

MAPPING THE MAIN RISKS FOR OFFSHORE OPERATIONS IN THE PECHORA SEA

SLAVKO NESIC¹, KONSTANTIN PIVOVAROV²,
VLADA STRELETSKAYA² & ANATOLY ZOLOTUKHIN^{2,3,4}

¹University of Belgrade, Serbia

²Gubkin Russian State University (NRU) of Oil and Gas, Gubkin University, Russia

³Northern Arctic Federal University, Arkhangelsk, Russia

⁴Stavanger University, Norway

ABSTRACT

The development of Prirazlomnoye oil field in the Pechora Sea was the first Russian oil and gas project in the Arctic. The environmental conditions are primarily function of water dynamics and ice cover for greatest part of the year. The marine environment in the Pechora Sea is characterized with many species including birds, fishes, benthic fauna and marine mammals. The food chains in the Arctic ecosystem are simple and very vulnerable to contamination. If pollutants harm one species, the whole food chain will be affected and can result in reducing a population of the specific species. In this paper, conceptual approach for environmental risk mapping is presented. The main pollution sources in the Pechora Sea were identified associated with possible risk and presented in the risk matrix. Qualitative analysis of possible risk events for water, air and soil pollution were analyzed and represented in appropriate bow-tie charts. Dangerous points in the Pechora Sea are mapped and their risk distribution are presented.

Keywords: Pechora Sea, offshore operations, risk mapping, marine environment, Arctic.

1 INTRODUCTION

Due to huge hydrocarbon reserves but at the same time being sensitive to anthropogenic impact, the uniqueness of the Arctic offshore fields is acknowledged all over the world. Despite high technological and financial risks, which call the profitability of Arctic projects into a question, the interest for the development of these regions is increasing. Currently, an intensive exploration process is going in Alaska (USA), offshore Greenland, in Norwegian and Barents (both Russia and Norway) seas and in Pechora Sea as well. Hydrocarbon resources are important to the Arctic countries and regions as “sources of income and resource rent” [1] and are the major economic driver in areas where activity is currently taking place [2]. But the importance of the field development in this area goes beyond the regional and national economies. Arctic can provide a new qualitative leap in the oil and gas industry through the adaptation to harsh operating conditions, increasing depth of drilling and a strong need for countries and companies to cooperate. Nowadays one of the most important area of the petroleum production in the Arctic is the Pechora Sea - an environmentally sensitive area, where petroleum industry is facing harsh weather conditions. Therefore, it is important to develop action plan and applications to support environmental protection, pollution prevention, as well as the tools to decrease probability and consequences of oil spills, such as environmental program, the environmental accounting system, environmental monitoring and environmental risk analysis. This paper describes environmental, technological and qualitative analysis of the main risks during offshore field development operations in the Pechora Sea.



2 OFFSHORE OPERATIONS IN THE PECHORA SEA

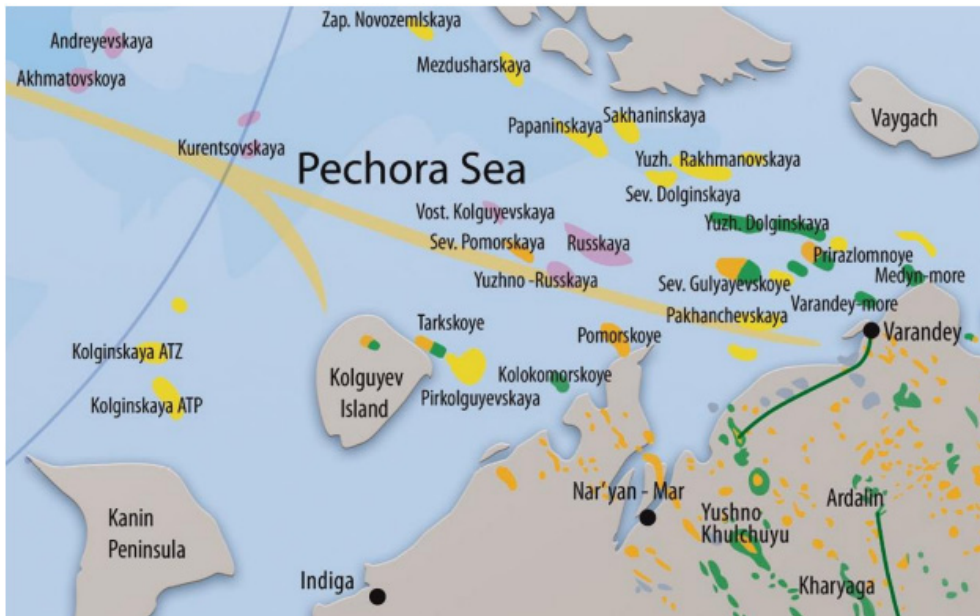


Figure 1: The structures and oilfields location in Pechora Sea.

