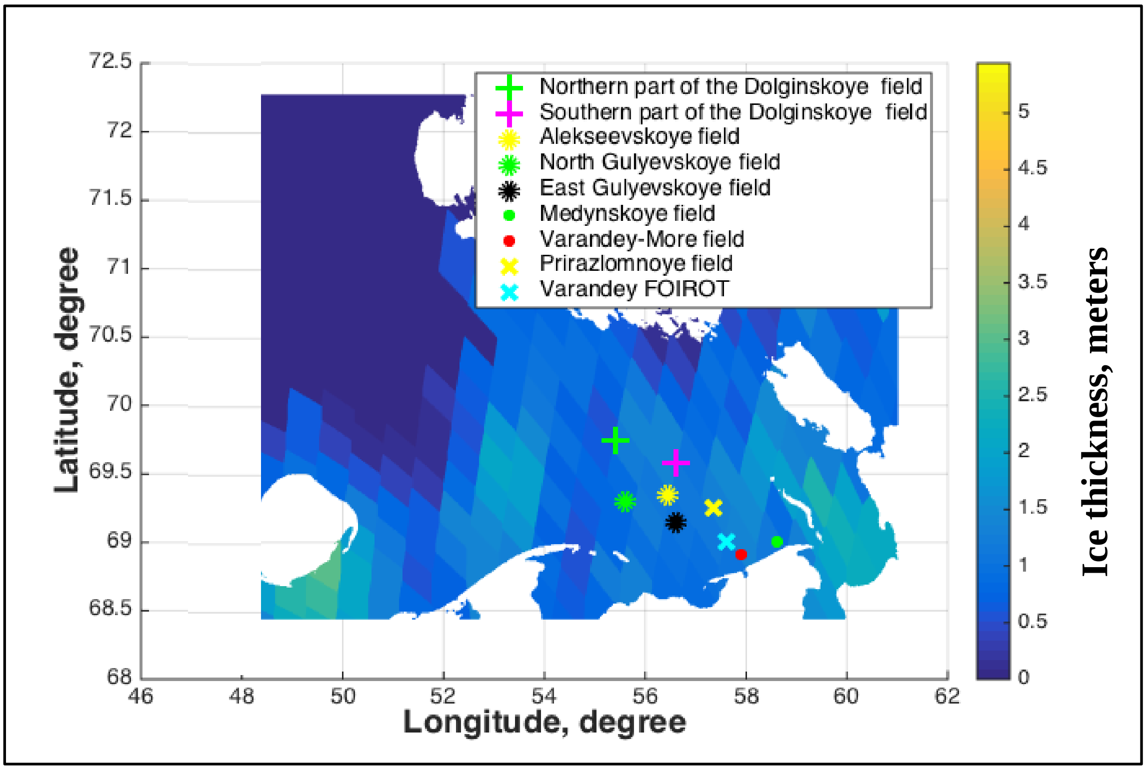


Figure 47 – Ice thickness in the Pechora Sea

Icebergs

Icebergs are not considered as a parameter because there is no such a hazard in the Pechora Sea.

4.4 Loading terminal siting

The main objective of the thesis is to define the location of the terminals in the Pechora Sea. The idea of optimal terminal location is based on the principles of MCDM. The decision-making problem can be solved by several methods (Caterino, Iervolino, Manfredi, Cosenza, p.1):

- Weighted Sum Model;
- Weighted Product Model;
- ELECTRE;
- TOPSIS;
- MAUT;
- PROMETHEE.
- VIKOR.

In order to find the best location for the terminal, more than 700 thousand nodes should be checked. Only first two methods are used in this work, as they are fully described in the literature while the rest of the methods are only listed without any comprehensive explanation. Both of these methods can be applied for the parameters with different dimensions. The Weighted sum (1) or weighted product (2) is defined by the cost function:

$$\boldsymbol{Z = w_1 * X_1 + w_2 * X_2 + w_3 * X_3 + w_4 * X_4} \quad \mathbf{(1)}$$

$$\boldsymbol{Z = {X_1}^{w_1} * {X_2}^{w_2} * {X_3}^{w_3} * {X_4}^{w_4}} \quad \mathbf{(2)}$$

Where X_1- remoteness of the terminal from the platforms; X_2- ice thickness; X_3- bottom conditions; X_4- water depth; w – weight. A node with the highest value of the function is the most suitable place for the terminal in accordance with the highlighted parameters (Efimov, Zolotukhin, Gudmestad, & Kornishin, 2014, p. 6). Weighted Product Model is used to checking the results of Weighted Sum Model. The weight of each criterion was estimated based on the pair-wise comparison principal (Zolotukhin, 2007). If the first criteria are considered to be more important than the second one, the first criterion gets the value one while the second one gets 0. All the marks for each criterion should be summarized.. The results of the weights estimation are shown in Tables 9 and 10.

Table 9 – Weight estimation for Cluster 1

	Water depth	Remotness	Ice thickness	Sum	Weight
Water depth	1	0	1	2	0,33
Remotness	1	1	1	3	0,5
Ice thickness	0	0	1	1	0,17
				6	**1**

Table 10 – Weight estimation for Clusters 2 and 3

	Water depth	Remotness	Ice thickness	Soil conditions	Sum	Weight
Water depth	1	0	1	1	3	0,3
Remotness	1	1	1	1	4	0,4
Ice thickness	0	0	1	0	1	0,1
Soil conditions	0	0	1	1	2	0,2
					10	**1**

Calculation of the dimensionless function Z in each knot gives the maps of function's distribution in the Pechora Sea. The evaluation was made in accordance with formulas (1) and (2). The best location of the terminal is shown below in Figures 48 to 51.

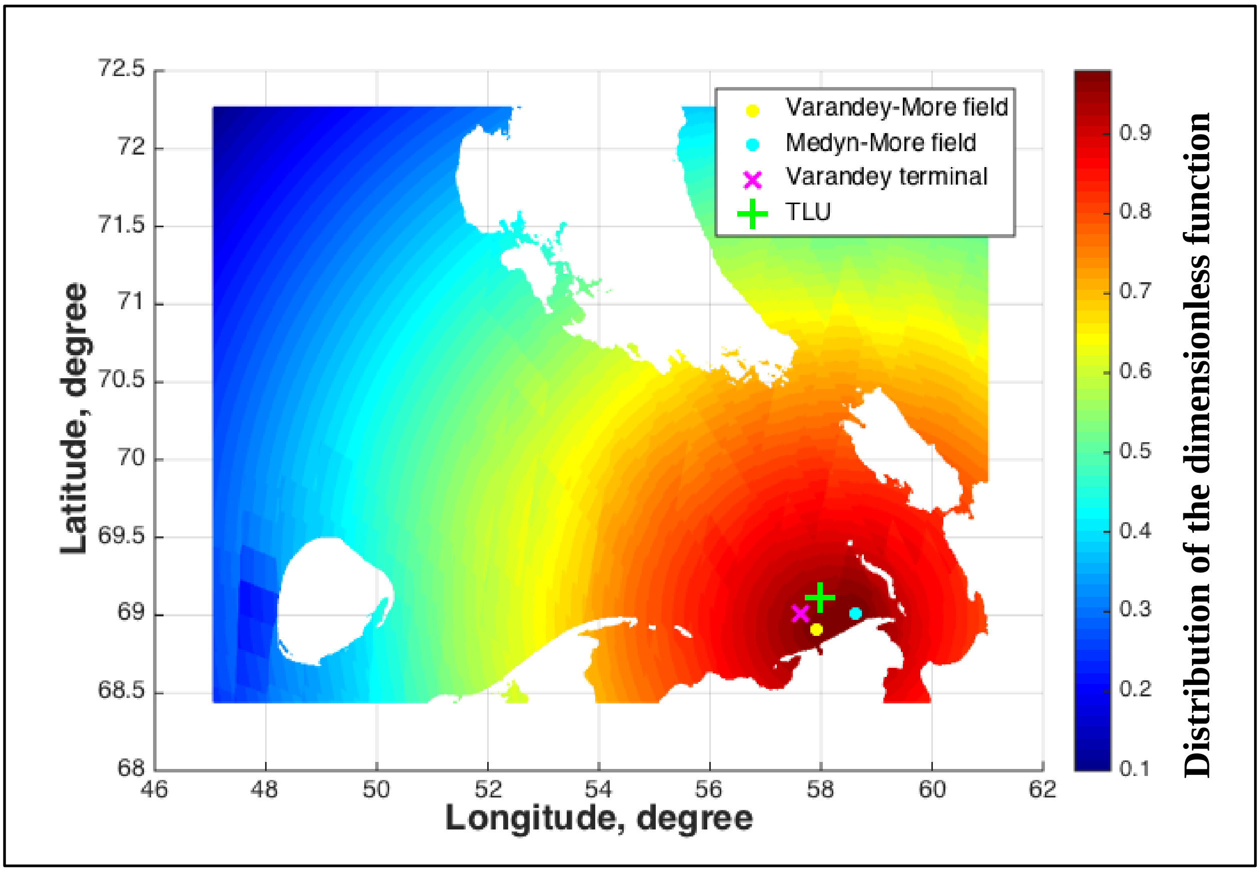
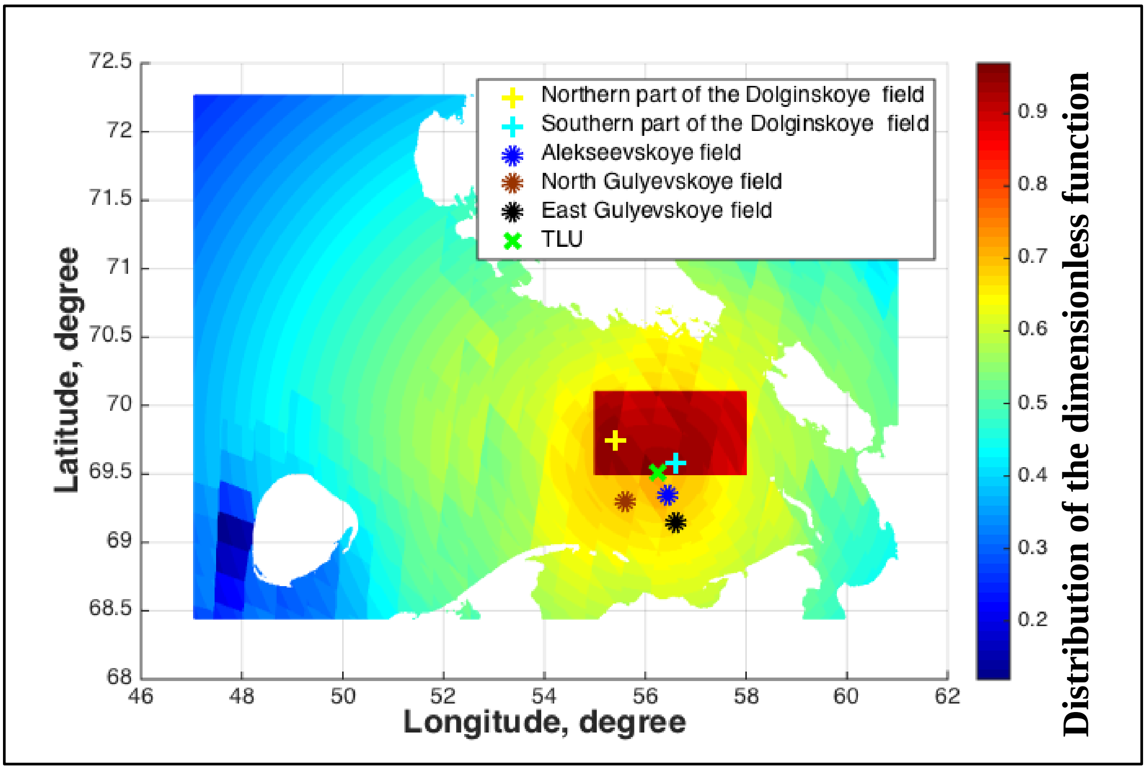
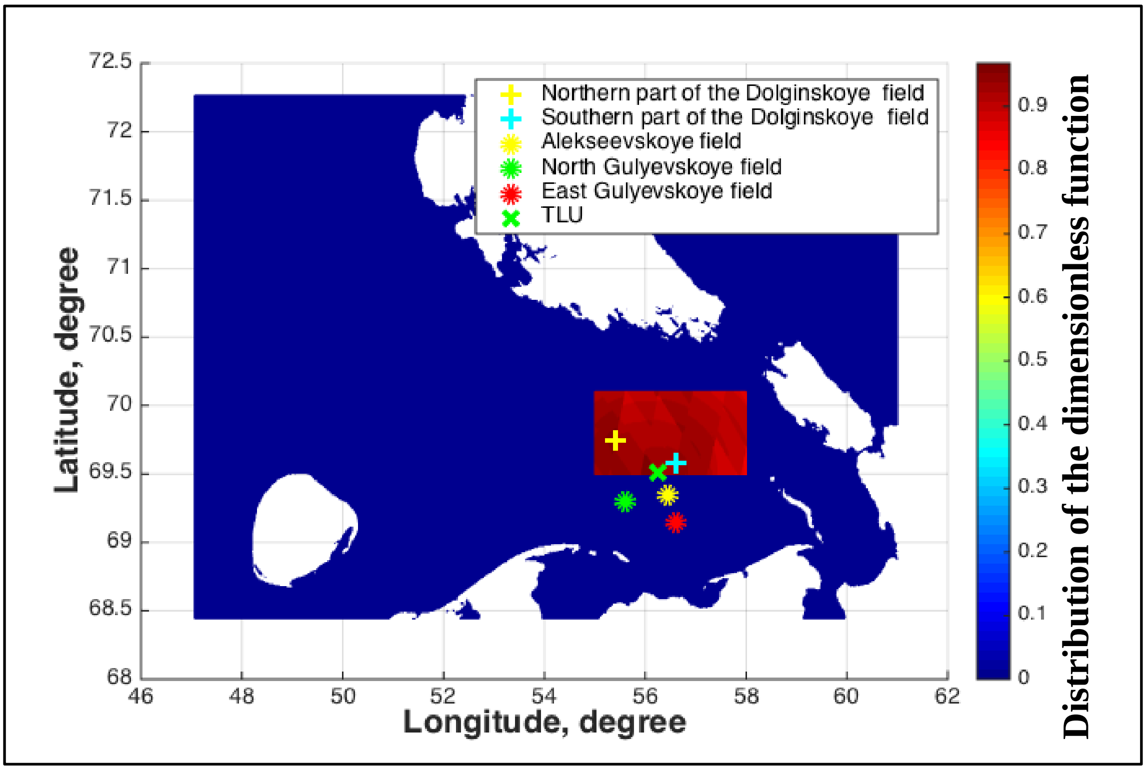


Figure 48 – Distribution of the dimensionless function Z in accordance with (1) for Cluster 1 (Scenarios 1 and 2). TLU [57.9917;69.1083]



a)



b)

Figure 49 – Distribution of the dimensionless function Z in accordance with (1) –a and (2)-b for Clusters 2 and 3 (Scenarios 1 and 2). TLU [56.2417;69.5083]

