Engineering environmental site investigations in the oilfields of the Western Urals: peculiarities and problems

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Abstract

Russian legislation requires companies to carry out environmental site investigations in all cases of civil or industrial projects. The investor or owner is the responsible party in the case of any pollution. Information on air, water and soils quality is the main result of environmental site investigations.

We carried out about 60 environmental site investigations of oilfields in the Western Urals. Environmental site investigations usually include field survey, biodiversity inventory, sampling of air, water and soils, radio-activity and noise measuring, analysis of monitoring data, socio-economic data analysis. We have never detected cases of air pollution, noise or radiation more than that which is allowable. Most common problems include contamination of surface water at the stage of borehole drilling, and contamination of subsurface water at a late stage of oilfield exploitation. Soil and groundwater salt pollution takes place at many local sites. Remains of soil damage and pollution incidents occur at many local sites. Most incidents took place in 1970-80s, when exploitation started. Pipeline accident rates depend on relief and surface deposits and are also related to oil prices.

Keywords: oilfields, environmental site investigations, air pollution, surface water, groundwater, soils.

1 Specific regional features

The regional specific features of the Western Urals are:

- prevalence of hard mineable reserves of extra-heavy crude oil contained in small oilfields of complex structure;

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- the increased content of nitrogen (in the range of 33 to 88%) in the composition of oil-gas, which makes its utilization very difficult;
- proximity to the economical centres of the country and relatively good provision with infrastructure objects.

The above-listed features lead to the greater period of execution of works as to the neighbouring regions, lower rates of oilfield exploitation and the depletion factor 0,41, which is relatively low for the European part of Russia [1]. In a relatively favourable economic situation, difficult conditions of oil production provided a faster implementation of advanced oil recovery techniques including lateral drilling, thermal and thermal-steam formation treatment, pumping the polymer solutions, etc., compared with other regions [2]. The Western Urals oil industry has been developing with the positive and negative experience of oil exploitation in the neighbouring regions. In 1970-80-s, similar to many other regions, major fields in the Western Urals were developed without any environmental impact statement. During the exploitation multiple oil spills and oilfield salt water spills took place, many soils were destroyed due to unsystematic movements of heavy trucks and heavy equipment, etc. Thus, when studying the routes in the Chutyrsko-Kiengopskoye oilfield we did not find typical soils with sustained genetic horizons on the territories free of forests and swamps. Instead there were homogeneous loamy masses under the fresh topsoil. We found numerous traces of oil spills that occurred in the initial period of developing the oilfield, which were in the form of a viscous asphalt-like mass on the ground surface, bitumen veins in the soil and sediments. Sturman *et al.* [3], who explored alluvium of gullies on the territory of the same oil-field, found mineral oil in 40 sites out of 150 (26.6%).

In the initial period the oilfields in Western Urals were developed by drilling numerous single wells, which considerably increased the occupied areas and the extent of communications and made the wells' servicing difficult. Bringing oil wells into service when hard roads were absent turned out to be a particularly negative practice. As a result, in the period of low prices for oil raw stock and all the relevant economic problems in 1980-90s, hundreds of oil wells failed and were not serviced over a long period of time. It resulted in the appearance of uncontrollable processes in the subsoil including interformational flow, hydrogen-sulphides contamination of the ground waters, multiple breaks in pipe ducts. In 1970-80s, drilling cuttings contaminated with oil and salts were stored in earth storages which did not have water isolation. It resulted in the formation of numerous local areas of groundwater pollution.

No large areas with groundwater or even surface water pollution or salinisation appeared in Udmurtia (Western Urals), compared to the neighbouring regions with their much greater volumes of oil production, for example, Bashkortostan and Tatarstan [4, 5]. As at the end of 1990-s and at the beginning of 2000-s, the sites with groundwater and surface water pollution, where maximum allowable concentration (MPC) of oil hydrocarbons and general salinity was above-critical, took up 1-3% of the area of the largest oilfields. Sites where the chlorides' natural background was above-critical occupied up to 20% of the major fields' area. Thus, after 30-year production activity at the Vyatka area of Arlanskoye oilfield, the concentration levels of contaminants in groundwaters of 98.8% of oilfield area were not above the maximum allowable concentration, and in 78.8% of the area their concentration was within the range of background values [6]. The case is approximately the same at the Chutyrsko-Kiengopskoye oilfield.

2 Specific features of execution phase and the scope of work

The specific features of environmental site investigations for oilfields in the Western Urals arise from the above-listed specific regional features. The areas under investigations are small and related to oil well drilling or field well construction (from single wells to the clusters of 20-25 wells), as well as to the pipeline construction or reconstruction and to other field facilities with the length of the linear pipeline portion up to 40 km. Almost all our investigation was carried out in operating oilfields. Oil-production enterprises have their own monitoring systems, environmental regulation records, plans for environmental protection and anti-damage measures. Over the period 2008-2011 we carried out environmental site investigations for 60 projects.