The first seismic surveying in the Barents Sea began in the 1970s. The Pechora Sea is the southeastern part of the Barents Sea and total area is more than 81000 square kilometers, water volume is 4.38 thousand cubic meters, average depth is 6 m, and maximum depth is 210m, where several oil and gas bearing structures were discovered. About 60 wells have been drilled in the area with very high discovery rate. The Pechora Sea has been claimed as one of the most perspective oil and gas region of the Russian Arctic. Six oil and gas fields have been discovered, i.e. Prirazlomnoye, Varandey-More, Medynskoye-More 2, Dolginskoye, North-Gulyaevskoe, Pomorskoye [3], [4].

The structures and oilfields location in Pechora Sea are shown in Fig. 1 [5]. The development of the Prirazlomnoye oil field was the first Russian oil and gas project in the Arctic. Oil production began in December 2013, in April 2014 Gazprom has shipped the first batch of the Arctic crude oil (ARCO) volume of 70 000 tones, and in November 2015 was extracted the millionth ton of the ARCO. From 1989 till now 32 wells were drilled, 19 production wells operated with electrical submersible pumps (ESP), 12 injection wells and one disposal well. The whole system involves new technologies in completion, stimulation and control of the wells to increase the efficiency of production [6].

3 PECHORA SEA MARINE ENVIRONMENT

The most representative biological species of the Pechora Sea are birds, especially the water birds. There are 130 species, of which 50% are water birds (Gavrilo et al., 2000). According to the surveys, the total number of the birds can reach 5.5 million, including 33.5 million ducks, 450–550 thousand of geese and 3545 thousand swans [7]. The most common birds in

the Pechora Sea are: Eiders, Scoters, Long-tailed ducks, Sawbills, Unidentified dabbling ducks, Barnacle geese, Brent geese, Divers, Fulmars, Waders, Skuas, Common gulls, Lesser back-backed gulls, Glaucous gulls, Kittiwakes, Arctic terns, Guillemots, Raptors and owls, Bewick's Swan, Whooper Swan, Common Eider, King Eider, Steller's Eider, Long-tailed Duck, Northern Fulmar, Glaucous Gull, Black-legged Kittiwake, Ivory Gull, Little Auk, Brünnich's Guillemot, Black Guillemot [8]. The marine fish resources of the Pechora Sea include about 70 species [9], [10]. In addition, a lot of species migrate from the Kara Sea and Barents Sea to spend a winter under the ice of the Pechora Sea [11]. The most common fish species in the Pechora Sea are herring, navaga, rainbow smelt, Arctic cod, capelin, American plaice and Arctic flounder. The most common non-commercial fish species are slender eel blenny and Arctic staghorn sculpin. Non-commercial fish species as gobies and species from Liparidae and Zoarcidae increase a biodiversity in the Pechora Sea [12]. Marine mammals in the Pechora Sea include walruses, polar bears, seals and white whales. Walruses are mostly located in the shores and Kolguyev Island.

4 POSSIBLE POLLUTANTS FROM THE OFFSHORE OPERATIONS IN THE PECHORA SEA

In offshore drilling, the largest wastes disposed from platforms are drilling fluids and cuttings. Lighter fluids will stay in the water column while the heavier components tend to sink on the bottom [13]. Drilling fluids and cuttings are very complex mixture of liquid fluids (water, oil or other organic fluids), clays (barite), viscosifiers (polymers), emulsifiers (alkyl acrylate sulphonate, polyethylene oxide), pH control agents, defloculants, shale control additives and rock particles. If that mixture is disposed to the sea, it can have a negative effect on benthic organisms [14], [15]. Disposed drilling cuttings in the North Sea have a total oil content between 10,000–600,000 mg/l [16]–[18]. Many studies show that biological degradation of hydrocarbon compounds is very slow and exist in just few millimeters and anaerobic degradation exists in 20–50 cm from the pile surface. Deeper parts of the piles in most cases are still unchanged are very resistant to chemical change [17]–[19]. Every disturbance of accumulated piles can cause erosion and uncover deep layers which can lead to leakage of possible contaminants [17].