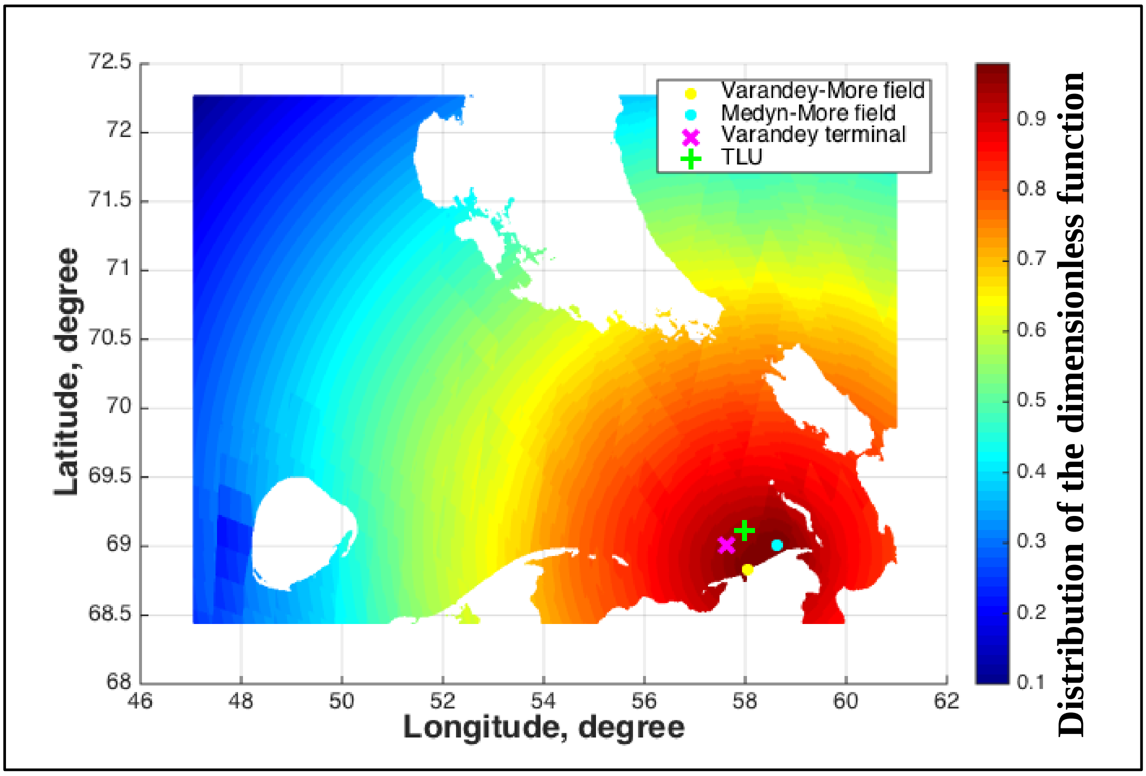


Figure 50 – Distribution of the dimensionless function Z in accordance with (1) for Cluster 1 (Scenario 3). TLU [57.9917;69.1083]

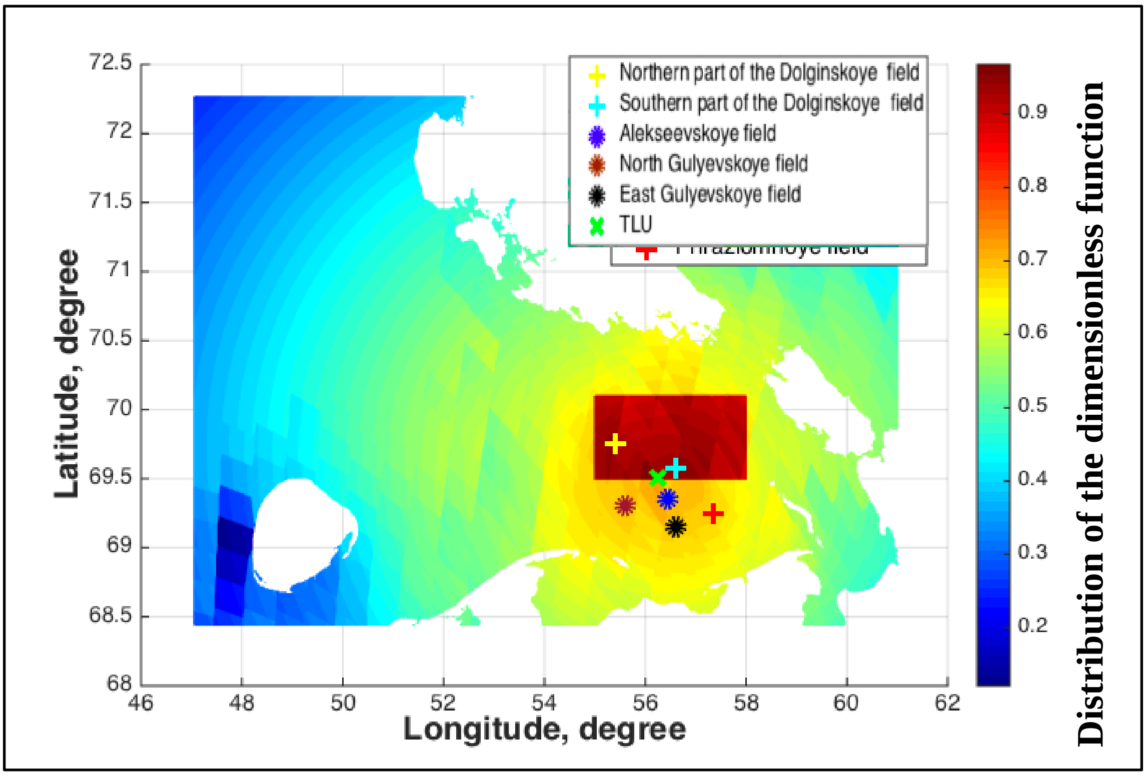


Figure 51 – Distribution of the dimensionless function Z in accordance with (1) for Cluster 2 and 3 (Scenario 4). TLU [56.2417;69.5083]

Based on the coordinates of the TLU, pipeline lengths can be calculated. The results are shown in Tables 11 to 14 below.

Table 11 – Pipeline system Scenario 1

№	Distance		Distance, km	Total distance, km
	From	To		
Cluster 1				
1	Varandey-More	Varandey terninal	15.945	56.001
2	Medyn-More	Varandey terninal	40.056	
Cluster 2 and 3				
1	North Gulyaevskoye	Alekseevskoye	33.830	134.511
2	West Gulyaevskoye	Alekseevskoye	23.011	
3	Alekseevskoye	TLU	19.396	
4	Northern part of the Dolginskoye	TLU	42.230	
5	Southern part of the Dolginskoye	TLU	16.044	

Table 12 – Pipeline system Scenario 2

№	Distance		Distance, km	Total distance, km
	From	To		
Cluster 1				
1	Varandey-More	TLU	22.292	49.934
2	Medyn-More	TLU	27.642	
Cluster 2 and 3				
1	North Gulyaevskoye	Alekseevskoye	33.830	134.511
2	West Gulyaevskoye	Alekseevskoye	23.011	
3	Alekseevskoye	TLU	19.396	
4	Northern part of the Dolginskoye	TLU	42.230	
5	Southern part of the Dolginskoye	TLU	16.044	

Table 13 – Pipeline system Scenario 3

№	Distance		Distance, km	Total distance, km
	From	To		
Cluster 1				
1	Varandey-More (onshore drilling)	TLU	31.037	58.679
2	Medyn-More	TLU	27.642	
Cluster 2 and 3				
1	North Gulyaevskoye	Alekseevskoye	33.830	134.511
2	West Gulyaevskoye	Alekseevskoye	23.011	
3	Alekseevskoye	TLU	19.396	
4	Northern part of the Dolginskoye	TLU	42.230	
5	Southern part of the Dolginskoye	TLU	16.044	

Table 14 – Pipeline system Scenario 4

№	Distance		Distance, km	Total distance, km
	From	To		
Cluster 1				
1	Varandey-More	TLU	22.292	49.934
2	Medyn-More	TLU	27.642	
Cluster 2 and 3				
1	North Gulyaevskoye	Alekseevskoye	33.830	186.222
2	West Gulyaevskoye	Alekseevskoye	23.011	
3	Alekseevskoye	TLU	19.396	
4	Northern part of the Dolginskoye	TLU	42.230	
5	Southern part of the Dolginskoye	TLU	16.044	
6	Prirazlomnoye	TLU	51.711	

Calculations were carried out for four scenarios of the complex arrangement. The Weighted sum and product models gave the same results in all calculations, and this is proves the reliability of the estimates.

The MCDM method has been tested for different scenarios. The obtained coordinates of the terminals satisfy all the selected criteria. Estimation of the weights can be done in different ways, depending on the number and experience of experts. MCDM method can "smooth" this problem. Even when the weights are distributed differently among the criteria, the results will be the same.

Scenarios 1 (2) and 4 gave the same coordinates of the terminal for Clusters 2 and 3, despite the different initial data. This fact looks strange. In case of only one criterion – remoteness, the best location of the terminal should move closer to the Prirazlomaya platform (see Figure 49). But the location of the terminal is determined by four parameters. The sum of three other criteria is even higher than the weight of remoteness. Therefore, the coordinates of the terminal are the same for Scenarios 1(2) and 4. For this reason, the coordinates of the terminals for Scenarios 2 and 3 are also the same.

The created program works properly and correctly, so the MCDM method might be used for other tasks. The number of platforms, the length of the pipeline system and the capacity of the terminal should be used for the estimation of economic efficiency.

5. Terminal concept selection

When the location of the terminal is determined, concept selection should be carried out. In Chapter 4, the best location of the terminal was found. Water depth at that point is 20,3 meters. Exploitation of the Varandey FOIROT shows that the terminal of such a type is a reliable solution for oil offloading in the Pechora Sea in the area with the same water depth. In this Chapter, the FOIROT geometry will be transformed in accordance with the particular conditions of cluster development and experience gained in the other project.

5.1 Structure of the terminal

The structure of the terminal should guarantee year round offloading of oil for almost 40 years in the Arctic conditions. The capacity of the terminal for Clusters 2 and 3 should be 12,5 mil. tons of processed oil. The terminal does not have any process facilities. The processed oil is pumped to the terminal via subsea pipelines. A steel caisson facility accommodates living quarters, helideck, risers, pig traps, and life support systems.

The terminal should provide offloading and mooring facilities with an angle of rotation 360^o. The primary source of power will be diesel fuel. Personnel should always be at the terminal. The number of personnel should be enough to operate all the systems and maintain the reliability at the design level.

Offloading arm

The offloading arm should be capable to rotate 360^o on ball bearing and provide offloading and mooring of tankers. The length of the offloading arm should be big enough to avoid tanker lean-off. The length might be 55 meters. The offloading arm should enable a shelter for the offloading hose for cleaning, inspection, and maintenance. Helideck should be attached to the deck area. Illumination must be a part of the offloading for loading in darkness.

The offloading arm should be a fixed boom type. There might be two alternatives: reel with an offloading hose and crane, similar to the Prirazlomnaya platform. Fixed boom construction, on the other hand, provides full drainage of the offloading hose, relatively simple and reliable. The crane boom prevents the end of the offloading hose from contact with water and any damage in case of disconnection better than the reel alternative. The fixed boom concept requires low inspection and maintenance. Also, the same concept has been already been implemented in the Varandey terminal. The reel alternative has a lot of disadvantages in comparison with the rotating offloading head. The complexity of the rotating crane solution is high, while the capabilities are the almost the same as the fixed boom concept. Thus, the fixed boom is the best solution for the terminal.

Foundation and tower

The Pechora Sea is covered by ice for about half a year. The diameter of the terminal at the waterline should be big enough to create a wake and hide the tanker from the direct action of the ice. The width of the structure is assumed to be 45 meters at the water contact. This is enough to protect the 70,000 DWT tanker from the ice field and provide a gap from the both sides of the tanker and the ice field. Other dimensions of the terminal foundation and tower are shown in Figure 52 by analogy with the Varandey FOIROT. In order to distribute the loads, the terminal should have an octagonal shape. The optimal sloping angle of the walls will be estimated further. Foundation should be piled to the bottom.

The terminal’s foundation and tower should have facilities for six risers and pig receivers. Platforms and terminals are connected with each other by two branches pipelines. Circulation of oil within the branches of the each pipeline is required to prevent precipitation of waxes and asphaltenes and maintain the oil temperature at the designed level. Each riser pipe and pipeline should have emergency shut-down valves.

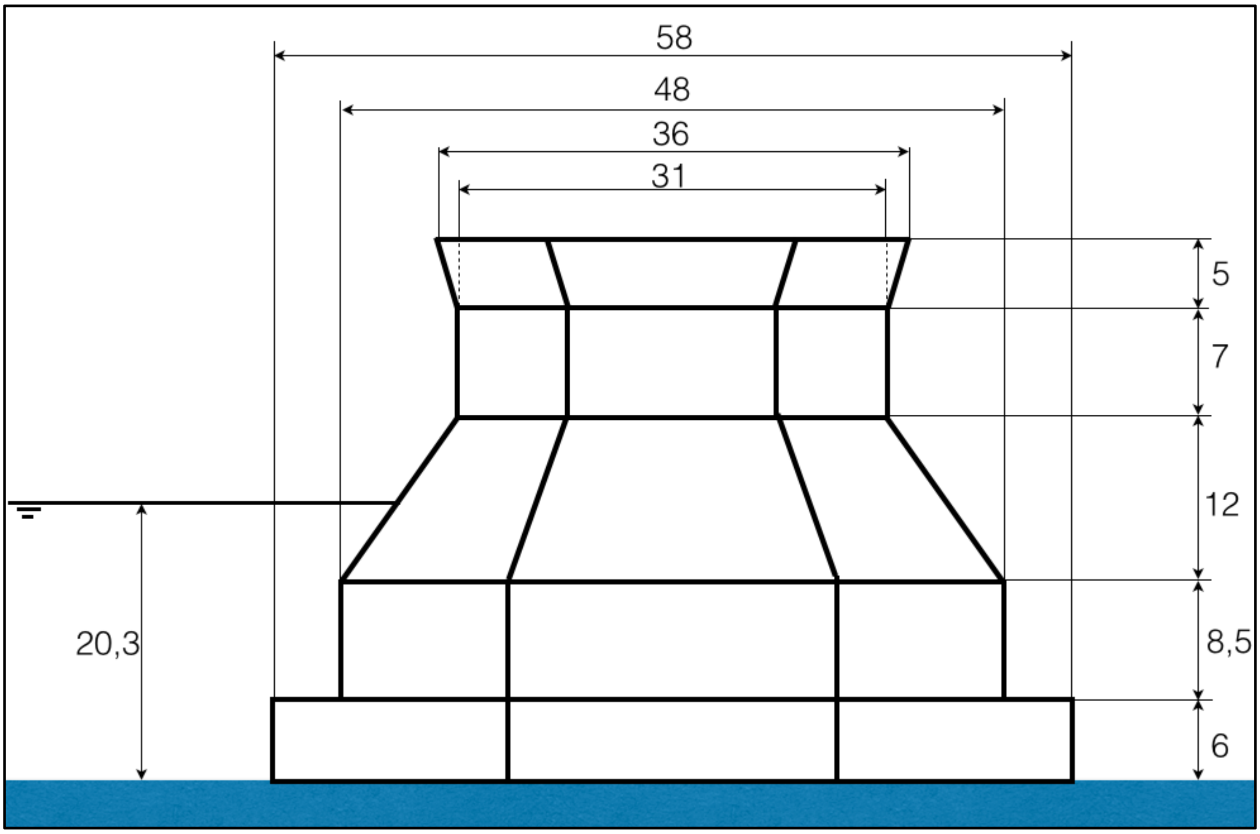


Figure 52 – Foundation of the terminal

5.2 Exploitation of the terminal

Oil from the terminal will be loaded to shuttle tankers 70, 000 DWT. Based on the experience of Varandey and Prirazlmnoye projects; all tankers should have bow loading equipment, GPS system, and dynamic positioning system.

When the tanker is ready for mooring, the offloading hose and hawser are transferred from the terminal simultaneously. Besides the tanker mooring, the hawser prevents the loading hose from overloading. The hawser must be under tension during the oil loading. Tankers shall be equipped with a towline at the stern to tow the tanker away from the terminal by the support boat in case of any accidents during the tanker positioning. Support vessel shall be on duty during the loading and mooring operations.