We have been carrying out environmental site investigations as an independent type of work since 2008, after changes in the law [7] come into force. Previously to that, over a period of 10 years, we carried out multiple reconnaissance investigations of oil production facilities in connection with environmental studies of projects.

The scope of work for environmental site investigations is specified according to the Code of Regulations (CR) 11-102-97 [8]. The analysis of published and archival data is rather efficient in Western Urals. The description of climatic, geological and groundwater conditions was obtained from archival and published materials. The value of aerospace photo interpretation under the conditions of anthropogenic landscapes of taiga zone, are rather limited. In reality, it helps to assess the state of cuttings, forest roads, ponds and dams, as well as to show up ground damage areas.

Route engineering environmental observations were made with the assistance of various specialists (geologist, geoecologist, soil scientist, geographers and biologists specializing in various areas) to obtain quantitative and qualitative measures and characteristics of state for all components of the environmental (relief and entrails, surface and ground waters, soils, vegetation, fauna, man’s impact) and ecosystems as a whole. Route networks are usually separate for each specialist and all the routes are made on the basis of specific tasks.

Mine workings which are used to obtain environmental information in prospecting for oilfield facilities, are of the type of prospect holes and soil cross-sections. To obtain environmental hydrogeological description, well-drilling is combined with geological survey. We undertook special well-drilling for environmental engineering surveys when we had to deal with significant anthropogenic deposits in the industrial areas of enterprises, not in oilfields.

Environmental surveys were often combined with hydro-meteorological ones. The surveys involve gathering and analyzing of the relevant archival and published data, making observations on the environmental consequences of the hazardous natural processes, including channel processes, as well as hydrological observations. Hydrological measurements are part of the surveys too.

There are different sampling strategies of the different analyses. Air sampling points are usually located on the boundary of industrial areas on the side of populated areas or (under the survey) alee at the moment of measurement. The samples of surface waters are taken above and below the section line of probable contamination caused by industrial objects. We took soil samples for various kinds of analyses in lowlands, outside of well dikings and other hazardous objects, or inside of well dikings. Sampling points for radiation survey were selected on industrial sites.

3 The results of oilfield environmental assessment

In general, according to both the survey's materials and monitoring data, the environmental survey results meet the existing standards for oilfield exploitation. Atmospheric emission is the greatest in the beginning of oilfield exploitation, at the earlier stage in the oilfield cycle, when the formation pressures and the initial reservoir free gas volume are great. The additional source of pollution in this period is emissions from drilling devices, especially from diesel plants that are used in the oil drilling, and runoff from drill sites or temporary roads. At the next stage of oilfield life cycle, when the stable oil recovery is realized, pollution is less and the main oil pollution sources are gas dissipation chimneys, oil tanks equipment, heaters. At the final stages of oilfield life cycle the most problems occur in connection with the lost circulation of ground water, due to which depth saline water raises and salinisation of the zone of active water cycle occurs. Nature conservation regulations' infringement and emergences can greatly increase the grade of pollution of all environment components at any stage.

3.1 Atmospheric

Typical concentrations of contaminants for single oilfields in Western Urals are represented in Table 1. The concentrations of contaminants are not high. Izhevskoye oilfield which is notable for higher concentrations of contaminants, and particularly of nitrogen dioxide, is located not far from Izhevsk and main roads, and the results confirm that the quota of oilfields into the air pollution is not predominant.

We have measured only 7 oilfield facilities in 6 oilfields so far. The measurements of the downwind concentrations were carried out on the boundaries of oilfield facilities. Table 2 shows the results of the measurements. At the distance of 100 meters away from oilfield facilities and downwind of them, the concentrations of the contaminants shown in table 2 were below the threshold of detection. Therefore, the concentrations of contaminants in the atmosphere air on the boundaries of oilfield facilities were observed to be above the threshold of detection only in cases there were additional sources of pollution such as the operating building and transportation equipment, gas dissipation chimneys, flares or used stripped pipes.

Table 1: Average and maximum concentrations of contaminants in the monitoring data of 2009-2010 for oilfields in the Western Urals, mg/m^3.

