The use of the basic parameters of water-physical properties of oil-contaminated soils in the technology of the biological remediation stage (Western Siberia)

M V Nosova1,2, V P Seredina2 and A S Rybn3
1 Joint Stock Company Tomsk Research and Design Institute of Oil and Gas, JSC TomskNIPIneft, 72, Mira ave, Tomsk, 634027, Russian Federation
2 National Research Tomsk Polytechnic University, TSU, Biological Institute, Department of Soil Science and Soil Ecology, 36, Lenin ave, Tomsk, 634050, Russian Federation
3 National Research Tomsk Polytechnic University, TPU, 30, Lenin ave, Tomsk, 634050, Russian Federation
E-mail: nsmvsh@mail.ru

Abstract. This report presents the results of field and experimental studies of water-physical properties of soils of oil-contaminated floodplain ecosystems of the mid-taiga subzone of Western Siberia. Features and basic patterns of their change in various contamination zones (epicenter - impact zone) are revealed. The state of water-physical properties of technologically contaminated soils is compared with background counterparts. Recommendations on the use of basic soil-hydrological constants (range of active moisture, wilting moisture, and field moisture capacity) in the technology of phytomelioration are suggested. Study objective: to analyze characteristics of the impact of oil pollution on water-physical properties of alluvial soils and the possibility of using obtained data for the purposes of remediation works.

1. Introduction
To solve the problem of technogenic soil formation and assess its manifestation, reliable quantitative characteristics are needed that reflect the impact of human economic activity on the diagnostic signs of root-inhabited soil horizons that are of top interest in the course of remediation works. Therefore, special attention should be paid to the study of water-physical properties of oil-contaminated soils, since these parameters affect a number of soil-biochemical processes and have a large impact on the main integral property of the soil - its fertility [1-3].

The hazard of oil pollution is associated with a high sensitivity of higher plants used for the final stage of remediation to it - phyto-reclamating sowing of oil-resistant herbs. It was determined that soil water-physical properties, which are the most important parameters for the favorable growth and development of plants, radically change under the impact of oil.

2. Materials and methods
Objects of this study are full-profile soil sections laid in the territory of crude oil spill in various pollution zones (epicenter, impact zone). The key area is located in the mid-taiga subzone of Western Siberia on the left bank of Ob River in the central part of the floodplain.
The methodology included a cross-spectrum comparative analysis of background soils and soils subject to oil pollution. The background was an unpolluted alluvial sod standard gleyey mid-fine heavy loamy soil. Due to the damage of soil horizons and the impossibility of their diagnosis, all specimens of technogenic soils were taken by layers and were identified in accordance with the genetic horizons of their background counterpart. Objects of research are 2 full-profile soil sections and 26 specimens of soil pits. The selected specimens were used to determine the following parameters: field moisture capacity - using the Kachinsky method; maximum hygroscopic content - according to the Nikolaeva method, when saturating soil with potassium sulfate; plant wilting moisture - by the calculation method using a coefficient of 1.5 from the maximum hygroscopic content; active moisture range - by the calculation method using the difference between the field moisture capacity and the plant wilting moisture; maximum water capacity and structural coefficient (Cstr) - according to generally accepted methods [4]. Petroleum products in the soil were determined by the fluorimetric method using Flurorat-02 fluid analyzer. The obtained results were processed by the method of mathematical statistics using STATISTICA 6.0 software.