Produced water is the largest byproduct generated during the oil and gas production and the main source of pollution at offshore platforms. The presence of water is identified in every stage of oilfield life, from the exploration, development, production and abandonment [20], [21]. Produced water represents the largest waste volume in oil and gas industry. The water-oil ratio (WOR) is increasing during the life cycle of the oilfield and the current global ratio is 3:1. In offshore facilities, the WOR is significantly higher [22]. Generally, the most of the onshore produced water treatment facilities are designed to remove suspended solids and dispersed oil compound to avoid disposal formation plugging. In offshore facilities, the common practice is discharging the treated produced water into the sea. To meet discharge quality and avoid toxicity effects on the marine environment, the content of hydrocarbons in producing water must be significantly lower [23].

Oil spills in the Arctic region are most dangerous types of pollution and it can have global consequences. Many reports and projects are prepared for spill response and management in the Arctic conditions [24]–[26]. There is a limited knowledge in environmental effects of oil spills in the Arctic zone mostly because there was not any large oil spill in this area [27], [28]. Problems with the oil spill detection must be overcome by using modern detection tools – sonars adapted for low visibility conditions [29]. Potential dangerous zones for the oil

spills are Varandey terminal, Prirazlomnoye offshore platform and transportation routes. There are three transportation routes in the Pechora Sea called South, Central and North routes. Every route is passing through zones with different distributions of birds, fishes and marine mammals and present potential place for oil spills. These three routes form two separated surfaces in the Pechora and the Barents seas, which can have a negative influence on marine environment.

Ice breaking can have adverse effect on whales, mammals and fishes. Recent studies show that the whales can hear ice breaking from 35–78 km and tend to avoid this area for 1–2 days [30]–[32] and walruses can avoid ice breaking from 230 m to more than 1 km [33], [34]. Movement of the animals caused by ice breaking requires additional energy consumption and displacement, which can result in competition and possible predation. Marine mammals are very sensitive to anthropogenic noise because sound is present in every part of their lives, from searching for food, navigation, reproduction and detection of predators or hazards [36].

Seabirds can be attracted by offshore facilities and icebreakers and exposed to contaminants especially during spawning period. Arctic routes are passing through several zones with high bird's population. Vulnerable bird species are gulls and sea ducks because their population is distributed on the shipping routes.

Due to low nutrition potential for marine life, every negative environmental impact such as oil spills, produced water discharges and ice breaking during the transport can affect food chains. Due to shallow waters, spilled oil or produced water discharge can reach the sea bottom, contaminate benthic fauna and accumulate in the sediments.

Walruses and seals are mostly located in the shores and Kolguyev Island. Polar bears are located north from the Prirazlomnoye platform and belugas in the middle of the Pechora Sea. They are distributed on the main Arctic routes except the North one.

5 QUALITATIVE ANALYSIS OF the MAIN RISKS DURING OFFSHORE OPERATIONS

In this section, a qualitative analysis of the main risks in offshore operations is performed. Such tools as risk matrix, bow-tie diagram, development of qualitative acceptance criteria and analysis of pollution risk sources were used here.

5.1 Risk matrix

The risk value in this study is evaluated as follows:

$$\text{Risk value} = \text{Probability rating} \times \text{Impact score}$$

A typical example of the risk matrix is shown in Table1.

Qualitative acceptance criteria used in this study are defined as follows:

- 1–4 = Low risk (acceptable risk)
- 5–9 = Medium risk (reasonably practicable)
- 10–16 = High risk (not acceptable risk)
- 20–25 = Very high risk (not acceptable risk)



Table 1: Risk matrix example.

Environmental impact		Probability rating (likelihood)				
		Very unlikely	Unlikely	Possible	Likely	Very likely
		1	2	3	4	5
Negligible	1	1 (Low)	2 (Low)	3 (Low)	4 (Low)	5 (Medium)
Slight	2	2 (Low)	4 (Low)	6 (Medium)	8 (Medium)	10 (High)
Moderate	3	3 (Low)	6 (Medium)	9 (Medium)	12 (High)	15 (High)
High	4	4 (Low)	8 (Medium)	12 (High)	16 (High)	20 (Very High)
Very high	5	5 (Medium)	10 (High)	15 (High)	20 (Very High)	25 (Very High)

Possible risk events for water pollution considered in this study are:

1. Platform wellhead leaking
2. Drilling cuttings discharge
3. Collapse of the riser or coiled-tubing
4. Deck drainage
5. Collapse of subsea oil pipeline
6. Sanitary and domestic wastes
7. Storage tanks leaking
8. Produced water discharge
9. Platform offloading leaking
10. Produced sand
11. Tanker (vessel) leaking
12. Fuel spill
13. Tanker (vessel) collision
14. Fracturing fluids spills
15. Terminal leaking
16. Oil spill
17. Terminal pipeline damage
18. Chemical discharges during construction
19. Drilling muds discharge
20. Damage of subsea pipelines by falling objects (anchors) and icebergs

Possible risk events for air pollution considered in this study are:

1. Natural gas flaring
2. Aerosol particles of the unburned fuel
3. Turbine (engine) exhaust
4. LNG tanker damage
5. Evaporation or venting of hydrocarbons during different operations
6. Damage of subsea pipelines by falling objects (anchors) and icebergs
7. Fuel exhaust (chopper, tanker, vessels)

Risk matrix for considered risks of water pollution is shown in Table 2.