When the loading hose is attached, and the tanker is moored, oil loading begins. Tension in the hawser should be monitored during the loading process. Responsible personnel should be on the deck of the tanker to control bow loading equipment, loading hose, and water area close to the point of their connection to prevent oil leakages and spills.

Before the loading hose disconnection, oil within the loading line and hose must be displaced into the tanker. Only after this procedure is carried out, the valves can be closed. Afterward, tension in the loading hose will be reduced by the tanker moving slightly forward.

5.3 Loads estimation

The terminal should withstand the combined action of:

- 100-year wave load;
- 100-year ice load;
- 10-year current load (Gudmestad, 2014).

Ice load

Global ice action on structures with vertical walls can be estimated using the following formula:

$$F = h \cdot \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \sigma_c \cdot cos\varphi \cdot R \cdot d\varphi = h \cdot \sigma_c \cdot 2R = \sigma_c D h$$

where σ_c – unconfined compressive strength; D – diameter of the structure; h – ice thickness.

In 1962, Korzhavin suggested another formula (Loset et.al., 2006):

$$F = IKm\sigma_c Dh$$

where I – Indentation factor; K – contact factor; m – shape factor.

Global ice action on sloping walls is made in accordance with the formulas:

$$\frac{F_H}{D} = \sigma_f \cdot \left(\frac{\rho_w g h^5}{E}\right)^{1/4} \cdot C_1 + C_2 \cdot h \cdot h_r \cdot \rho_i \cdot g$$

$$C_1 = 0.68 \cdot \frac{sin\alpha + \mu \cdot cos\alpha}{cos\alpha - \mu \cdot sin\alpha}$$

$$C_2 = (sin\alpha + \mu \cdot cos\alpha) \cdot \left(\frac{sin\alpha + \mu \cdot cos\alpha}{cos\alpha - \mu \cdot sin\alpha} + ctg\alpha\right)$$

where E – Young's modulus of ice; h_r – the height of the rubble on the structure's slope; ρ_w and ρ_i – the water and ice densities; g – gravity acceleration; α – sloping angle. For initial data and results, see Tables 15 to 17.

Table 15 – Initial data

№	Parameter	Unit	Value	Comments
1	D	m	45	Diameter of the structure
2	h	m	1,7	Ice thickness
3	σ_c	MPa	1,37	Unconfined compressive strength
4	σ_f	MPa	0,7	Flexural strength
5	μ	MPa	0,3	Dynamic friction coefficient
6	ρ_w	kg/m^3	1025	Density of water
7	ρ_i	kg/m^3	910	Density of ice
8	k_h	---	1,5	Factor of hummocks

Table 16 – Ice load on the structure with vertical walls

№	Parameter	Unit	Value	Comments
1	F	MN	93,16	Ice force
2	F	MN	75,46	Ice force (Korzhavin equation)

Table 17 – Ice load on the structure with vertical walls

№	α	C_1	C_2	Total horizontal force, MN
1	20	0,61	2,61	16,94
2	25	0,72	2,52	16,58
3	30	0,86	2,54	16,96
4	35	1,04	2,66	18,01
5	40	1,27	2,90	19,85
6	45	1,59	3,30	22,84
7	50	2,07	3,97	27,76
8	55	2,90	5,21	36,72
9	60	4,72	8,01	56,99
10	65	12,17	19,74	141,36

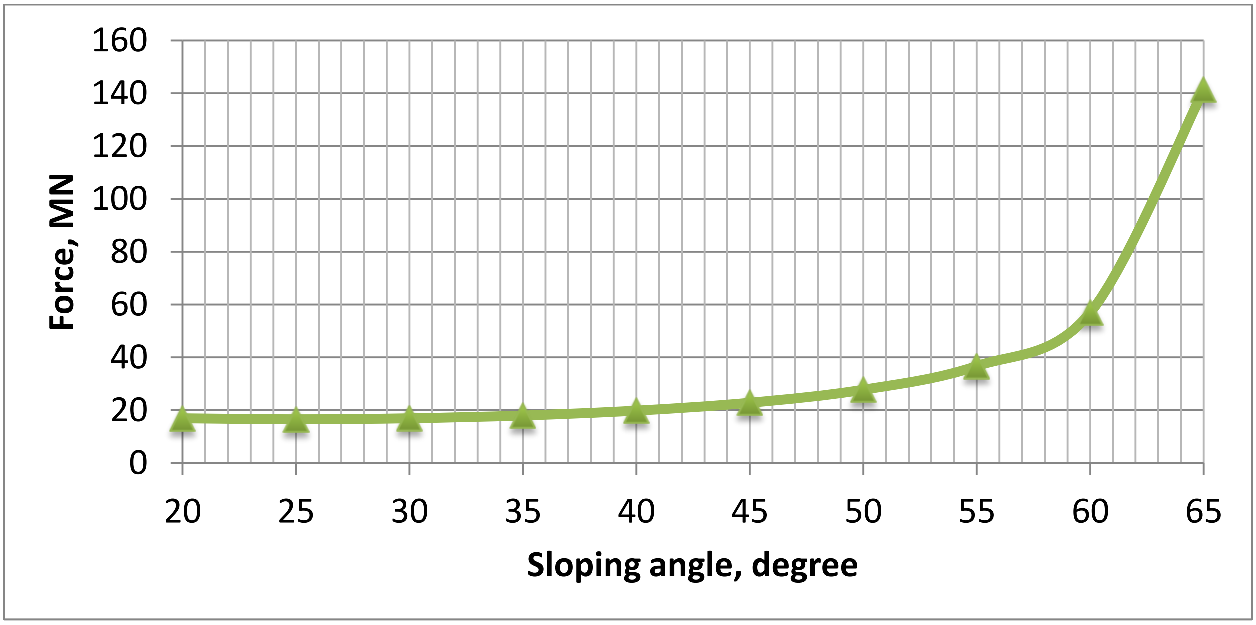


Figure 53 – Horizontal force depending on the sloping angle

Figure 53 shows the following rule: the lower a sloping angle, the lower is ice force. Marine structures with a sloping angle equal to 20 degrees are not used, as the foundation of such structures should be huge. One can see, that after 55 degrees, ice force increases rapidly. The sloping angle of 55 degrees is chosen for further calculations and the total horizontal force **F_i=36,72 MN**.

The presence of hummocks in the Pechora Sea should be taken into account. Generally, it is possible to multiply the total horizontal ice force by the factor of hummocks **F_i*k_h=36,72*1,5=55,08 MN (Gudmestad, 2015).**

<u>Wave load</u>

Wave action on the marine structures in Russia is determined by SNiP. 2.06.04 and VSN 41.88. We suppose to use the structure with sloping walls at the water line. Only VSN 41.88 contains an algorithm for the wave load estimation on the structures with sloping walls:

$$F_w = \frac{\pi \rho g h K \Delta z}{8 * ch(KD)} \sum_{i=1}^{n} C(z_i) D^2 (z_i) * ch(K * (d - z_i))$$

where n – number of intervals; K – wave number; Δz – length of the interval; z_i – depth of the center of i-th interval; $D(z_i)$ – diameter of the structure at the depth of z_i; $C(z_i)$ – coefficient corresponding to Figure 54. For initial data and results, see Tables 18 to 20.

The terminal was split into 10 equal intervals

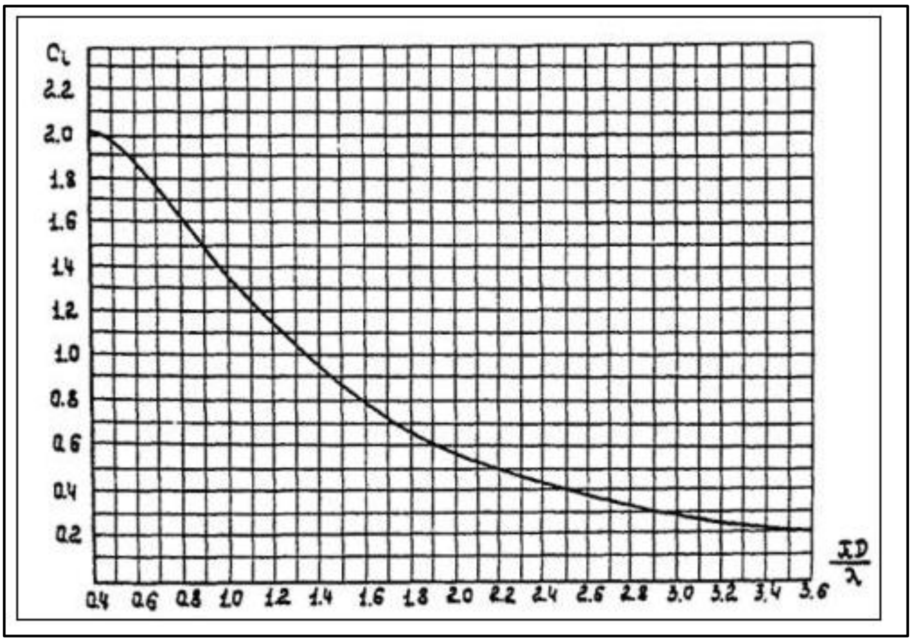


Figure 54 - C(zi) coefficient (VSN)

Table 18 – Initial data

№	Parameter	Unit	Value	Comments
1	ρ_w	kg/m^3	1025	Density of water
2	h	m	9,2	100-year wave height
3	d	m	20,3	Water depth
4	λ	m	115	100-year wave height
5	τ	s	9,1	100-year period

Table 19 – Preliminary results

№	Δz	z_i	D	π*D/λ	C
1	2	1	41,28	1,13	1,22
2	2	3	44,08	1,20	1,17
3	2	5	46,88	1,28	1,07
4	2	7	48,00	1,31	1,02
5	2	9	48,00	1,31	1,02
6	2	11	48,00	1,31	1,02
7	2	13	48,00	1,31	1,02
8	2	15	58,00	1,58	0,82
9	2	17	58,00	1,58	0,82
10	2	19	58,00	1,58	0,82

Table 20 – Wave load

№	Parameter	Unit	Value	Comments
1	K	1/m	0,05	Wave number
2	**F_w**	**MN**	**69,41**	**Wave load**

<u>Current load</u>

Current load can be calculated by the formula:

$$F_c = \frac{1}{2} C_d D d v^2$$

where C_d –drag coefficient; D – diameter of the structure; d – water depth; v – current speed. Drag factor depends on the Reynolds number (Figure 55). For initial data and results, see Tables 21 and 22.

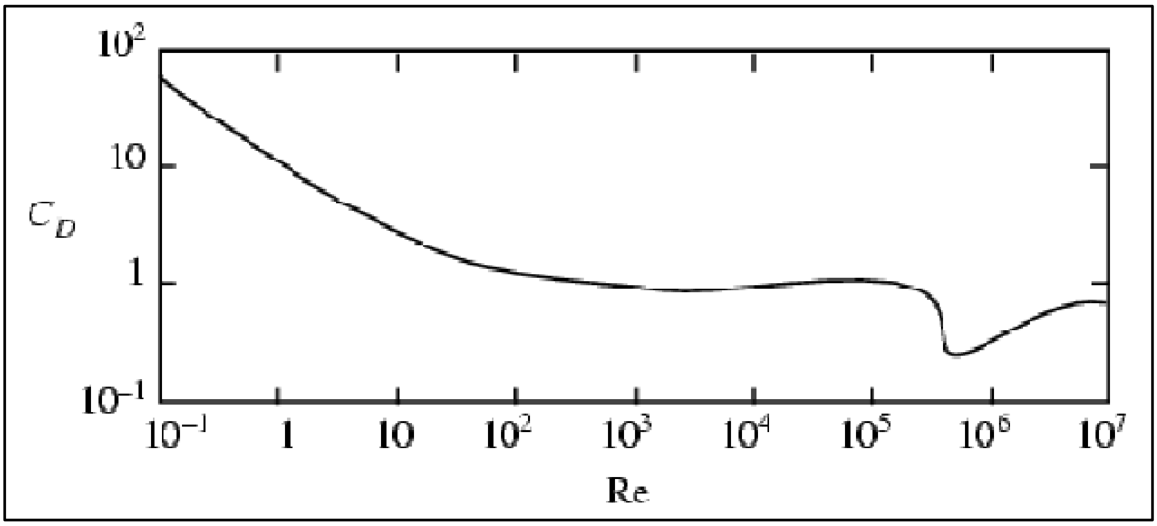


Figure 55 - Drag coefficient estimation

Table 21 – Initial data

№	Parameter	Unit	Value	Comments
1	D	m	48	Diameter
2	V	m/s	0,8	Current speed
3	ρ_w	kg/m^3	1025	Density of water
4	d	m	20,3	Water depth

Table 22 – Current load

№	Parameter	Unit	Value	Comments
1	Re	---	3E+07	Reynolds Number
2	C_d	---	1	Drag factor
3	**Fc**	**MN**	**0,32**	**Current load**

Wind load

Wind load on the offshore structure can be determined by the formula:

$$F_{wind} = \frac{1}{2}\rho_a V^2 \sum_{i=1}^{n} S_i \phi_i c_i$$

where n – number of intervals; ρ_a – mass density of air; V – wind speed at height of 10 m above the waterline over 10 min; S_i – windage area of i-th element; ϕ_i – factor of the wind speed change; c_i - resistance factor.

$$\phi_i = \left(\frac{z}{10}\right)^{0,18}$$

For initial data and results, see Tables 23 and 24.

Table 23 – Initial data

№	Parameter	Unit	Value	Comments
1	ρ_a	t/m^3	0,0012	Mass density of air
2	V	m/s	33	wind speed at the height of 10 m above the waterline over 10 min
3	S	m^2	900	Windage area

Table 24 – Wind load

№	Parameter	Unit	Value	Comments
1	$\mathbf{F_{wind}}$	**MN**	**0,60**	**Wind load**

5.4 Risk estimation

As it was discussed in Chapter 4, there are only two possible alternatives of oil offloading in the Pechora Sea: via hoses supported by special cranes and via the ice-resistant terminal with the pipelines network. Exploitation of the first technology revealed a number problem, while the second one works perfectly. Now we can estimate the risks connected with the both concepts.

The risk is defined by the consequence and probability categories. Generally, there are three groups of risks: Low, Medium and High. Low risk is considered as an acceptable risk (Rausand, 2011, p. 52). Government, standards, norms, etc. determine risk acceptance criteria. Risk acceptance criteria – criteria, which are used to make a decision about acceptable risk (DNV-RP-H101, 2003). Risk acceptance criteria might be qualitative or quantitative.

When we make a risk assessment, we should do it for four categories:

- safety for people;
- environmental impact;
- assets and reputation.

As it was mentioned above, the risk is defined by probability and consequences. We define several categories of probability and consequences in accordance with acceptable criteria. They are shown in Table 25.

Table 25 – Consequences categories

Consequences	Personnel	Environment	Assets
A	Negligible damage	Insignificant damage	Insignificant damage
B	Minor damage	Minor damage	Minor damage
C	Medium damage	Moderate damage	Moderate damage
D	One fatality	Considerable damage	Considerable damage
E	Several fatalities	Serious damage	Serious damage

The probability categories are based on the frequency of hazards occurrence (Norsok Standard Z-013, 2010):

- Rarely occurred;
- Happened several times per year in industry;
- Has occurred in operating company;
- Happened several times per year in operating company;
- Happened several times per year in location.

In case of quantitative analysis, for personal safety it is possible to use FAR, GIR, IR or IRPA (Norsok Standard Z-013, 2010). Environmental impact can be estimated by the period of recovery time or in the volume of spilled chemicals, and for assets – level of loosed money.

HAZID is a special technique, used for the identification and evaluation of hazards and weaknesses, associated with the operation or activity under consideration. The hazard may be a physical object (e.g. a barge), an activity (e.g. offloading operation) or a material (e.g. hydraulic oil).