3. Results

The methodology included a cross-spectrum comparative analysis of background soils and soils subject to oil pollution. The background was an unpolluted alluvial sod standard gleyey mid-fine heavy loamy soil. Due to the damage of soil horizons and the impossibility of their diagnosis, all specimens of technogenic soils were taken by layers and were identified in accordance with the genetic horizons of their background counterpart. Objects of research are 2 full-profile soil sections and 26 specimens of soil pits. The selected specimens were used to determine the following parameters: field moisture capacity - using the Kachinsky method; maximum hygroscopic content - according to the Nikolaeva method, when saturating soil with potassium sulfate; plant wilting moisture - by the calculation method using a coefficient of 1.5 from the maximum hygroscopic content; active moisture range - by the calculation method using the difference between the field moisture capacity and the plant wilting moisture; maximum water capacity and structural coefficient (Cstr) - according to generally accepted methods [4]. Petroleum products in the soil were determined by the fluorimetric method using Flurorat-02 fluid analyzer. The obtained results were processed by the method of mathematical statistics using STATISTICA 6.0 software (figure 1).

![Figure 1. Oil content in oil-contaminated soils.](image-url)
Therefore, during pollution, water-physical parameters acquire properties unfavorable for plant growth and development, and the biogenic-accumulative horizon of soils is subject to the greatest transformations (figure 2).

![Figure 2. Oil content in oil-contaminated soils. Water-physical properties of alluvial soils: A - background, B - epicenter of pollution, C – impact zone of pollution. Note: HM - hygroscopic moisture, MWC - maximum water capacity, AMR – active moisture range, FMC- field moisture capacity, WM- wilting moisture, MHC - maximum hygroscopic content.](image)

Under the influence of oil pollutants significant changes in the parameters of hygroscopic moisture and maximum water capacity of oil-contaminated soils occur. The values of hygroscopic moisture and maximum water capacity are lower than background values, which is associated with the absence of organic pollutants in the pore space of initial soils. As far as the depth decreases, the values of these parameters also decrease, and it is associated with the compaction of soil horizons and an increase in their granulometric composition. Depending on the maximum water capacity of soils, the water application rate is established, however, at the final stage of remediation works - phytomeliorative sowing of oil-resistant herbs - these rates are not regulated by land reclamation plans [6].

Excessive moisture contributes to the development of anaerobic processes that reduce soil fertility and plant layer density - a visual parameter for the assessment of the quality of remediation works. The maximum hygroscopic content is a parameter characterizing the water resistance of the soil structure, and therefore, its anti-erosion resistance. In chemically-transformed soils this parameter is higher (14.99%) as compared to background soils (7.70%), which is associated with oily films covering soil aggregates. However, these changes cannot be called positive due to the fact that they are associated with the anaerobic effect of oil, the weakening of intermolecular forces between soil and water particles, and the acquisition of hydrophobic properties by the soil. In the background specimens the wilting moisture is 2 times lower (10.30%) than in a newly contaminated soil at the epicenter of the oil slick (22.48%) and at the periphery of the oil spill (20.98%). High values of this parameter show a significant amount of moisture in the soil, which is physiologically inaccessible to plants [7-8]. Plant wilting moisture monitoring is especially relevant in the vegetative phase of growth. Due to the fact that the seedlings are extremely sensitive to the critical state of soil moisture. In the process of contamination there is a complete absence of the active moisture range in the upper horizons and minimal values of this parameter in the lower part of the soil profile (1.9% -2.5%) in the center of the oil slick. The picture is different with the soil correlated with the impact zone of the newly contaminated area. Probably, in the process of lateral migration of oil from the epicenter of pollution
to the impact zone, hydrocarbons lost most of their heavy (resinous-asphaltenic materials) fractions. Therefore, as you move away from the source of pollution, the range of active moisture begins to recover (up to 6.5%), and, accordingly, the productivity of the soil increases. This regularity is confirmed by the results of statistical analysis - there is a negative correlation between the concentration of oil and the range of active moisture \((r = -0.59\) at \(p = 0.289\) at a depth of 0-10 cm), which shows a reliable feedback between these signs.