Table 2: Risk matrix for considered risks of water pollution.

Environmental impact		Probability rating (likelihood)				
		Very unlikely	Unlikely	Possible	Likely	Very likely
		1	2	3	4	5
Negligible	1				13	12
Slight	2				19	
Moderate	3			10, 11, 15		
High	4	4, 5, 6, 8		1, 14, 16, 17		
Very high	5	7, 9	2, 3	18, 20		

Risk matrix for considered risks of air pollution is show in Table 3.

Table 3: Risk matrix for considered risks of air pollution

Environmental impact		Probability rating (likelihood)				
		Very unlikely	Unlikely	Possible	Likely	Very likely
		1	2	3	4	5
Negligible	1				3	2
Slight	2			5	4	1
Moderate	3					
High	4			6		
Very high	5		7			

Possible risk events for soil pollution considered in this study are:

1. Platform wellhead leaking
2. Terminal pipeline damage
3. Collapse of the riser or coiled-tubing
4. Drilling cuttings discharge
5. Collapse of subsea oil pipeline
6. Produced water discharge
7. Storage tanks leaking
8. Fuel spill
9. Platform offloading leaking
10. Fracturing fluids spills
11. Tanker (vessel) leaking

12. Oil spill
13. Tanker (vessel) collision
14. Damage of subsea pipelines by falling objects (anchors) and icebergs
15. Terminal leaking
16. Terminal pipeline damage

Risk matrix for considered risks of soil pollution is show in table 4. Cumulative risk events for water, air and soil pollution are presented in table 5. As follows from table 5, most of the classified risk events (17), belong to the intersecting cells with High/Very high environmental impact rows and Unlikely/Possible probability. columns, of which nearly half of the events (8), belong to the cell “High environmental impact+Possible probability”.

Table 4: Risk matrix for considered risks of soil pollution.

Environmental impact		Probability rating (likelihood)				
		Very unlikely	Unlikely	Possible	Likely	Very likely
		1	2	3	4	5
Negligible	1					
Slight	2					
Moderate	3		5, 6, 8			
High	4	4	1, 13	10, 11, 12		
Very high	5	2, 3, 7, 9		14, 15		

Table 5: A cumulative risk events for water, air and soil pollution.

Environmental impact		Probability rating (likelihood)				
		Very unlikely	Unlikely	Possible	Likely	Very likely
		1	2	3	4	5
Negligible	1				2	2
Slight	2			1	2	1
Moderate	3		3	3		
High	4	5	2	8		
Very high	5	6	3	4		

5.2 Bow-tie diagrams for water, air and soil pollution

Bow-tie diagrams present a simple and useful tool for displaying causal relationship between potential causes, methods of prevention, methods of mitigation and consequences of potential incident scenarios. In this article, bow-tie diagrams for water, air and soil pollution are presented.

Bow-tie diagram for water pollution in oil platform is shown on Fig. 2.

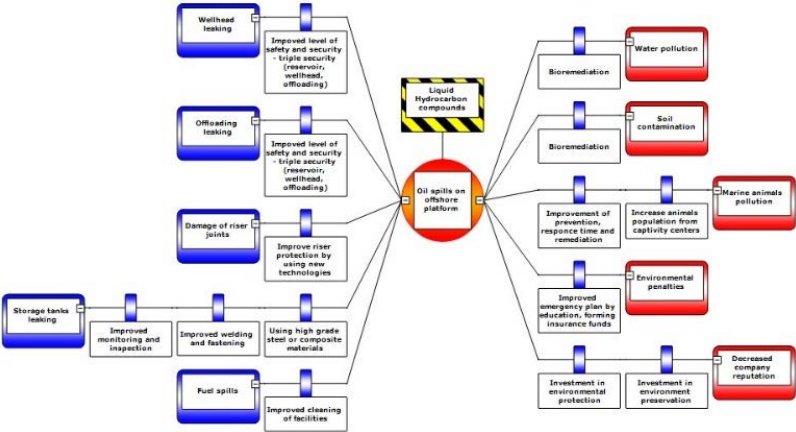


Figure 2: Bow-tie diagram for water pollution in the oil platform.