Risk matrices are used to consider hazards through accident probability and consequences. Such matrices can be divided into different number of cells. In my work, I consider 5x5 matrix. All hazards are allocated to a probability and consequence category according to acceptance criteria.

The main point of this paragraph is generation and a comparison of risk matrices for two processes: oil offloading from the terminal and offloading via special cranes, installed on a platform. In order to make this, firstly we should carry out an HAZID analysis of the offloading process on the shuttle tanker. Accidents with shuttle tankers happen almost every year (Figure 56).

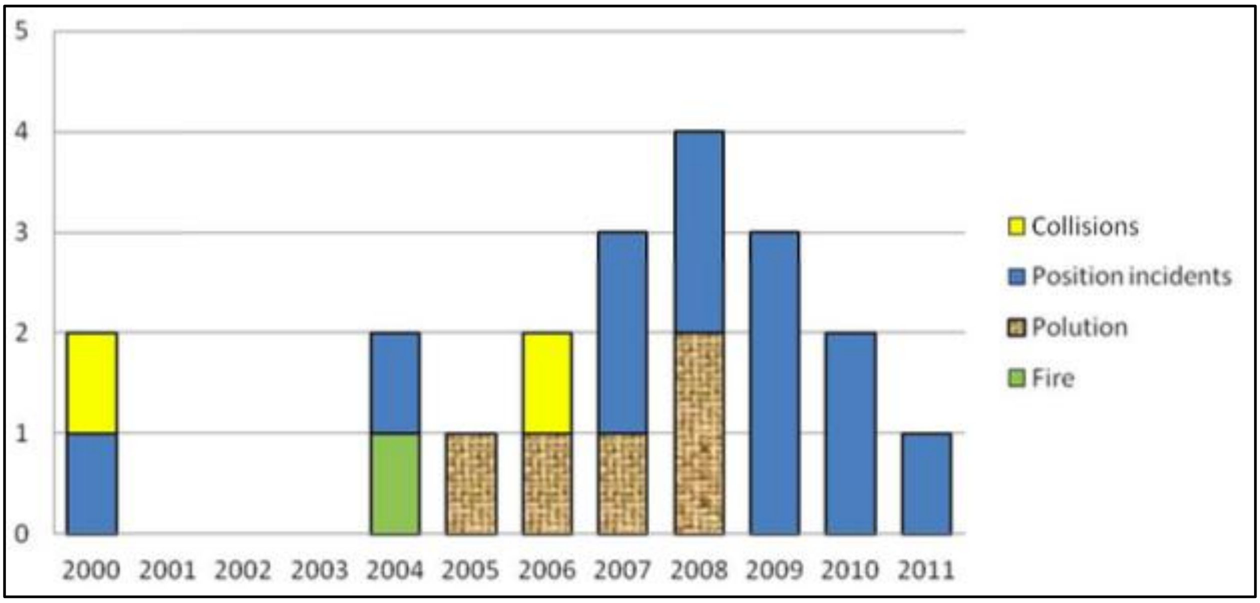


Figure 56 - Reported number of accidences from 2000 to 2011 with shuttle tankers (Kvitrud, Kleppestø, & Skilbrei, 2012)

Main hazards for offloading by tanker:

1. Tanker lean-off;
2. Position system failure;
3. Misunderstanding of the offloading procedure;
4. Nonequivalent loading of the tanker;
5. Impossibility of carrying out an operation;
6. The collision of a tanker with a foreign body.

Table 26 –HAZID analysis

№	Causes	Hazard	Consequence	Mitigating measures
1	• Rapid change of the weather conditions • Rapid change of total load direction • Extreme loads • Incorrect position of the tanker during the offloading • Inadequate knowledge of the procedures • Blackout	Tanker lean-off	• Damage to the internal pipelines and systems • Oil spills/Fire • Collapse of the tower of terminal • Damage to the foundation of the terminal • Fire/ explosion • Personal injury/ fatality • Leakages of technical liquid • Capsizing of tanker	• Procedures and instructions should be followed • Personal training • Several sources of weather forecast • Fast response of supply vessel
2	• Cooling water failure (engine) • Thruster failure • Engine failure • Loss of satellite signal • Logic or programming errors in the DP system. • Blackout • Incorrect use of equipment/ incorrect settings • Low fuel pressure	Position system failure	• Rupture of the hose • Damage to crane bearing • Emergency disconnection • Position incidents	• Last generation DP system (IMO classification) • Supply vessels on duty
3	• Different regulation documents/ standards • Regulation documents are not updated	Misunderstanding of the offloading procedure	• Delay in operation	• Use of the same regulation documents • Coordination of the crew

				• Additional training
4	• Failure of the distribution device during the process of offloading	Nonequivalent loading of the tanker	• Lack of tanker stability • Supplier default	• Regular control of distribution equipment • Tide control of offloading procedure
5	• Not suitable weather conditions • Poor logistic • Lack sources	Impossibility of carrying out an operation	• Delay in operation	• Good logistic strategy • Pre-planned offloading and transportation
6	• Bad visibility (fog) • Huge motion of vessel (rotational and translational motions) • Human errors • DP system failure	Collision of a tanker with a foreign body (ice ridge)	• Thruster failure • Oil spill • Fire/ explosion • Personal injury/ fatality • Leakages of technical liquid • Delay in delivery	• Double hull tankers • Fast response of supply vessel • Quick response of personnel • Regular checking of navigation system

Now we can estimate probability and consequences of the hazards for each alternative, see Tables 27 and 28.

Table 27 – Risk matrix for the offloading via hoses

Probability			1	2	3	4	5
			Very unlikely	Unlikely	Possibly	Likely	Very likely
Consequences	E	Very high			1		
	D	High	4		2	5	
	C	Medium			3		
	B	Low				6	
	A	Negligible					

Table 28 – Risk matrix for the offloading via terminal

Probability			1	2	3	4	5
			Very unlikely	Unlikely	Possibly	Likely	Very likely
Consequences	E	Very high					
	D	High	4	5			
	C	Medium			1,3		
	B	Low			2	6	
	A	Negligible					

The terminal concept can significantly reduce the risks associated with the process of oil offloading. The area for maneuvering around the platform is much lower than for the terminal with a rotating head. The combined actions of the external loads and limit the angle of rotation of offloading cranes and force tankers to disconnect frequently. The number of connections/disconnections increases, resulting in pumps malfunctioning. As a result of these, OPEX will increase dramatically, as one day of an ice tanker rent costs $50,000.

Offshore platforms in the Arctic and sub-arctic regions combine drilling, production, processing and storing facilities. The number of personnel engaged in all the activities is high, about 200-300 people. Tanker contact with the platform might cause significant oil spills, damage to the equipment and a lot of human injuries. In order to minimize these risks, tankers have to disconnect even in case of the smallest threat.

Thus, the concept of the ice-resistant terminal with the rotating head has a lot of benefits in comparison with the direct offloading from the platform via hoses:

- Tanker always holds the position with the lowest environmental load due to the rotating beam.
- Faster mooring and offloading operations. Vary important for areas with the restrictions on weather windows.
- Consequences of any accident with the tanker are much lower

Otherwise, the construction of the terminal is a very costly adventure.

6. Cost analysis

In the previous chapters, the idea of the ice-resistant fixed terminal was suggested for the cluster development of the Pechora Sea. The offloading terminal provides more flexibility in mooring and offloading operations, reduces the risks of any accidents and delays in supply. These are the main advantages of the offloading terminal.

On the other hand, it is obvious that the construction of the terminal would reduce the economic efficiency of the whole project. Economic estimation is required to understand how much does it costs to create and serve the terminal. The initial data used for calculations was obtained in personal communications with my supervisors.

6.1 Way of estimation

To estimate the economic efficiency of the project, four main parameters should be calculated:

1. NPV;
2. IRR;
3. Profitability index;
4. Net profit margin.

The process of the economic efficiency consists of the following steps:

1. Calculation of Revenue:

$$Revenue_i = Q_i * P$$

where Q_i – volume of the offloaded oil, mln.t per i-th year; P – oil price, USD/t.

2. Estimation of CAPEX.
3. Estimation of OPEX.
4. Estimation of Amortization.

Here we assume linear principle of amortization

$$Amortization_i = CAPEX/N$$

where

$CAPEX$ – total capital expenditures, mln. USD;

N – service period, years.

5. Estimation of Taxes.

Here we assume 40 % tax rate

$$Tax_i = 0{,}4 * (Revenue_i - OPEX_i)$$

6. Estimation of Cash flow:

$$Cash\ flow_i = Cash\ inflow_i - Cash\ outflow_i$$

$$Cash\ inflow_i = Revenue_i$$

$$Cash\ outflow_i = CAPEX_i - OPEX_i - Amortization_i - Tax_i$$

7. Estimation of Discounted Cash flow:

$$PV_i = \frac{Cash\ flow_i}{(1+r)^i}$$

Where

r – discount rate, %;

i – number of the year.

8. Estimation of NPV:

$$NPV = \sum_{i=0}^{N} PV_i$$

9. Estimation of Profitability Index:

$$PI = \frac{NPV}{\sum_{i=0}^{N} \frac{CAPEX_i}{(1+r)^i}}$$

10. Estimation of Net profit margin:

$$NPM = \frac{Cash\ Inflow}{Cash\ Outflow}$$

6.2 Required CAPEX and OPEX

6.2.1 Platforms and wells

Because of the severe ice conditions, shallow waters and presence of the ice ridges, only gravity based structures can be used for development of the Cluster 3. Development of Cluster 2 also requires two gravity structures (Boyko, 2014).

CAPEX for platforms include construction, transportation, modernization, amortization, oil spill response measures and decommissioning of the platforms. A lot of money are required for the drilling of wells.

Because of the lack of information regarding the fields, it was assumed that the properties of fluids and reservoir rocks are the same. The only thing is known – age of the fields is the same and they are lying at the same depth, so the assumption is allowable. The flow rate depends on the net oil thickness. Recoverable resources of one well are in direct proportion to the recoverable resources of the field (this means no well interference is assumed).

$$V = H * A * m * s * f$$

where V –recoverable reserves of oil; H – net pay thickness; A – area of the field; m – porosity; s – saturation; f – recoverable factor.

Knowing the initial production rate at the Prirazlomnoye field, initial production rates can be estimated (Table 29):

Table 29 – Initial production rates per well

№	Field	Recoverable resources, mln. tonnes	Area, km^2	Production rate t/d
1	Northern part of the Dolginskoye	150	200	1341,7
2	Southern part of the Dolginskoye	70	100	1252,2
3	Alekseevskoye field	50	70	1277,8
4	North Gulyevskoye field	20	40	894,4
5	East Gulyevskoye field	14	30	834,8
6	Prirazlomnoye	70	50	1610,0

Based on the annual production rate of each field and assuming the production rates, the required number of the producing fields can be found. The relation between production and injection wells are 1:0,33 (Bilalov, 2014). Finally, the number of wells is shown in Table 30.

Table 30 – Number of wells

№	Field	Number of production wells	Number of injection wells
1	Northern part of the Dolginskoye	53	18
2	Southern part of the Dolginskoye	26	9
3	Alekseevskoye	19	7
4	North Gulayevskoye	12	4
5	South Gulayevskoye	8	3

Required CAPEX and OPEX are estimated in Table 31.

Table 31 – CAPEX and OPEX for the platforms (cost of one well – 40 mln. USD)

№	Field	CAPEX-wells	CAPEX-platform	OPEX
		mln. USD		
1	Northern part of the Dolginskoye	2840,000	3000,000	90,000
2	Southern part of the Dolginskoye	1400,000	2300,000	69,000
3	Alekseevskoye	1040,000	2300,000	69,000
4	North Gulayevskoye	640,000	1800,000	54,000
5	South Gulayevskoye	440,000	1800,000	54,000

6.2.2 Terminal and Pipeline system

Terminal

CAPEX for the construction of the terminal are shown in Table 32. Expenditures are divided into two big parts: construction of the TLU and development of the infrastructure, design documentation, mobilization of equipment, etc.

Table 32 – CAPEX for the terminal

№	Parameter	Unit	CAPEX, mln. USD
1	TLU	mln.USD	145,000
2	Other	mln.USD	145,000
		Total CAPEX, mln. USD	**290,000**

Pipeline system

The distance between the platforms and terminal has been already estimated in Chapter 4. In order to guarantee the high reliability of the pipeline transportation, two branches of the pipelines are required. Such a system enables to organize oil circulation within two branches and minimize any risks of precipitation. Pigs can clean the pipelines. Expenditures for the pipelines construction are in Table 33.

Table 33 – CAPEX for the pipeline system

№	Pipeline	Length, km	CAPEX, mln. USD
1	North Dolgynskoye-TLU	84,460	168,92
2	South Dolgynskoye-TLU	32,088	64,176
3	Alexeevskoye-TLU	38,792	77,584
4	Alexeevskoye-North Gulayevskoye	67,660	135,32
5	Alexeevskoye-East Gulayevskoye	46,022	92,044
		Total CAPEX, mln. USD	**538,044**

Annual OPEX are supposed to be 3% from CAPEX. OPEX are estimated in Tables 34 and 35.

Table 34 – OPEX for the terminal

№	Parameter	Unit	OPEX, mln. USD
1	TLU	mln.USD	4,350
2	Other	mln.USD	4,350
		Total OPEX, mln. USD/year	**8,700**

Table 35 – OPEX for the pipeline system

№	Pipeline	OPEX, mln. USD
1	North Dolgynskoye-TLU	5,068
2	South Dolgynskoye-TLU	1,925
3	Alexeevskoye-TLU	2,328
4	Alexeevskoye-North Gulayevskoye	4,060
5	Alexeevskoye-East Gulayevskoye	2,761
	Total OPEX, mln. USD/year	**16,141**

6.2.3 Fleet

The oil transportation scheme should be organized in accordance with Option 3 described in Chapter 4, when processed oil is loaded onto ice-class tankers from one TLU common for several fields. Afterward, the oil will be transported by the shuttle tankers to the terminal station. All the vessels are supposed to be rented, so there will be no CAPEX.

Supply and support vessels

Supply and support vessels are required to provide platforms with food, diesel fuel, equipment, water, etc. A modern supply (multipurpose supply vessel) vessel can act as an icebreaker, tractor and evacuation boat.

Required number of the multipurpose supply/support ships:

- 5 vessels to provide an ice management function the platforms
- 3 vessels to deliver different stuff for each cluster and terminal;
- 1 vessels to provide an ice management for the terminal and evacuate the personnel;
- 1 tugboat for mooring operations at the terminal.

Tanker fleet

Initial data for the estimation of the tanker fleet is shown in Table 36.

Table 36 – Initial data

№	Parameter	Unit	Value	Comments
1	DWT_{st}	mln.t	0,07	DWT of the shuttle tanker
2	DWT_{lt}	mln.t	0,25	DWT of the linear tanker
3	T_{st}	day	5	Required time for the return trip of the shuttle tanker (Terminal-Murmansk-Terminal)
4	T_{lt}	day	14	Required time for the return trip of the linear tanker (Murmansk-Amsterdam-Terminal)
5	N_{st}	ship ping	73	Maximum number of shippings of one shuttle tanker per year
6	N_{lt}	ship ping	26	Maximum number of shippings of one linear tanker per year

Calculation of the required number of vessels is shown in Appendix Table 44. Estimation of OPEX for the tanker fleet is represented in Table 37.

Table 37 – OPEX for tanker fleet

№	Type of vessel	Rent, mln. USD/day	Rent, mln. USD/year	Fuel consumption per round trip, t	Fuel price, mln.USD/t	Fuel, mln. USD/trip
1	Linear tanker	0,06	21,900	2000	0,00015	0,3
2	Shuttle tanker	0,065	23,725	800	0,00015	0,12
3	Supply vessel	0,055	18,250	0	0,00015	0
4	Tugboat	0,03	10,950	0	0,00015	0

Comment: For supply vessel and tug boat fuel is included the rent price.