Oilfields		SO_2	CO	NO_2	NO	H_2S	Hydro-carbons C_1-C_{10}
Mishkinskoye	average.	0,005	1,2	0,008	<0,001	<0,001	1,84
	maximum	0,012	3	0,073	0,006	0,005	4,54
Chutyrskoye	average.	0,005	1,2	0,008	<0,001	<0,001	1,99
	maximum	0,026	4	0,028	0,013	0,005	4,6
Izhevskoye	average.	0,006	1,14	0,046	<0,001	<0,001	2,28
	maximum	0,03	3	0,09	0,001	0,002	4,46
Karsovaiskoye	average.	0,003	0,42	0,006	<0,001	<0,001	1,39
	maximum	0,009	2	0,019	0,002	0,001	4,36
*Allowable concentrations**	*average.*	*0,05*	*3*	*0,04*	*0,06*	*0,08*	*50*
	maximum.	*0,5*	*5*	*0,2*	*0,4*		

*Allowable concentrations according to Russian regulations

3.2 Surface waters

In the study by Gagarina [6], surface water monitoring carried out in the areas of oilfields showed that at the earlier stage in the oilfield cycle the highest but unsteady rates of oil hydrocarbons concentrations are observed. The frequency of the excess for maximum allowable concentrations (MAC) is in the range of 11 to 26%. The increased content of oil hydrocarbons in the period during which rivers are not covered with ice (especially during spring snowmelt) indicates that there is oil washing-off from water collections. The significant pollution factor at this stage is surface runoff from drill and construction areas.

At the stage of realizing the stable recovery when main field facilities are constructed and there is no loss of ground water circulation a decrease of oil hydrocarbons contamination is observed. Usually, at this period there is no difference between background data and control points' data.

At the final stages of oilfield life cycle, significant increases in general salinity, chloride content (rises above the MAC level in 80-100%) and oil hydrocarbons content (rises above MAC level in the range of 11 to 29%) due to

Table 2: The results of the measurements of the concentrations of contaminants.

Oilfields, oilfield facilities	Concentrations above the threshold of detection	The conditions of measurements
Zotovskoye, oil loading station, at the entrance	NO_2 0,041 mg/m^3	At the distance of 40 m away there was an oil tank truck with its engine running. At the distance of 100 m away from the oil loading station NO_2 was below the threshold of detection (0,02 mg/m^3).
Potapovskoye, well 350, at the diking	Benzene 0,614 mg/m^3 (2,05 times more allowable concentration)	At the distance of 30 m away repair operations with pipes' stripping were carried out, the pipes had been in service and temporarily served as a local source of oil hydrocarbons release. At 100 m away from the diking, benzene was below the threshold of detection (0,05 mg/m^3)
Severo-Nikolskoye, fuel oil heater and well cluster 2, at the diking	NO_2 0,026 mg/m^3	At 100 m away there was a flare. At 100 m away from the diking NO_2 was below the threshold of detection (0,02 mg/m^3).
Severo-Nikolskoye, well cluster 1, the dike and at the distance of 100 m away	Absent	4 pumping machines, no other sources of pollution
Okunyevskoye, well 1474, at the diking	Absent	1 pumping machine, no other sources of pollution
Gorlinskoye, well cluster 4a, at the diking	NO_2 0,02 mg/m^3	3 pumping machines and repair operations with the use of building equipment

salinisation of ground water, pipeline wear and equipment wear occur. Another factor influencing the ground water state is the regularity of control and repair works carried out in oilfields.

The chemical analyses of samples extracted from the rivers during the engineering environmental investigations confirm that the quota of the anthropogenic factor into the formation of chemical water composition is insignificant as compared to the natural factor. However, it should be noted that surface water samples were collected only in the oilfields, the exploitations of which were at the stages of increasing and stable recovery, and (once) in the prospect area, in those there were no oilfield facilities. The anthropogenic quota of the water quality at the above stages of oilfield exploitation appeared, mainly, in the increase of oil content near infrastructure transport objects. There were single facts of breaking fish farm regulations by oil content indications, which was caused by runoff from roads or from the surface of water collections under rainfall conditions but not by oil production factors. Significantly more often (in 50-80% of samples), the norms of pH were exceeding, as well as the presence of ammonia (up to 1.5 times of the MAC), iron (up to 3–5 times of the MAC), manganese (up to 180 times of the MAC) in excess of applicable state standards for fish farms was observed [11] though the excess was not knowingly related to oil production factors. Glazovskaya [9] describes mechanisms of accumulation of iron and manganese in ground and surface waters in the courses of gleization and chelation under the varying oxidation-reduction conditions which are typical for the taiga zone. Extreme concentrations of manganese were recorded in rivers, the watersheds of which had 100% forest cover while lacking anthropogenic objects but under the conditions of extremely hot and dry summer of 2010, considerate decrease of water flow and activation of the processes of organic residues' humification.

3.3 Ground waters

For the above-mentioned reasons, the quality of ground waters is described by the environmental survey data to a small degree. According to the monitoring data of 2009, 36 sites of ground water pollution were found in 26 out of 73 oilfields being developed in Udmurtia (Western Urals) [10]. There were several types of ground water pollution caused by oil production.