4. Discussion
Assessment of the fertility of the upper layers of alluvial soils made it possible to establish that their humus-accumulative horizon is the most productive one and is of the greatest interest for the remediation of disturbed lands, however, this particular horizon is subject to the greatest transformation [9-11]. To restore its initial state, significant operational investments are required, therefore, the use of roll geotextile can become a promising method for restoring water-physical properties of soils. This material will restore the projective top soil within one summer season, eliminate the risks associated with inadequate agrotechnical treatment of soils, and also provide natural detoxification of residual oil pollutants in the soil. The structure of geotextile makes it possible to fix fertilizers and plant mixtures in it, which will not be washed out by sediments, as well as by waters during periodic flooding of the floodplain. The possibility of creating a projective top soil stable in terms of the area and density directly depends on the remediation mixture, which should be selected in accordance with climatic characteristics, the soil cover and hydrological characteristics of the area of geotextile application. An additional measure that provides the greatest effect from the use of roll geotextile can be the introduction of oil-resistant grasses, crops that improve the soil structure, into the biological stage of remediation - (Lupinus polyphyllus), rye (Secale cereale), yellow sweet clover (Melilotus officinalis), meadow clover (Trifolium pretense).

5. Conclusion
Therefore, in humid areas the formation of solid bituminous crusts on the surface, as well as in the soil profile, under conditions of oil pollution, dramatically changes the air and water regime, which negatively affects all soil characteristics. Changes in the main soil-hydrological constants (active moisture range, wilting moisture capacity, maximum water capacity) show the acquisition of hydrophobic properties by the soil, the emergence of moisture in humus horizons inaccessible to plants, and show the need for additional reclamation works with the possibility of further monitoring the dynamics of changes in water-physical properties, which are not studied to the fullest extent in typical land remediation plans

Acknowledgments
We are grateful to JSC «TomskNIPINefte» for the opportunity to publish this article to the sponsors, as well as the staff of the Department of Soil Science and Soil Ecology of the National Research Tomsk State University.

References
[1] Pikovskiy Y I, Gennadiev A N, Kovach R G et al 2017 Hydrocarbon status of alluvial soils in the istra morphostructural node (Moscow oblast). Eurasian Soil Science 50(12) 1363-74
[2] Seredina V P and Sadykov M E 2011 The soils of West Siberia middle taiga oil deposits and a predictive estimate of contamination hazard with organic pollutants. Contemporary Problems of Ecology 5 457-61
[3] Pikovskii Y I, Smirnova M A, Gennadiev A N et al 2019 Parameters of the native hydrocarbon status of soils in different bioclimatic zones. Eurasian Soil Science 52(11) 1333-46
[4] Shein E V and Goncharov V M 2006 Agrophysics (Rostov-na-Donu: Fenix publ.) 400
[5] Gennadiyev A N 2016 Oil and environment. Bulletin of the Moscow state University. Seriya 5. Geography 6 30-9
[6] Seredina V P, Kolesnikova E V, Kondykov V A, Nepotrebn A I and Ognev S A 2017 Peculiarities of oil pollution influence on soils of middle taiga in Western Siberia. *Oil-industry* **5** 108-12

[7] Shein E V 2009 The particle-size distribution in soils: problems of the methods of study, interpretation of the results, and classification. *Eurasian Soil Science* **3** 284-291

[8] Vodyanitskii Y N, Savichev A T, Avetov N A and Shishkonakova E A 2018 Soil pollution in sites of oil extraction in Western Siberia, Russia. *Oil Pollution. Issues, Impacts, Outcomes: Nova Science publishers Inc New York* **1** 32

[9] Eekmeier E and Wiesenberg G L B 2009 Short-chain n-alkanes (C16-20) in ancient soil are useful molecular markers for prehistoric biomass burning. *J. Archaeological Science* **36** 1590-6

[10] Pinedo J, Ibáñez R, Lijzen J P A and Irabien A 2014 Human risk assessment of contaminated soils by oil products: total TPH content versus fraction approach. *Hum. Ecol. Risk Assess. Int. J.* **20** 5 1231-48

[11] Wiens J A 2013 *Oil in the environment: legacies and lessons of the Exxon Valdez oil spill* (United Kingdom, Cambridge: Press Cambridge University) 482