Total CAPEX and OPEX are shown in Tables 38 – 40.

Table 38 – Total CAPEX

№	Parameter	CAPEX, mln. USD
1	Terminal	**290,000**
1.1	TLU	145,000
1.2	Other	145,000
2	Pipeline system	**538,044**
2.1	North Dolgynskoye-TLU	168,920
2.2	South Dolgynskoye-TLU	64,176
2.3	Alexeevskoye-TLU	77,584
2.4	Alexeevskoye-North Gulayevskoye	135,320
2.5	Alexeevskoye-East Gulayevskoye	92,044
3	Platforms	**11200,000**
3.1	North Dolginskoye	3000,000
3.2	South Dolginskoye	2300,000
3.3	Alekseevskoye	2300,000
3.4	North Gulayevskoye	1800,000
3.5	South Gulayevskoye	1800,000
	Total CAPEX, mln. USD	**12028,044**

Table 39 – OPEX per year

№	Parameter	OPEX, mln. USD/year
1	Terminal	**8,700**
1.1	TLU	4,350
1.2	Other	4,350
2	Pipeline system	**16,141**
2.1	North Dolgynskoye-TLU	5,068
2.2	South Dolgynskoye-TLU	1,925

2.3	Alexeevskoye-TLU	2,328
2.4	Alexeevskoye-North Gulayevskoye	4,060
2.5	Alexeevskoye-East Gulayevskoye	2,761
3	Tanker fleet	**74,825**
3.1	Linear tanker	21,900
3.2	Shuttle tanker	23,725
3.3	Supply vessel	18,250
3.4	Tugboat	10,950
4	Platforms	**336,000**
4.1	North Dolginskoye	90,000
4.2	South Dolginskoye	69,000
4.3	Alekseevskoye	69,000
4.4	North Gulayevskoye	54,000
4.5	South Gulayevskoye	54,000
	Total OPEX, mln. USD/year	**435,666**

Table 40 – OPEX per trip

№	Parameter	OPEX, mln. USD/trip
1	Linear tanker	0,300
2	Shuttle tanker	0,120
	Total OPEX, mln. USD/trip	**0,420**

6.3 Estimation of the economic efficiency

Following the formulas in paragraph 6.1 and initial data in paragraph 6.2 the economic efficiency of the development scheme for Clusters 2 and 3 were estimated. The calculation in all details is shown in Appendix Tables 45-50 and Figures 57-59 for one case. The results of the calculations are shown in Tables 41 – 43. For the scheme without the terminal the following changes were made in the model:

- CAPEX and OPEX for the terminal are excluded;
- CAPEX and OPEX for the pipelines between the terminal, both parts of the Dolgynskoye and Alekseevskoye fields are omitted;
- CAPEX of platforms was increased on 100 mln. USD. This is a price of the offloading system and changes in the construction of the platforms;
- The required number of vessels was re-estimated.

Table 41 – Estimation of the economic efficiency (60 USD/b)

№	Parameter	Unit	Value	
			With the terminal	Without the terminal
1	Total CAPEX	mln. USD	18388,044	18187,364
2	Total OPEX	mln. USD	19696,889	19386,588
3	Total cash inflow	mln. USD	123087,753	123087,753
4	Total cash outflow	mln. USD	65951,150	64901,549
5	Total cash flow	mln. USD	57136,603	58186,204
6	NPV	mln. USD	4216,470	4539,215
7	Payback period	Years	13	12
8	IRR	%	18%	19%
9	Net profit margin	----	1,87	1,90
10	PI	---	1,57	1,63

Table 42 – Estimation of the economic efficiency (80 USD/b)

№	Parameter	Unit	Value	
			With the terminal	Without the terminal
1	Total CAPEX	mln. USD	18388,044	18187,364
2	Total OPEX	mln. USD	19696,889	19386,588
3	Total cash inflow	mln. USD	164117,004	164117,004
4	Total cash outflow	mln. USD	74157,000	73107,399
5	Total cash flow	mln. USD	89960,004	91009,604
6	NPV	mln. USD	9285,275	9608,020
7	Payback period	Years	10	9
8	IRR	%	23%	24%
9	Net profit margin	----	2,21	2,24
10	PI	---	2,25	2,32

Table 43 – Estimation of the economic efficiency (100 USD/b)

№	Parameter	Unit	Value	
			With the terminal	Without the terminal
1	Total CAPEX	mln. USD	18388,044	18187,364
2	Total OPEX	mln. USD	19696,889	19386,588
3	Total cash inflow	mln. USD	205146,255	205146,255
4	Total cash outflow	mln. USD	82362,850	81313,250
5	Total cash flow	mln. USD	122783,405	123833,005
6	NPV	mln. USD	14354,080	14676,825
7	Payback period	Years	9	8
8	IRR	%	28%	28%
9	Net profit margin	----	2,49	2,52
10	PI	---	2,94	3,02

In the Tables above one can see that the construction of the terminal does not change the economic efficiency of the project dramatically. PI remains high for the all considered alternatives. NPV of the project with the terminal differs from the concept without it on about 300 mln. USD. This is a big value, especially when the oil price is not high.

On the other hand, this value becomes insignificant when we talk about the oil spill danger. Regarding the Gulf of Mexico, BP demands compensation from Halliburton 21 bln. USD for the accident in the Gulf of Mexico (RiaNovosti, 2012). About 4,9 million barrels of oil came into the water (Deepwater Horizon oil spill, 2015). Environmental conditions in the Arctic are fragile and the operation conditions are harsher rather than in the Gulf of Mexico, so the probable price of the oil spill might be also 21 bln. USD. In the face of oil spill danger, construction of the offloading terminal might be considered as the most reliable and suitable decision for the Pechora Sea.

Conclusion

The review of the worldwide experience of oil production in the Arctic revealed that the Pechora Sea is a very challenging area. There are no regions in the world with such combination of water depth, environmental loads and remoteness. The tanker transport is the preferable way of oil delivery from the Pechora Sea. There are only two alternatives for oil offloading: via hoses supported by the special cranes and via a terminal.

The oil offloading via the system of hoses and cranes has been used in the Pechora Sea only for several years. Gained experience is not significant, nevertheless several conclusions can be made.

1. The cranes have a limited angle of rotation.

The total vector of external loads changes rapidly in the Pechora Sea. The loads are high, especially in the winter season, and they can displace the tanker from the desirable position. This system is installed on the corners of the platform. As the rotation angle of the cranes is limited, the tanker has to disconnect and move to the opposite loading crane. Tanker mooring, connection and disconnection require at least 3 hours. Thus, the oil can’t be offloaded in time.

2. Probability and consequences of any accidents are higher.

DP system failure and tanker lean-off are not rare accidents for marine projects. A Marine platform contains production, drilling and storage facilities. Generally, the personnel on the platform is 200-300 people. In case of tanker lean-off, the consequences might be very serious.

All above mentioned disadvantages are not critical and not enough to claim that this approach is not suitable for the Pechora Sea. At the same time, development of a new concept of oil offloading and transportation is required, as the technology of oil offloading via the system of cranes and hoses is not absolutely secure and thus, the most effective.

The analysis of the environmental condition of the Pechora Sea region, the existing infrastructure and technologies, revealed that the concept of ice-resistant fixed terminal is the most suitable technology for the Pechora Sea.

Location of the terminal was determined by use of the MCDM concept. Application of the MCDM methods is a new approach and has not been used before for this purpose. Possible environmental loads on the terminal were calculated. The terminal was designed to minimize the loads and provide the easiest way of tankers approach, mooring and offloading. The principles of the terminal exploitation were described.

Offloading of oil via the terminal has a number of advantages:

• The tanker always holds the position with the lowest environmental load due to the rotating beam.

• Faster mooring and offloading operations. Very important for areas with restrictions on weather windows.

• Consequences of any accident with the tanker are low. Personnel of the terminal would be about 10 people. There will be no storage and processing equipment at the terminal.

• Oil companies operating in the Arctic make a great importance to the safety.

A risks analysis for oil offloading has been done. Offloading via a terminal is a more reliable operation in comparison with the direct offloading from the platform. Reliability is crucial for the fragile flora and fauna of the Arctic region.

Construction of the ice-resistant terminal requires a lot of money. Evaluation of the economic efficiency revealed that the difference between the project with and without the terminal is about 300 million USD. We see that the expenditures are high, but this money can be reasonable in case of any oil spills or delays in oil supply.

Thus, in this thesis a new concept of oil offloading and transportation for the Pechora Sea has been developed. Previously, there was only one way of oil offloading. The concept of the ice-resistant terminal can become an excellent addition to the cluster approach of the Pechora Sea development. The terminal can serve several oil fields and act as a "hub" in the Pechora Sea.

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Appendix

Table 44 – Required number of vessels

Year	Number of shippings		Number of vessels			
	Linear tanker	Shuttle tanker	Linear tanker	Shuttle tanker	Supply vessel	Tugboat
2020	0	0	0	0	0	0
2021	8	29	1	1	5	1
2022	16	57	1	1	5	1
2023	24	86	1	2	5	1
2024	32	114	2	2	5	1
2025	40	142	2	2	5	1
2026	45	161	2	3	5	1
2027	50	179	2	3	5	1
2028	50	179	2	3	5	1
2029	50	179	2	3	5	1
2030	50	179	2	3	6	1
2031	50	179	2	3	6	1
2032	50	179	2	3	7	1
2033	50	179	2	3	7	1
2034	50	179	2	3	7	1
2035	50	179	2	3	7	1
2036	50	179	2	3	8	1
2037	50	179	2	3	8	1
2038	50	177	2	3	8	1
2039	48	171	2	3	8	1
2040	47	166	2	3	8	1
2041	40	143	2	2	8	1
2042	39	137	2	2	8	1
2043	36	128	2	2	7	1
2044	34	119	2	2	7	1
2045	31	111	2	2	7	1
2046	25	90	1	2	6	1
2047	24	83	1	2	6	1
2048	22	76	1	2	6	1
2049	20	71	1	1	6	1
2050	12	42	1	1	5	1
2051	11	39	1	1	5	1
2052	11	36	1	1	5	1
2053	10	34	1	1	5	1
2054	9	31	1	1	5	1
2055	9	29	1	1	5	1
2056	7	22	1	1	3	1

Table 45- Estimation of the economic efficiency of the project with the terminal (oil price 60 $/b)

№		Sum, mln. USD	2016	2017	2018	2019	2020	2021		2025		2040		2050		2056
1	Offloaded oil	**296,826**	**0,000**	0,000	0,000	0,000	0,000	1,986		9,929		11,564		2,941		1,524
2	Revenue	**164117,004**	0,000	0,000	0,000	0,000	0,000	1097,914		5489,569		6393,654		1626,316		842,498
3	CAPEX	**18388,044**	0,000	1925,000	1421,667	1306,127	1183,711	373,737		373,737		215,273		0,000		0,000
3.1	Terminal	**290,000**	0,000	0,000	96,667	96,667	96,667	0,000		0,000		0,000		0,000		0,000
3.1.1	*TLU*	***145,000***	*0,000*	*0,000*	*48,333*	*48,333*	*48,333*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.1.2	*Other*	***145,000***	*0,000*	*0,000*	*48,333*	*48,333*	*48,333*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.2	Pipeline system	**538,044**	0,000	0,000	0,000	84,460	162,044	0,000		0,000		0,000		0,000		0,000
3.2.1	*North Dolgynskoye-TLU*	***168,920***	*0,000*	*0,000*	*0,000*	*84,460*	*84,460*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.2.2	*South Dolgynskoye-TLU*	***64,176***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.2.3	*Alexeevskoye-TLU*	***77,584***	*0,000*	*0,000*	*0,000*	*0,000*	*77,584*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.2.4	*Alexeevskoye-North Gulayevskoye*	***135,320***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.2.5	*Alexeevskoye-East Gulayevskoye*	***92,044***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.3	Platform	**11200,000**	0,000	1925,000	1325,000	1125,000	925,000	0,000		0,000		0,000		0,000		0,000
3.3.1	*North Dolgynskoye*	***3000,000***	*0,000*	*1050,000*	*750,000*	*650,000*	*550,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.3.2	*South Dolgynskoye*	***2300,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.3.3	*Alexeevskoye*	***2300,000***	*0,000*	*875,000*	*575,000*	*475,000*	*375,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.3.4	*North Gulyevskoye*	***1800,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.3.5	*East Gulyevskoye*	***1800,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.4	Wells	**6360,000**	0,000	0,000	0,000	0,000	0,000	373,737		373,737		215,273		0,000		0,000
3.4.1	*North Dolgynskoye*	***2840,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*258,182*		*258,182*		*0,000*		*0,000*		*0,000*
3.4.2	*South Dolgynskoye*	***1400,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*127,273*		*0,000*		*0,000*
3.4.3	*Alexeevskoye*	***1040,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*115,556*		*115,556*		*0,000*		*0,000*		*0,000*
3.4.4	*North Gulyevskoye*	***640,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.4.5	*East Gulyevskoye*	***440,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*88,000*		*0,000*		*0,000*
4	OPEX	**19696,889**	0,000	0,000	0,000	0,000	0,000	372,600		441,385		743,436		407,979		217,590
4.1	Terminal	**313,200**	0,000	0,000	0,000	0,000	0,000	8,700		8,700		8,700		8,700		8,700
4.1.1	*TLU*	***156,600***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*4,350*		*4,350*		*4,350*		*4,350*		*4,350*
4.1.2	*Other*	***156,600***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*4,350*		*4,350*		*4,350*		*4,350*		*4,350*
4.2	Pipeline system	**395,304**	0,000	0,000	0,000	0,000	0,000	7,395		7,395		16,141		7,014		1,925
4.2.1	*North Dolgynskoye-TLU*	***146,960***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*5,068*		*5,068*		*5,068*		*0,000*		*0,000*
4.2.2	*South Dolgynskoye-TLU*	***50,057***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*1,925*		*1,925*		*1,925*
4.2.3	*Alexeevskoye-TLU*	***76,808***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*2,328*		*2,328*		*2,328*		*2,328*		*0,000*
4.2.4	*Alexeevskoye-North Gulayevskoye*	***69,013***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*4,060*		*0,000*		*0,000*
4.2.5	*Alexeevskoye-East Gulayevskoye*	***52,465***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*2,761*		*2,761*		*0,000*
4.3	Platform	**8625,000**	0,000	0,000	0,000	0,000	0,000	159,000		159,000		336,000		192,000		69,000
4.3.1	*North Dolgynskoye*	***2610,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*90,000*		*90,000*		*90,000*		*0,000*		*0,000*
4.3.2	*South Dolgynskoye*	***1794,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*69,000*		*69,000*		*69,000*
4.3.3	*Alexeevskoye*	***2277,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*69,000*		*69,000*		*69,000*		*69,000*		*0,000*
4.3.4	*North Gulyevskoye*	***918,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*54,000*		*0,000*		*0,000*
4.3.5	*East Gulyevskoye*	***1026,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*54,000*		*54,000*		*0,000*
4.4	Tanker fleet	**10363,385**	0,000	0,000	0,000	0,000	0,000	197,505		266,290		382,595		200,265		137,965
4.4.1	*Linear tanker*	***1630,200***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*24,300*		*55,800*		*57,900*		*25,500*		*24,000*
	Number of shippings	***1200***	*0*	*0*	*0*	*0*	*0*	*8*		*40*		*47*		*12*		*7*