One of the most frequently occurring types of pollution is the local pollution of ground water bodies caused by abandoned earth storages which are not isolated and contain bore mud. The size of such polluted sites can be about several dozens, or even hundreds of square meters. The maximum allowable concentrations of chlorides, sulphates and general salinity can be exceeded by 5-10 times. Since there is no additional inflow of contaminants, in the course of time (dozens of years) and under the influence of ground watercourses the polluted-nonpolluted interface of the above sites is washed out increasing the area of pollution and decreasing the contaminant concentrations. The abandoned earth storages for bore mud are usually found during the engineering environmental investigations which should be combined with hydrogeological surveys. Buried earth storages are rarely found while following surface routes especially under forest conditions or on agricultural land.

Other wide-spread sources of ground water pollution are runoff from pipelines, mainly, from saline water conduits. The level and composition of this type of ground water pollution is close to the previously considered type. The difference varies over time and is highly related to the state of pipelines and also with oil prices.

Groundwater pollution caused by the cross-feed in wells' hole annulus is less frequent (13 out of 36 pollution points in Udmurtia in 2009) but more dangerous. Swelling of clayey minerals is known [4, 11] to occur in the filtration of salt waters as opposed to the fresh water filtration; however, during the salt water filtration, active porosity is increased. The intensity of the salt water filtration is increased in the course of time, therefore, this type of pollution spreads as a self-exciting process. The similar process occurred in Western Urals in 1980-1990 when the records showed a gradual increase of oil content (up to 150 times above MAC in Mishkinskoye oilfield in 1998 [12]), chlorides (up to 83.6 times above MAC in the Vyatka area of Arlanskoye oilfield [12]) and general salinity (up to 51.2 times above the MAC in the same area in 2000 [12]). Currently, after the most part of repair works on well pipelines was carried out and inactive wells had been buried, the levels and areas of groundwater pollution were significantly reduced. The highest level of MAC excess in 2009 was 20 times in case of oil hydrocarbons and 17 times in relation to chlorides; in the majority of cases it was in the range of 1-2 times [10].

Under the inexpediency of drilling special wells for an environmental hydrogeological survey, the study of groundwater pollution during engineering environmental investigations is limited by the analysis of data on engineering geological investigations and institutional monitoring concerning the assessment of the state and the ascertainment of spatio-temporal tendencies. At the absence of monitoring data for new developing oilfields, we collected water samples from springs to get background characteristics of ground waters. We found that MAC of iron and manganese only were exceeded, which is caused by hydrochemical specific features of the taiga zone, the way it was observed upon studying surface water. In addition, we recorded the excess of MAC of nitrogen caused by bad sanitary conditions of settlements and stock farms.

3.4 Soils

The analysis of soil samples collected during the investigations has resulted in the following conclusions:

- no incidences of MAC excess or approximately allowable concentration excess of heavy and toxic metals (lead, arsenic, mercury, cadmium) were recorded. The pollution index values (Zc) were in compliance with the allowable level both when reckoned on the basis of approximate values stated in the Code of Regulations 11-102-97 [8] and when reckoned with taking into consideration the regional background;

- no incidences of MAC excess or even the detection threshold excess were recorded with respect to benzpyrene and pesticides (dichloro-diphenyl-trichloroethane (DDT), hexachlorocyclohexane (HCCH);
- according to the monitoring data, oil hydrocarbons concentrations above MAC 1000 mg/kg and chloride concentrations above 0.02% of the dry soil mass were recorded in 10.3% and 8.3% of samples, respectively; according to the survey data, the oil product concentrations were recorded in 6.0% of samples (only when sampled inside the dykings).

Under the features of humid climate in Western Urals (humidity factor is in the range of 1.1 to 1.4) the accumulation of oil hydrocarbons and chlorides in soils does not occur. The monitoring results with the excess of MAC alternate for the results without the excess. The most probable cause of the occasional soil contamination in the area of oilfield facilities is an unauthorized water drain off the field dykings during and immediately following rainfall and snow melt events. It is typical that the excess of oil hydrocarbons and chloride concentrations was recorded only in the oilfields with clayey soils.

3.5 Physical characteristics

According to the measurements performed at 86 sites, radiation characteristics were in compliance with the natural background (from 5-6 μSv/h on sand to 10-12 μSv/h on clays) and applicable standards. Radon flux was below the threshold of detection in all cases. The noise level was measured only in engineering environmental investigations. 48 measurements were performed; no excess of standards in regard to an operating area within the bounds of a sanitary protection zone, as well as for dwelling zones on the boundary of a sanitary protection zone was recorded.

3.6 Detection of rare plant and animal species

Biological surveys which were conducted while performing works in forests (excluding areas of recent loggings), meadows and water-logged areas usually led to the detection of 1-5 habitats of rare plant and animal species.

4 Conclusion

Thus, the present environmental requirements regarding oilfield exploitation appears to be working and environmental contamination is within specified limits. Environmental investigations when planning oilfields, and during their exploitation are among the main instruments to minimize environmental impact of oilfields in Russia.

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