Bow-tie diagram for air pollution is shown on Fig. 3.

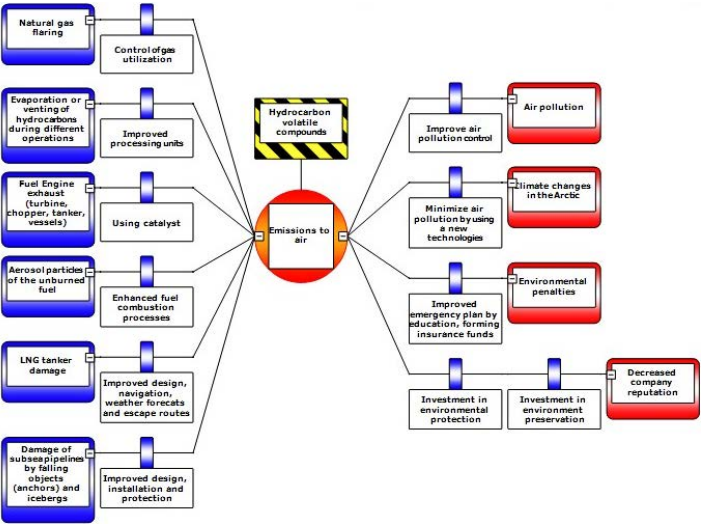


Figure 3: Bow-tie diagram for air pollution.

6 MAPPING RISK OF POTENTIAL POLLUTION IN THE PECHORA SEA

For the purpose of potential pollution's mapping the Pechora Sea was divided into several zones. Those areas were studied and assessed by using multi-criterion approach (water, soil and air pollution risks). The methodology of mapping was based on the fuzzy logic theory [37] and its implementation for the technological accessibility assessment of the Arctic seas [38]. Potential pollution risk mapping was made here for the case of the Prirazlomnoye oil field development and the routes of oil transportation from this field. For simplicity of the analysis other fields in the Pechora Sea were not considered in this study since their addition would change the map and make it more complex. As follows from this Figure, the oil field development and the oil transport may affect quite a number of zones in the Pechora Sea, and their impact may spread on the entire area of the sea. Analysis of the risk caused by air, water and soil pollution was done for every zone of the sea. Using fuzzy logic and methodology developed in [38], we split the whole range of impact into eight different classes, where the 1st class has the lowest and the 8th – the highest risk factor (see Fig. 4).

By combining air, water and soil types of pollution risks using fuzzy logic it is possible to build one aggregate pollution risk map shown in Fig. 5.

As follows from the figure, the highest risk factor is near the Prirazlomnoye oil field and the transportation routes. It is important to note here that this map illustrates only risk associated with air, water and oil pollution and does not account for the weather and ice conditions.

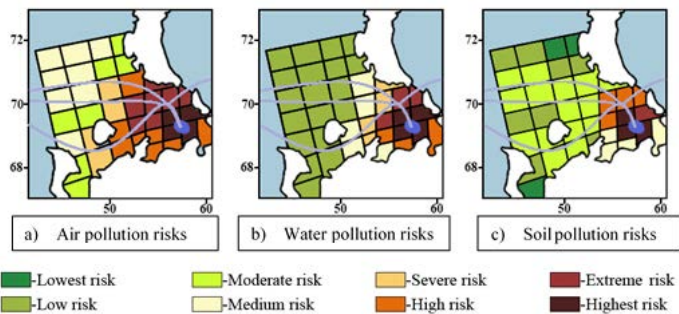


Figure 4: Air, water and pollution risks in the Pechora Sea.

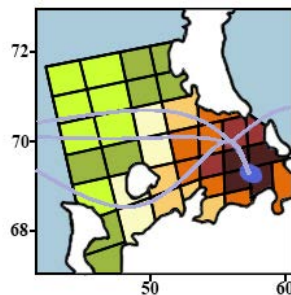


Figure 5: Map of pollution risk caused by oil production from the Prirazlomnoye oil field and the oil transportation routes.

7 CONCLUSIONS

Petroleum production in the Arctic is facing harsh weather conditions and heavy cost compared with other petroleum provinces. Serious threats compose Arctic ecosystem vulnerability, such as risk of oil spills and difficulties in spill response in ice-infested waters. The challenges will be even higher in the future, as production is expected to move further offshore and to more remote areas, where industry faces the lack of infrastructure, rescue services and transportation options.

Minimization of different kinds of the environmental impact can be achieved by reducing emission to atmospheric air as well as discharges to water and waste disposed into the sea. It is important to note that treatment of produced water takes special place, not only due to ecological reasons, but also because of being a major component of the oil and gas production cost.

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