	Number of vessels	***58***	*0*	*0*	*0*	*0*	*0*	*1*		*2*		*2*		*1*		*1*
4.4.2	*Shuttle tanker*	***2338,385***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*27,205*		*64,490*		*91,095*		*28,765*		*26,365*
	Number of shippings	***4263***	*0*	*0*	*0*	*0*	*0*	*29*		*142*		*166*		*42*		*22*
	Number of vessels	***77***	*0*	*0*	*0*	*0*	*0*	*1*		*2*		*3*		*1*		*1*
4.4.3	*Supply vessel*	***3996,750***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*91,250*		*91,250*		*146,000*		*91,250*		*54,750*
4.4.4	*Tug boat*	***2398,050***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*54,750*		*54,750*		*87,600*		*54,750*		*32,850*
5	Amortization	**7188,044**	0,000	179,701	179,701	179,701	179,701	179,701		179,701		179,701		179,701		179,701
6	Tax	**57768,046**	0,000	0,000	0,000	0,000	0,000	290,125		2019,273		2260,087		487,335		249,963
7	Cash inflow	**164117,004**	0,000	0,000	0,000	0,000	0,000	1097,914		5489,569		6393,654		1626,316		842,498
8	Cash outflow	**74157,000**	0,000	2104,701	1601,368	1485,828	1363,412	1071,101		2004,460		2268,454		831,348		522,273
9	Cash flow	**89960,004**	0,000	-2104,701	-1601,368	-1485,828	-1363,412	26,812		3485,108		4125,200		794,969		320,225
10	Discounted Cash flow	**9285,275**	0,000	-1879,197	-1276,601	-1057,583	-866,473	15,214		1256,765		271,777		16,863		3,441
11	NPV	**9285,275**	**0,000**	**-1879,197**	**-3155,798**	**-4213,381**	**-5079,854**	**-5064,640**		**-1502,985**		**8249,664**		**9240,177**		9285,275

Table 46- Estimation of the economic efficiency of the project with the terminal (oil price 80 $/b)

№		Sum, mln. USD	2016	2017	2018	2019	2020	2021		2025		2040		2050		2056
1	Offloaded oil	296,826	0,000	0,000	0,000	0,000	0,000	1,986		9,929		11,564		2,941		1,524
2	Revenue	123087,753	0,000	0,000	0,000	0,000	0,000	823,435		4117,177		4795,241		1219,737		631,874
3	CAPEX	18388,044	0,000	1925,000	1421,667	1306,127	1183,711	373,737		373,737		215,273		0,000		0,000
3.1	Terminal	290,000	0,000	0,000	96,667	96,667	96,667	0,000		0,000		0,000		0,000		0,000
3.1.1	TLU	145,000	0,000	0,000	48,333	48,333	48,333	0,000		0,000		0,000		0,000		0,000
3.1.2	Other	145,000	0,000	0,000	48,333	48,333	48,333	0,000		0,000		0,000		0,000		0,000
3.2	Pipeline system	538,044	0,000	0,000	0,000	84,460	162,044	0,000		0,000		0,000		0,000		0,000
3.2.1	North Dolgynskoye-TLU	168,920	0,000	0,000	0,000	84,460	84,460	0,000		0,000		0,000		0,000		0,000
3.2.2	South Dolgynskoye-TLU	64,176	0,000	0,000	0,000	0,000	0,000	0,000		0,000		0,000		0,000		0,000
3.2.3	Alexeevskoye-TLU	77,584	0,000	0,000	0,000	0,000	77,584	0,000		0,000		0,000		0,000		0,000
3.2.4	Alexeevskoye-North Gulayevskoye	135,320	0,000	0,000	0,000	0,000	0,000	0,000		0,000		0,000		0,000		0,000
3.2.5	Alexeevskoye-East Gulayevskoye	92,044	0,000	0,000	0,000	0,000	0,000	0,000		0,000		0,000		0,000		0,000
3.3	Platform	11200,000	0,000	1925,000	1325,000	1125,000	925,000	0,000		0,000		0,000		0,000		0,000
3.3.1	North Dolgynskoye	3000,000	0,000	1050,000	750,000	650,000	550,000	0,000		0,000		0,000		0,000		0,000
3.3.2	South Dolgynskoye	2300,000	0,000	0,000	0,000	0,000	0,000	0,000		0,000		0,000		0,000		0,000
3.3.3	Alexeevskoye	2300,000	0,000	875,000	575,000	475,000	375,000	0,000		0,000		0,000		0,000		0,000
3.3.4	North Gulyevskoye	1800,000	0,000	0,000	0,000	0,000	0,000	0,000		0,000		0,000		0,000		0,000
3.3.5	East Gulyevskoye	1800,000	0,000	0,000	0,000	0,000	0,000	0,000		0,000		0,000		0,000		0,000
3.4	Wells	6360,000	0,000	0,000	0,000	0,000	0,000	373,737		373,737		215,273		0,000		0,000
3.4.1	North Dolgynskoye	2840,000	0,000	0,000	0,000	0,000	0,000	258,182		258,182		0,000		0,000		0,000
3.4.2	South Dolgynskoye	1400,000	0,000	0,000	0,000	0,000	0,000	0,000		0,000		127,273		0,000		0,000
3.4.3	Alexeevskoye	1040,000	0,000	0,000	0,000	0,000	0,000	115,556		115,556		0,000		0,000		0,000
3.4.4	North Gulyevskoye	640,000	0,000	0,000	0,000	0,000	0,000	0,000		0,000		0,000		0,000		0,000
3.4.5	East Gulyevskoye	440,000	0,000	0,000	0,000	0,000	0,000	0,000		0,000		88,000		0,000		0,000
4	OPEX	19696,889	0,000	0,000	0,000	0,000	0,000	372,600		441,385		743,436		407,979		217,590
4.1	Terminal	313,200	0,000	0,000	0,000	0,000	0,000	8,700		8,700		8,700		8,700		8,700
4.1.1	TLU	156,600	0,000	0,000	0,000	0,000	0,000	4,350		4,350		4,350		4,350		4,350
4.1.2	Other	156,600	0,000	0,000	0,000	0,000	0,000	4,350		4,350		4,350		4,350		4,350
4.2	Pipeline system	395,304	0,000	0,000	0,000	0,000	0,000	7,395		7,395		16,141		7,014		1,925
4.2.1	North Dolgynskoye-TLU	146,960	0,000	0,000	0,000	0,000	0,000	5,068		5,068		5,068		0,000		0,000
4.2.2	South Dolgynskoye-TLU	50,057	0,000	0,000	0,000	0,000	0,000	0,000		0,000		1,925		1,925		1,925
4.2.3	Alexeevskoye-TLU	76,808	0,000	0,000	0,000	0,000	0,000	2,328		2,328		2,328		2,328		0,000
4.2.4	Alexeevskoye-North Gulayevskoye	69,013	0,000	0,000	0,000	0,000	0,000	0,000		0,000		4,060		0,000		0,000
4.2.5	Alexeevskoye-East Gulayevskoye	52,465	0,000	0,000	0,000	0,000	0,000	0,000		0,000		2,761		2,761		0,000
4.3	Platform	8625,000	0,000	0,000	0,000	0,000	0,000	159,000		159,000		336,000		192,000		69,000
4.3.1	North Dolgynskoye	2610,000	0,000	0,000	0,000	0,000	0,000	90,000		90,000		90,000		0,000		0,000
4.3.2	South Dolgynskoye	1794,000	0,000	0,000	0,000	0,000	0,000	0,000		0,000		69,000		69,000		69,000
4.3.3	Alexeevskoye	2277,000	0,000	0,000	0,000	0,000	0,000	69,000		69,000		69,000		69,000		0,000
4.3.4	North Gulyevskoye	918,000	0,000	0,000	0,000	0,000	0,000	0,000		0,000		54,000		0,000		0,000
4.3.5	East Gulyevskoye	1026,000	0,000	0,000	0,000	0,000	0,000	0,000		0,000		54,000		54,000		0,000
4.4	Tanker fleet	10363,385	0,000	0,000	0,000	0,000	0,000	197,505		266,290		382,595		200,265		137,965
4.4.1	Linear tanker	1630,200	0,000	0,000	0,000	0,000	0,000	24,300		55,800		57,900		25,500		24,000
	Number of shippings	1200	0	0	0	0	0	8		40		47		12		7

	Number of vessels	***58***	*0*	*0*	*0*	*0*	*0*	*1*		*2*		*2*		*1*		*1*
4.4.2	*Shuttle tanker*	***2338,385***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*27,205*		*64,490*		*91,095*		*28,765*		*26,365*
	Number of shippings	***4263***	*0*	*0*	*0*	*0*	*0*	*29*		*142*		*166*		*42*		*22*
	Number of vessels	***77***	*0*	*0*	*0*	*0*	*0*	*1*		*2*		*3*		*1*		*1*
4.4.3	*Supply vessel*	***3996,750***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*91,250*		*91,250*		*146,000*		*91,250*		*54,750*
4.4.4	*Tug boat*	***2398,050***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*54,750*		*54,750*		*87,600*		*54,750*		*32,850*
5	Amortization	**7188,044**	0,000	179,701	179,701	179,701	179,701	179,701		179,701		179,701		179,701		179,701
6	Tax	**41356,346**	0,000	0,000	0,000	0,000	0,000	180,334		1470,317		1620,722		324,703		165,713
7	Cash inflow	**123087,753**	0,000	0,000	0,000	0,000	0,000	823,435		4117,177		4795,241		1219,737		631,874
8	Cash outflow	**65951,150**	0,000	2104,701	1601,368	1485,828	1363,412	1016,206		1729,982		1948,771		750,032		480,148
9	Cash flow	**57136,603**	0,000	-2104,701	-1601,368	-1485,828	-1363,412	-192,770		2387,195		2846,470		469,705		151,726
10	Discounted Cash flow	**4216,470**	0,000	-1879,197	-1276,601	-1057,583	-866,473	-109,383		860,846		187,531		9,964		1,631
11	NPV	**4216,470**	**0,000**	**-1879,197**	**-3155,798**	**-4213,381**	**-5079,854**	**-5189,237**		**-2898,723**		**3517,492**		**4192,595**		4216,470

Table 47- Estimation of the economic efficiency of the project with the terminal (oil price 100 $/b)

№		Sum, mln. USD	2016	2017	2018	2019	2020	2021		2025		2040		2050		2056
1	Offloaded oil	**296,826**	**0,000**	0,000	0,000	0,000	0,000	1,986		9,929		11,564		2,941		1,524
2	Revenue	**205146,255**	0,000	0,000	0,000	0,000	0,000	1372,392		6861,961		7992,068		2032,895		1053,123
3	CAPEX	**18388,044**	0,000	1925,000	1421,667	1306,127	1183,711	373,737		373,737		215,273		0,000		0,000
3.1	Terminal	**290,000**	0,000	0,000	96,667	96,667	96,667	0,000		0,000		0,000		0,000		0,000
3.1.1	*TLU*	***145,000***	*0,000*	*0,000*	*48,333*	*48,333*	*48,333*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.1.2	*Other*	***145,000***	*0,000*	*0,000*	*48,333*	*48,333*	*48,333*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.2	Pipeline system	**538,044**	0,000	0,000	0,000	84,460	162,044	0,000		0,000		0,000		0,000		0,000
3.2.1	*North Dolgynskoye-TLU*	***168,920***	*0,000*	*0,000*	*0,000*	*84,460*	*84,460*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.2.2	*South Dolgynskoye-TLU*	***64,176***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.2.3	*Alexeevskoye-TLU*	***77,584***	*0,000*	*0,000*	*0,000*	*0,000*	*77,584*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.2.4	*Alexeevskoye-North Gulayevskoye*	***135,320***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.2.5	*Alexeevskoye-East Gulayevskoye*	***92,044***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.3	Platform	**11200,000**	0,000	1925,000	1325,000	1125,000	925,000	0,000		0,000		0,000		0,000		0,000
3.3.1	*North Dolgynskoye*	***3000,000***	*0,000*	*1050,000*	*750,000*	*650,000*	*550,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.3.2	*South Dolgynskoye*	***2300,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.3.3	*Alexeevskoye*	***2300,000***	*0,000*	*875,000*	*575,000*	*475,000*	*375,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.3.4	*North Gulyevskoye*	***1800,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.3.5	*East Gulyevskoye*	***1800,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.4	Wells	**6360,000**	0,000	0,000	0,000	0,000	0,000	373,737		373,737		215,273		0,000		0,000
3.4.1	*North Dolgynskoye*	***2840,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*258,182*		*258,182*		*0,000*		*0,000*		*0,000*
3.4.2	*South Dolgynskoye*	***1400,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*127,273*		*0,000*		*0,000*
3.4.3	*Alexeevskoye*	***1040,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*115,556*		*115,556*		*0,000*		*0,000*		*0,000*
3.4.4	*North Gulyevskoye*	***640,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.4.5	*East Gulyevskoye*	***440,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*88,000*		*0,000*		*0,000*
4	OPEX	**19696,889**	0,000	0,000	0,000	0,000	0,000	372,600		441,385		743,436		407,979		217,590
4.1	Terminal	**313,200**	0,000	0,000	0,000	0,000	0,000	8,700		8,700		8,700		8,700		8,700
4.1.1	*TLU*	***156,600***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*4,350*		*4,350*		*4,350*		*4,350*		*4,350*
4.1.2	*Other*	***156,600***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*4,350*		*4,350*		*4,350*		*4,350*		*4,350*
4.2	Pipeline system	**395,304**	0,000	0,000	0,000	0,000	0,000	7,395		7,395		16,141		7,014		1,925
4.2.1	*North Dolgynskoye-TLU*	***146,960***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*5,068*		*5,068*		*5,068*		*0,000*		*0,000*
4.2.2	*South Dolgynskoye-TLU*	***50,057***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*1,925*		*1,925*		*1,925*
4.2.3	*Alexeevskoye-TLU*	***76,808***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*2,328*		*2,328*		*2,328*		*2,328*		*0,000*
4.2.4	*Alexeevskoye-North Gulayevskoye*	***69,013***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*4,060*		*0,000*		*0,000*
4.2.5	*Alexeevskoye-East Gulayevskoye*	***52,465***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*2,761*		*2,761*		*0,000*
4.3	Platform	**8625,000**	0,000	0,000	0,000	0,000	0,000	159,000		159,000		336,000		192,000		69,000
4.3.1	*North Dolgynskoye*	***2610,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*90,000*		*90,000*		*90,000*		*0,000*		*0,000*
4.3.2	*South Dolgynskoye*	***1794,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*69,000*		*69,000*		*69,000*
4.3.3	*Alexeevskoye*	***2277,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*69,000*		*69,000*		*69,000*		*69,000*		*0,000*
4.3.4	*North Gulyevskoye*	***918,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*54,000*		*0,000*		*0,000*
4.3.5	*East Gulyevskoye*	***1026,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*54,000*		*54,000*		*0,000*
4.4	Tanker fleet	**10363,385**	0,000	0,000	0,000	0,000	0,000	197,505		266,290		382,595		200,265		137,965
4.4.1	*Linear tanker*	***1630,200***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*24,300*		*55,800*		*57,900*		*25,500*		*24,000*
	Number of shippings	***1200***	*0*	*0*	*0*	*0*	*0*	*8*		*40*		*47*		*12*		*7*

	Number of vessels	***58***	*0*	*0*	*0*	*0*	*0*	*1*		*2*		*2*		*1*		*1*
4.4.2	*Shuttle tanker*	***2338,385***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*27,205*		*64,490*		*91,095*		*28,765*		*26,365*
	Number of shippings	***4263***	*0*	*0*	*0*	*0*	*0*	*29*		*142*		*166*		*42*		*22*
	Number of vessels	***77***	*0*	*0*	*0*	*0*	*0*	*1*		*2*		*3*		*1*		*1*
4.4.3	*Supply vessel*	***3996,750***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*91,250*		*91,250*		*146,000*		*91,250*		*54,750*
4.4.4	*Tug boat*	***2398,050***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*54,750*		*54,750*		*87,600*		*54,750*		*32,850*
5	Amortization	**7188,044**	0,000	179,701	179,701	179,701	179,701	179,701		179,701		179,701		179,701		179,701
6	Tax	**74179,746**	0,000	0,000	0,000	0,000	0,000	399,917		2568,230		2899,453		649,966		334,213
7	Cash inflow	**205146,255**	0,000	0,000	0,000	0,000	0,000	1372,392		6861,961		7992,068		2032,895		1053,123
8	Cash outflow	**82362,850**	0,000	2104,701	1601,368	1485,828	1363,412	1125,997		2278,939		2588,136		912,663		564,398
9	Cash flow	**122783,405**	0,000	-2104,701	-1601,368	-1485,828	-1363,412	246,395		4583,022		5403,931		1120,232		488,725
10	Discounted Cash flow	**14354,080**	0,000	-1879,197	-1276,601	-1057,583	-866,473	139,811		1652,684		356,022		23,763		5,252
11	NPV	**14354,080**	**0,000**	**-1879,197**	**-3155,798**	**-4213,381**	**-5079,854**	**-4940,042**		**-107,247**		**12981,836**		**14287,759**		14354,080

Table 48- Estimation of the economic efficiency of the project without the terminal (oil price 60 $/b)

№		Sum, mln. USD	2016	2017	2018	2019	2020	2021		2025		2040		2050		2056
1	Offloaded oil	**296,826**	**0,000**	0,000	0,000	0,000	0,000	1,986		9,929		11,564		2,941		1,524
2	Revenue	**123087,753**	0,000	0,000	0,000	0,000	0,000	823,435		4117,177		4795,241		1219,737		631,874
3	CAPEX	**18187,364**	0,000	1975,000	1375,000	1175,000	1075,000	373,737		373,737		215,273		0,000		0,000
3.1	Terminal	**0,000**	0,000	0,000	0,000	0,000	0,000	0,000		0,000		0,000		0,000		0,000
3.1.1	*TLU*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.1.2	*Other*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.2	Pipeline system	**227,364**	0,000	0,000	0,000	0,000	0,000	0,000		0,000		0,000		0,000		0,000
3.2.1	*North Dolgynskoye-TLU*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.2.2	*South Dolgynskoye-TLU*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.2.3	*Alexeevskoye-TLU*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.2.4	*Alexeevskoye-North Gulayevskoye*	***135,320***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.2.5	*Alexeevskoye-East Gulayevskoye*	***92,044***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.3	Platform	**11600,000**	0,000	1975,000	1375,000	1175,000	1075,000	0,000		0,000		0,000		0,000		0,000
3.3.1	*North Dolgynskoye*	***3150,000***	*0,000*	*1075,000*	*775,000*	*675,000*	*625,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.3.2	*South Dolgynskoye*	***2400,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.3.3	*Alexeevskoye*	***2450,000***	*0,000*	*900,000*	*600,000*	*500,000*	*450,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.3.4	*North Gulyevskoye*	***1800,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.3.5	*East Gulyevskoye*	***1800,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.4	Wells	**6360,000**	0,000	0,000	0,000	0,000	0,000	373,737		373,737		215,273		0,000		0,000
3.4.1	*North Dolgynskoye*	***2840,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*258,182*		*258,182*		*0,000*		*0,000*		*0,000*
3.4.2	*South Dolgynskoye*	***1400,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*127,273*		*0,000*		*0,000*
3.4.3	*Alexeevskoye*	***1040,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*115,556*		*115,556*		*0,000*		*0,000*		*0,000*
3.4.4	*North Gulyevskoye*	***640,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.4.5	*East Gulyevskoye*	***440,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*88,000*		*0,000*		*0,000*
4	OPEX	**19386,588**	0,000	0,000	0,000	0,000	0,000	368,230		437,015		713,566		402,871		209,230
4.1	Terminal	**0,000**	0,000	0,000	0,000	0,000	0,000	0,000		0,000		0,000		0,000		0,000
4.1.1	*TLU*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
4.1.2	*Other*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
4.2	Pipeline system	**121,478**	0,000	0,000	0,000	0,000	0,000	0,000		0,000		6,821		2,761		0,000
4.2.1	*North Dolgynskoye-TLU*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
4.2.2	*South Dolgynskoye-TLU*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
4.2.3	*Alexeevskoye-TLU*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
4.2.4	*Alexeevskoye-North Gulayevskoye*	***69,013***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*4,060*		*0,000*		*0,000*
4.2.5	*Alexeevskoye-East Gulayevskoye*	***52,465***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*2,761*		*2,761*		*0,000*
4.3	Platform	**11312,000**	0,000	0,000	0,000	0,000	0,000	220,000		220,000		430,000		249,000		96,000
4.3.1	*North Dolgynskoye*	***3596,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*124,000*		*124,000*		*124,000*		*0,000*		*0,000*
4.3.2	*South Dolgynskoye*	***2496,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*96,000*		*96,000*		*96,000*
4.3.3	*Alexeevskoye*	***3168,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*96,000*		*96,000*		*96,000*		*96,000*		*0,000*
4.3.4	*North Gulyevskoye*	***969,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*57,000*		*0,000*		*0,000*
4.3.5	*East Gulyevskoye*	***1083,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*57,000*		*57,000*		*0,000*
4.4	Tanker fleet	**7953,110**	0,000	0,000	0,000	0,000	0,000	148,230		217,015		276,745		151,110		113,230
4.4.1	*Linear tanker*	***1630,200***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*24,300*		*55,800*		*57,900*		*25,500*		*24,000*
	Number of shippings	***1200***	*0*	*0*	*0*	*0*	*0*	*8*		*40*		*47*		*12*		*7*

	Number of vessels	***58***	*0*	*0*	*0*	*0*	*0*	*1*		*2*		*2*		*1*		*1*
4.4.2	*Shuttle tanker*	***2983,160***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*50,930*		*88,215*		*91,095*		*52,610*		*52,730*
	Number of shippings	***4298***	*0*	*0*	*0*	*0*	*0*	*29*		*142*		*166*		*43*		*44*
	Number of vessels	***104***	*0*	*0*	*0*	*0*	*0*	*2*		*3*		*3*		*2*		*2*
4.4.3	*Supply vessel*	***3339,750***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*73,000*		*73,000*		*127,750*		*73,000*		*36,500*
4.4.4	*Tug boat*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
5	Amortization	**6587,364**	0,000	164,684	164,684	164,684	164,684	164,684		164,684		164,684		164,684		164,684
6	Tax	**41480,466**	0,000	0,000	0,000	0,000	0,000	182,082		1472,065		1632,670		326,746		169,057
7	Cash inflow	**123087,753**	0,000	0,000	0,000	0,000	0,000	823,435		4117,177		4795,241		1219,737		631,874
8	Cash outflow	**64901,549**	0,000	2139,684	1539,684	1339,684	1239,684	997,693		1711,469		1909,858		730,929		458,443
9	Cash flow	**58186,204**	0,000	-2139,684	-1539,684	-1339,684	-1239,684	-174,257		2405,708		2885,383		488,809		173,431
10	Discounted Cash flow	**4539,215**	0,000	-1910,432	-1227,427	-953,561	-787,842	-98,878		867,522		190,095		10,369		1,864
11	NPV	**4539,215**	**0,000**	**-1910,432**	**-3137,859**	**-4091,420**	**-4879,261**	**-4978,140**		**-2647,134**		**3833,866**		**4513,077**		4539,215

Table 49- Estimation of the economic efficiency of the project without the terminal (oil price 80 $/b)

№		Sum, mln. USD	2016	2017	2018	2019	2020	2021		2025		2040		2050		2056
1	Offloaded oil	**296,826**	**0,000**	0,000	0,000	0,000	0,000	1,986		9,929		11,564		2,941		1,524
2	Revenue	**164117,004**	0,000	0,000	0,000	0,000	0,000	1097,914		5489,569		6393,654		1626,316		842,498
3	CAPEX	**18187,364**	0,000	1975,000	1375,000	1175,000	1075,000	373,737		373,737		215,273		0,000		0,000
3.1	Terminal	**0,000**	0,000	0,000	0,000	0,000	0,000	0,000		0,000		0,000		0,000		0,000
3.1.1	*TLU*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.1.2	*Other*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.2	Pipeline system	**227,364**	0,000	0,000	0,000	0,000	0,000	0,000		0,000		0,000		0,000		0,000
3.2.1	*North Dolgynskoye-TLU*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.2.2	*South Dolgynskoye-TLU*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.2.3	*Alexeevskoye-TLU*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.2.4	*Alexeevskoye-North Gulayevskoye*	***135,320***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.2.5	*Alexeevskoye-East Gulayevskoye*	***92,044***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.3	Platform	**11600,000**	0,000	1975,000	1375,000	1175,000	1075,000	0,000		0,000		0,000		0,000		0,000
3.3.1	*North Dolgynskoye*	***3150,000***	*0,000*	*1075,000*	*775,000*	*675,000*	*625,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.3.2	*South Dolgynskoye*	***2400,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.3.3	*Alexeevskoye*	***2450,000***	*0,000*	*900,000*	*600,000*	*500,000*	*450,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.3.4	*North Gulyevskoye*	***1800,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.3.5	*East Gulyevskoye*	***1800,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.4	Wells	**6360,000**	0,000	0,000	0,000	0,000	0,000	373,737		373,737		215,273		0,000		0,000
3.4.1	*North Dolgynskoye*	***2840,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*258,182*		*258,182*		*0,000*		*0,000*		*0,000*
3.4.2	*South Dolgynskoye*	***1400,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*127,273*		*0,000*		*0,000*
3.4.3	*Alexeevskoye*	***1040,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*115,556*		*115,556*		*0,000*		*0,000*		*0,000*
3.4.4	*North Gulyevskoye*	***640,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.4.5	*East Gulyevskoye*	***440,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*88,000*		*0,000*		*0,000*
4	OPEX	**19386,588**	0,000	0,000	0,000	0,000	0,000	368,230		437,015		713,566		402,871		209,230
4.1	Terminal	**0,000**	0,000	0,000	0,000	0,000	0,000	0,000		0,000		0,000		0,000		0,000
4.1.1	*TLU*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
4.1.2	*Other*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
4.2	Pipeline system	**121,478**	0,000	0,000	0,000	0,000	0,000	0,000		0,000		6,821		2,761		0,000
4.2.1	*North Dolgynskoye-TLU*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
4.2.2	*South Dolgynskoye-TLU*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
4.2.3	*Alexeevskoye-TLU*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
4.2.4	*Alexeevskoye-North Gulayevskoye*	***69,013***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*4,060*		*0,000*		*0,000*
4.2.5	*Alexeevskoye-East Gulayevskoye*	***52,465***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*2,761*		*2,761*		*0,000*
4.3	Platform	**11312,000**	0,000	0,000	0,000	0,000	0,000	220,000		220,000		430,000		249,000		96,000
4.3.1	*North Dolgynskoye*	***3596,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*124,000*		*124,000*		*124,000*		*0,000*		*0,000*
4.3.2	*South Dolgynskoye*	***2496,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*96,000*		*96,000*		*96,000*
4.3.3	*Alexeevskoye*	***3168,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*96,000*		*96,000*		*96,000*		*96,000*		*0,000*
4.3.4	*North Gulyevskoye*	***969,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*57,000*		*0,000*		*0,000*
4.3.5	*East Gulyevskoye*	***1083,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*57,000*		*57,000*		*0,000*
4.4	Tanker fleet	**7953,110**	0,000	0,000	0,000	0,000	0,000	148,230		217,015		276,745		151,110		113,230
4.4.1	*Linear tanker*	***1630,200***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*24,300*		*55,800*		*57,900*		*25,500*		*24,000*
	Number of shippings	***1200***	*0*	*0*	*0*	*0*	*0*	*8*		*40*		*47*		*12*		*7*

	Number of vessels	***58***	*0*	*0*	*0*	*0*	*0*	*1*		*2*		*2*		*1*		*1*
4.4.2	*Shuttle tanker*	***2983,160***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*50,930*		*88,215*		*91,095*		*52,610*		*52,730*
	Number of shippings	***4298***	*0*	*0*	*0*	*0*	*0*	*29*		*142*		*166*		*43*		*44*
	Number of vessels	***104***	*0*	*0*	*0*	*0*	*0*	*2*		*3*		*3*		*2*		*2*
4.4.3	*Supply vessel*	***3339,750***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*73,000*		*73,000*		*127,750*		*73,000*		*36,500*
4.4.4	*Tug boat*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
5	Amortization	**6587,364**	0,000	164,684	164,684	164,684	164,684	164,684		164,684		164,684		164,684		164,684
6	Tax	**57892,166**	0,000	0,000	0,000	0,000	0,000	291,874		2021,022		2272,035		489,378		253,307
7	Cash inflow	**164117,004**	0,000	0,000	0,000	0,000	0,000	1097,914		5489,569		6393,654		1626,316		842,498
8	Cash outflow	**73107,399**	0,000	2139,684	1539,684	1339,684	1239,684	1052,588		1985,947		2229,540		812,244		500,568
9	Cash flow	**91009,604**	0,000	-2139,684	-1539,684	-1339,684	-1239,684	45,326		3503,622		4164,114		814,072		341,930
10	Discounted Cash flow	**9608,020**	0,000	-1910,432	-1227,427	-953,561	-787,842	25,719		1263,441		274,341		17,268		3,675
11	NPV	**9608,020**	**0,000**	**-1910,432**	**-3137,859**	**-4091,420**	**-4879,261**	**-4853,542**		**-1251,395**		**8566,038**		**9560,658**		9608,020

Table 50- Estimation of the economic efficiency of the project without the terminal (oil price 100 $/b)

№		Sum, mln. USD	2016	2017	2018	2019	2020	2021		2025		2040		2050		2056
1	Offloaded oil	**296,826**	**0,000**	0,000	0,000	0,000	0,000	1,986		9,929		11,564		2,941		1,524
2	Revenue	**205146,255**	0,000	0,000	0,000	0,000	0,000	1372,392		6861,961		7992,068		2032,895		1053,123
3	CAPEX	**18187,364**	0,000	1975,000	1375,000	1175,000	1075,000	373,737		373,737		215,273		0,000		0,000
3.1	Terminal	**0,000**	0,000	0,000	0,000	0,000	0,000	0,000		0,000		0,000		0,000		0,000
3.1.1	*TLU*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.1.2	*Other*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.2	Pipeline system	**227,364**	0,000	0,000	0,000	0,000	0,000	0,000		0,000		0,000		0,000		0,000
3.2.1	*North Dolgynskoye-TLU*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.2.2	*South Dolgynskoye-TLU*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.2.3	*Alexeevskoye-TLU*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.2.4	*Alexeevskoye-North Gulayevskoye*	***135,320***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.2.5	*Alexeevskoye-East Gulayevskoye*	***92,044***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.3	Platform	**11600,000**	0,000	1975,000	1375,000	1175,000	1075,000	0,000		0,000		0,000		0,000		0,000
3.3.1	*North Dolgynskoye*	***3150,000***	*0,000*	*1075,000*	*775,000*	*675,000*	*625,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.3.2	*South Dolgynskoye*	***2400,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.3.3	*Alexeevskoye*	***2450,000***	*0,000*	*900,000*	*600,000*	*500,000*	*450,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.3.4	*North Gulyevskoye*	***1800,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.3.5	*East Gulyevskoye*	***1800,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.4	Wells	**6360,000**	0,000	0,000	0,000	0,000	0,000	373,737		373,737		215,273		0,000		0,000
3.4.1	*North Dolgynskoye*	***2840,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*258,182*		*258,182*		*0,000*		*0,000*		*0,000*
3.4.2	*South Dolgynskoye*	***1400,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*127,273*		*0,000*		*0,000*
3.4.3	*Alexeevskoye*	***1040,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*115,556*		*115,556*		*0,000*		*0,000*		*0,000*
3.4.4	*North Gulyevskoye*	***640,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
3.4.5	*East Gulyevskoye*	***440,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*88,000*		*0,000*		*0,000*
4	OPEX	**19386,588**	0,000	0,000	0,000	0,000	0,000	368,230		437,015		713,566		402,871		209,230
4.1	Terminal	**0,000**	0,000	0,000	0,000	0,000	0,000	0,000		0,000		0,000		0,000		0,000
4.1.1	*TLU*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
4.1.2	*Other*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
4.2	Pipeline system	**121,478**	0,000	0,000	0,000	0,000	0,000	0,000		0,000		6,821		2,761		0,000
4.2.1	*North Dolgynskoye-TLU*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
4.2.2	*South Dolgynskoye-TLU*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
4.2.3	*Alexeevskoye-TLU*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
4.2.4	*Alexeevskoye-North Gulayevskoye*	***69,013***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*4,060*		*0,000*		*0,000*
4.2.5	*Alexeevskoye-East Gulayevskoye*	***52,465***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*2,761*		*2,761*		*0,000*
4.3	Platform	**11312,000**	0,000	0,000	0,000	0,000	0,000	220,000		220,000		430,000		249,000		96,000
4.3.1	*North Dolgynskoye*	***3596,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*124,000*		*124,000*		*124,000*		*0,000*		*0,000*
4.3.2	*South Dolgynskoye*	***2496,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*96,000*		*96,000*		*96,000*
4.3.3	*Alexeevskoye*	***3168,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*96,000*		*96,000*		*96,000*		*96,000*		*0,000*
4.3.4	*North Gulyevskoye*	***969,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*57,000*		*0,000*		*0,000*
4.3.5	*East Gulyevskoye*	***1083,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*57,000*		*57,000*		*0,000*
4.4	Tanker fleet	**7953,110**	0,000	0,000	0,000	0,000	0,000	148,230		217,015		276,745		151,110		113,230
4.4.1	*Linear tanker*	***1630,200***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*24,300*		*55,800*		*57,900*		*25,500*		*24,000*
	Number of shippings	***1200***	*0*	*0*	*0*	*0*	*0*	*8*		*40*		*47*		*12*		*7*

	Number of vessels	***58***	*0*	*0*	*0*	*0*	*0*	*1*		*2*		*2*		*1*		*1*
4.4.2	*Shuttle tanker*	***2983,160***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*50,930*		*88,215*		*91,095*		*52,610*		*52,730*
	Number of shippings	***4298***	*0*	*0*	*0*	*0*	*0*	*29*		*142*		*166*		*43*		*44*
	Number of vessels	***104***	*0*	*0*	*0*	*0*	*0*	*2*		*3*		*3*		*2*		*2*
4.4.3	*Supply vessel*	***3339,750***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*73,000*		*73,000*		*127,750*		*73,000*		*36,500*
4.4.4	*Tug boat*	***0,000***	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*		*0,000*		*0,000*		*0,000*		*0,000*
5	Amortization	**6587,364**	0,000	164,684	164,684	164,684	164,684	164,684		164,684		164,684		164,684		164,684
6	Tax	**74303,867**	0,000	0,000	0,000	0,000	0,000	401,665		2569,978		2911,401		652,010		337,557
7	Cash inflow	**205146,255**	0,000	0,000	0,000	0,000	0,000	1372,392		6861,961		7992,068		2032,895		1053,123
8	Cash outflow	**81313,250**	0,000	2139,684	1539,684	1339,684	1239,684	1107,484		2260,426		2549,223		893,560		542,693
9	Cash flow	**123833,005**	0,000	-2139,684	-1539,684	-1339,684	-1239,684	264,908		4601,535		5442,845		1139,335		510,430
10	Discounted Cash flow	**14676,825**	0,000	-1910,432	-1227,427	-953,561	-787,842	150,316		1659,360		358,586		24,168		5,485
11	NPV	**14676,825**	**0,000**	**-1910,432**	**-3137,859**	**-4091,420**	**-4879,261**	**-4728,945**		**144,343**		**13298,211**		**14608,240**		14676,825

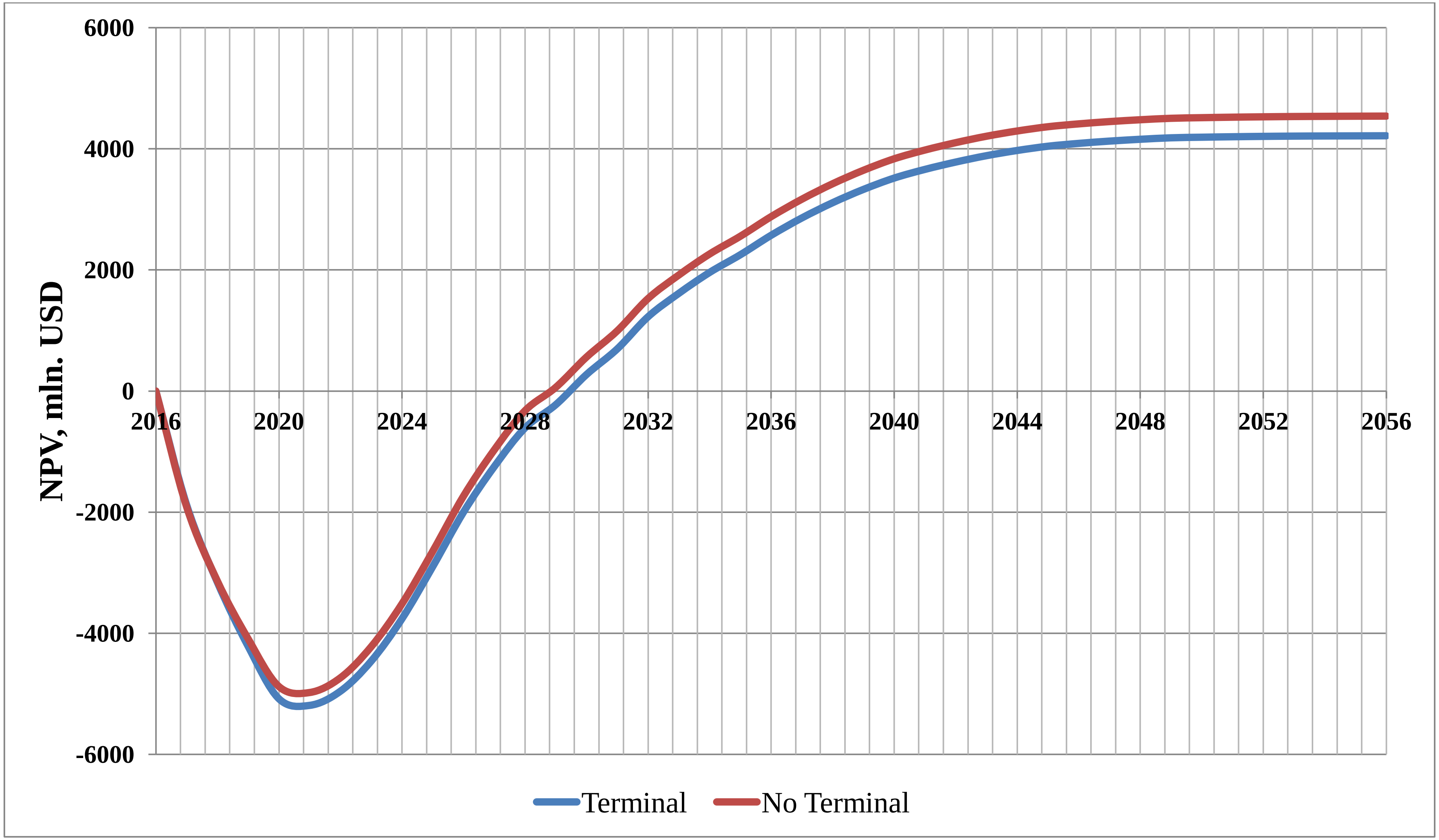

Figure 57 - NPV of the project (oil price 60 $/b)

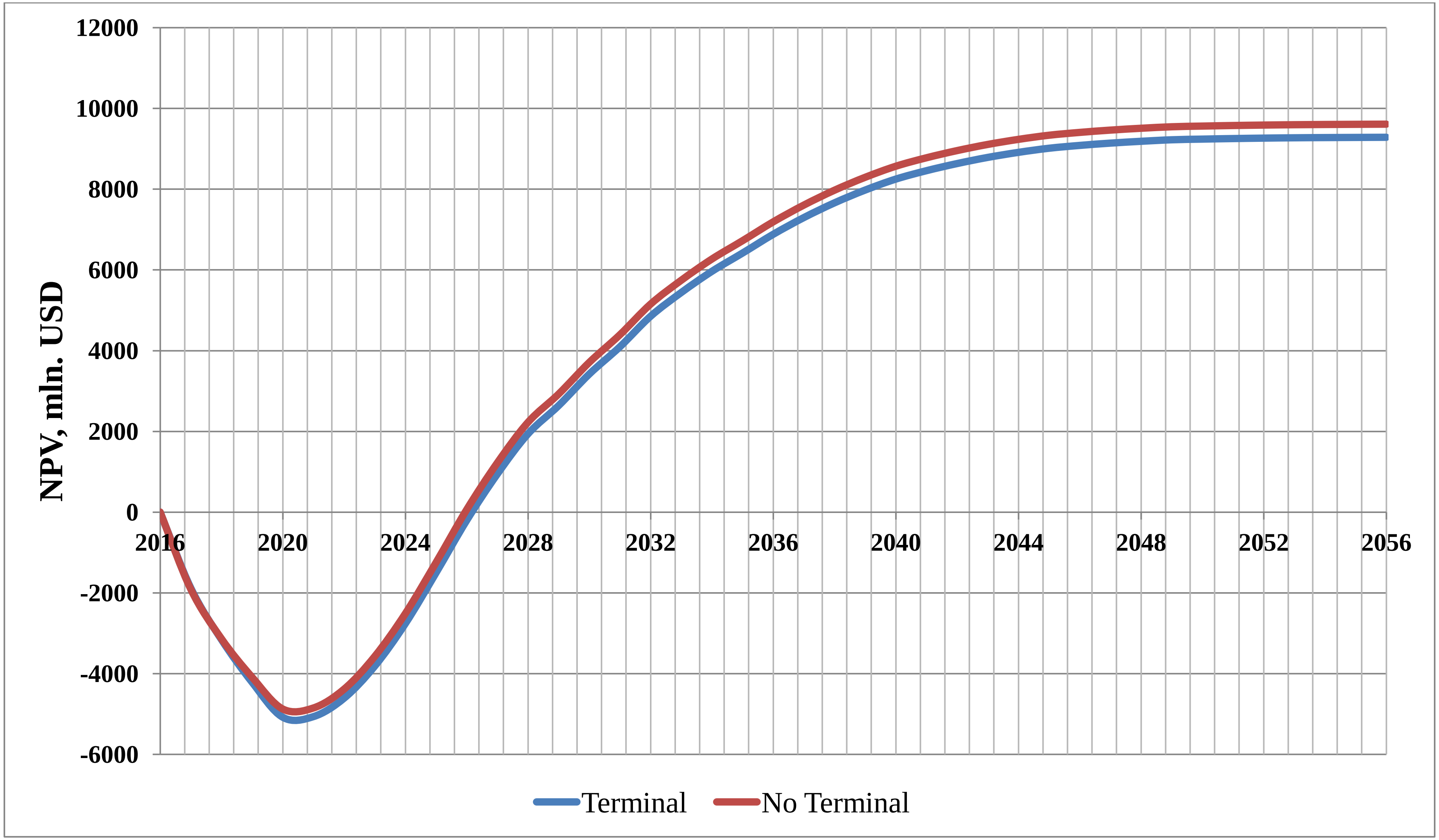

Figure 58 - NPV of the project (oil price 80 $/b)

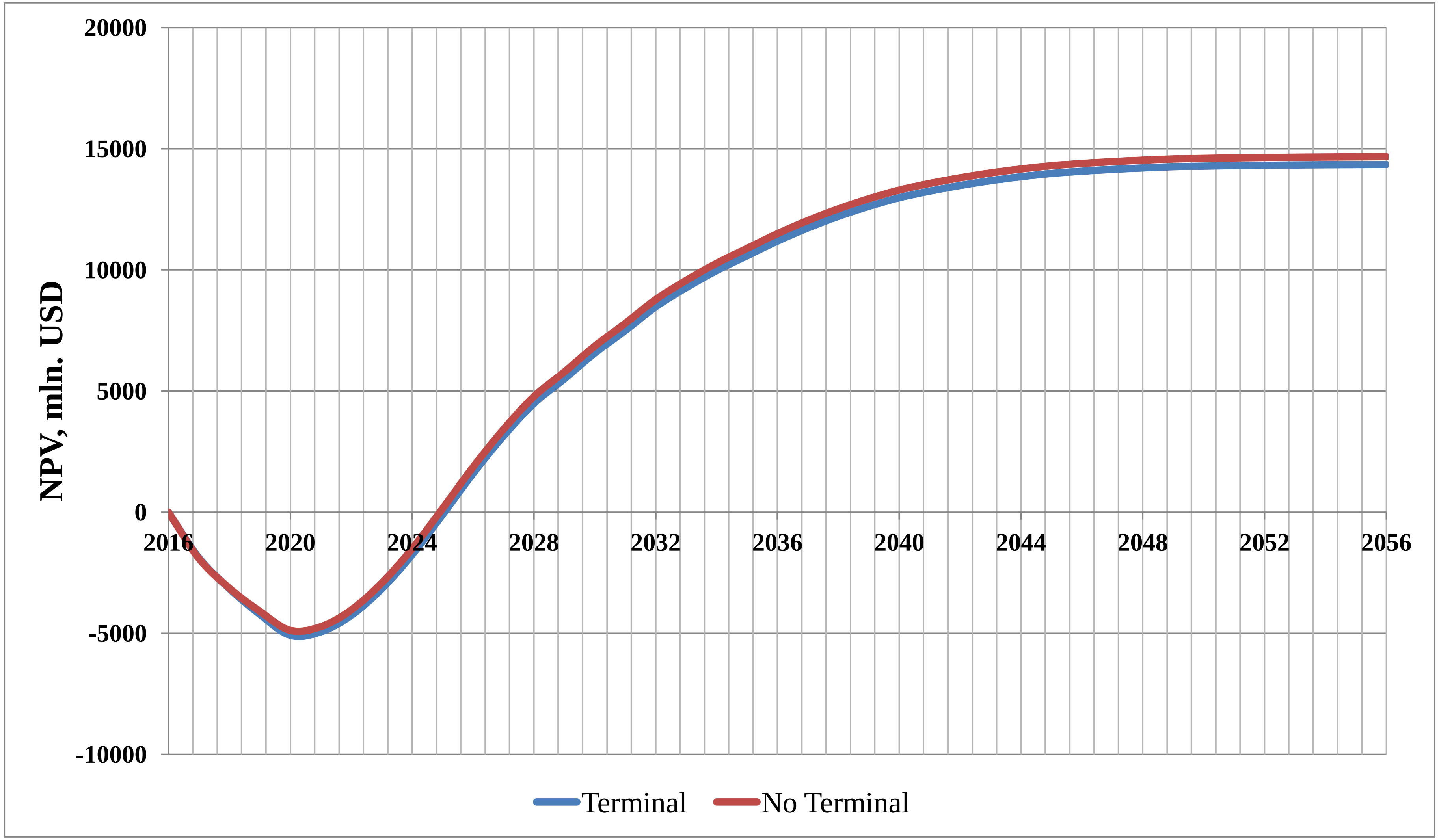

Figure 59 - NPV of the project (oil price 100 $/b)