ESTIMATION OF DIFFUSE RUNOFF COMING INTO THE
UPPER VOLGA BASIN WITH DRAINAGE WATER
CONTAINING BIOGENIC SUBSTANCES

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https://doi.org/10.26782/jmcms.spl.10/2020.06.00034

Abstract

The paper contains an assessment of the possible coming of polluting
biogenic substances into the water bodies of the Upper Volga basin from the
functioning reclaimed lands, the area of which is 961.12 thousand hectares or 44% of
the total reclaimed land in the region. Drainage systems are located mainly on the
floodplain lands of the tributaries of the Volga river, from which the surface and
drainage runoff are uncontrollably discharged into the river network, which causes
significant damage to the water bodies of the basin. The calculation of surface runoff
is made on the basis of the natural reclamation zoning of the territory, which made it
possible to identify homogeneous reclamation subzones and provinces characterized
by the same type of the surface runoff formation. To calculate the content of biogenic
substances in the drainage runoff, a justification of its volume was made depending
on the amount of precipitation, the discharge of flood waters and drainage
parameters. Assessment of pollution of diffuse runoff was performed using empirical
dependencies for each biogenic substance and its form in the soil: nitrogen,
phosphorus and potassium. The calculation took into account the content of this
biogenic element in the soil, its rate of application with mineral and organic
fertilizers, solubility and transition into mobile forms, the washout of the absorbed
substance by solid runoff and of the dissolved substance with the surface runoff, as
well as absorption of biogenic elements by agricultural plants during the growing
season. It was shown that nitrogen and potassium compounds play the main role in
the pollution of both surface and drainage waters, the amount of which is 98% of the
total amount of pollution, while phosphorus compounds have a lesser impact. The
total annual volume of surface runoff in the Upper Volga basin for average long-term
conditions is estimated at 216,698 thousand m³, drainage water - 1,564,436 thousand
m³, which is 7.3 times more. The washout of biogenic pollutants approximately
amounted to 12.32 thousand tons/year, of which the main share of 8.08 thousand
tons/year (65%) falls on drainage waters, which requires the development of protective measures to reduce and clean the drainage runoff.

**Keywords:** Pollution; reclamation; surface runoff; drainage water; nitrogen; phosphorus; potassium; biogenic elements; water bodies.

I. Introduction

The Volga River basin requires immediate measures to protect the river waters from depletion and pollution. Over the past decade, the Volga River and its tributaries have been characterized as extremely dirty, despite a decrease in the volume and an increase in the efficiency of treatment of controlled sources of wastewater discharge [XXII]. Traditionally, it was thought that the main source of river pollution is untreated wastewater from industrial and public utilities. Therefore, the main focus was on the upgrading and creation of new sewage treatment plants. The volume of industrial wastewater has decreased, modern wastewater treatment plants have significantly improved the quality of discharged wastewater, especially the wastewater from public utilities. Controlled discharge from separate sources of pollution in the Upper Volga basin in the period of 1990-2012 decreased almost 3.5 times in volume, for oil products - 6 times; sulphates- 19.3 times; chlorides - 3.4; zinc - 15; copper - 17.8; nitrogen - 3.5; phosphorus - 7.2. The total biochemical oxygen demand (BOD$_{total}$) decreased 7.6 times. However, the expected improvement in water quality in river systems and water bodies did not occur, especially with regard to the Volga tributaries. This effect is mainly associated with diffuse (distributed) pollution sources. Therefore, special attention should be given to considering the role of diffuse pollution of water bodies in the Volga River basin [IX]. Agricultural land can be a significant source of pollution, including reclaimed land, on which surface runoff is formed, as well as drainage runoff in a significant amount.

The total area of the Volga river basin is about 1,360 thousand km$^2$. The Upper Volga regions mainly belong to the European part of the Nonchernozem Zone (nonblack earth zone) of Russia. Geomorphologically, it is a medium-high plain with a hummock-and-hollow topography with extensive flat marshy lowlands and marshes, dissected by a river-and-gully network. The soil cover is dominated by sod-podzolic and peat-podzolic-gley soils on moraine loams and surface sediments, water-glacial and lake-glacial sands and sandy loams which are characterized by excessive moisture; about 50% of agricultural land is marshy or over-moistened. This causes the predominant distribution of drainage reclamation systems for agricultural industry. Soils are characterized by high acidity, which requires the constant introduction of lime and gypsum, usually on the soil surface, which can also become a source of diffuse pollution. The area of the land reclaimed by drainage is 2175.7 thousand hectares; currently only 961.12 thousand hectares are used, on which surface and drainage runoff are formed. Drainage is carried out mainly in the valleys of the small and middle rivers on the floodplains, where fertile alluvial or organogenic soils have been formed, in which vegetables, potatoes and fodder crops are cultivated. Small rivers, being simultaneously receivers of drainage runoff from reclaimed lands and an integral part of the hydrographic network of the Volga basin,
transport pollution coming from the territory of small basins directly into the Volga. Drainage runoff refers to uncontrolled separate sources of pollution and, as a rule, is discharged directly into the river network. With the drainage runoff, organic matter, mineral fertilizer residues, and ions of chemical elements enter the water bodies [VIII, IV]. Based on numerous studies [XX, XXI, II, VI, XII, XVI], the concentration of drainage runoff and the washout of salts from the reclaimed mineral soils is characterized by the following values depending on the type of soil:

loamy soils: nitrogen - 5 ... 91 mg/l (1.4 ... 4.1 kg/ha), phosphorus - 0.4 ... 0.5 mg/l (up to 1 kg/ha), potassium - 2.10 mg/l (3 ... 12 kg/ha), calcium - 61 ... 107 mg/l (20 ... 147 kg/ha), magnesium 21 ... 28 mg/l (10 ... 76 kg/ha), sulfur - 38 ... 172 mg/l (84 ... 420 kg/ha);

sandy loam soils: nitrogen - 2.0 ... 121.0 mg/l (8 ... 84 kg/ha), phosphorus - 0.2 ... 0.3 mg/l (0.6 ... 1.2 kg/ha), potassium - 0.2 ... 14.0 mg/l (up to 14 kg/ha), calcium - 53 ... 74 mg/l (22 ... 238 kg/ha), magnesium - 13 ... 58 mg/l, 32 ... 62 kg/ha, sulfur - up to 400 kg/ha.

A particular danger is the drainage of floodplain lands, where crops are cultivated by intensive technology, requiring increased doses of mineral fertilizers and plant protection products. Here, a washout of surface waters takes place during floods, heavy rains and prolonged rains into the river bed. Thus, from the agricultural land of the floodplain lands of the Ryazan region in the Oka river (Volga tributary) the average annual washout of nitrogen was 23.9 kg/ha, of which 13.7 kg/ha of nitrates, 1.6 kg/ha of nitrites and 8.6 kg/ha of ammonium [II]. The discharge of drainage waters by the reclamation system causes a surge in the concentration of biogenic and mineral substances in the river water. Confirmation of this is the discharge of drainage water into a minor Volga tributary, the Yakhroma river, from the reclaimed areas of its floodplain which caused an increase in the concentrations of ammonium ions in the water of the river, which exceed the maximum allowable concentrations (MAC_fishery) more than 2-11.5 times on average, increasing the allowable values for the mesotrophic level by 4.7 - 77 times. In the summer, an excess of standard ammonia values of 1.4–4 times was registered on the river below the drainage water discharges [XXIII]. The present research has also established the pollution of drainage waters with organochlorine compounds up to 23 µg/l and with dissolved organic carbon up to 22.8 mg/l. Increased concentrations of salts in the drainage runoff from the reclaimed massif of the Yakhroma floodplain have been registered, which is caused by the long-term agricultural use of floodplain lands with the introduction of high doses of mineral fertilizers.

The abundance of precipitation, especially during the period of snowmelt in the region under consideration, leads to the formation of a significant amount of surface runoff and diffuse washout of biogenic substances directly from the soil cover of the drained lands. The removal of substances by surface runoff results in erosion, leaching and dissolution processes. During erosion, mainly the suspended soil particles are washed out, on which the biogenic substances are absorbed, in particular phosphorus, while during dissolution and leaching, the dissolved chemicals are washed out with the runoff. The main factors influencing the formation of surface runoff, its quality and the washing out of biogenic substances are: climatic conditions,
terrain, soil surface condition, and the migration capacity of nutrients. On average, up to 80 kg of nitrate nitrogen, 3 kg of phosphorus and 60 kg of potassium can be washed out per hectare of arable land per year, depending on the type of soil, the amount and nature of precipitation, the type of plants, and the dose of fertilizer application [XI]. For example, in the Tver region, in a well-fertilized field with a thickness of the runoff of 70, 80 and 130 mm, the washout of phosphorus was 0.25, 0.5 and 0.9 kg/ha, respectively, and washout nitrogen was much higher: with a thickness of the runoff of 100 mm, the washout of dissolved nitrogen from perennial grasses during the observation period was about 1.5 kg/ha, from winter crops - 4.5 kg/ha, and from land plowed in autumn - 9 kg/ha. All these processes, in one way or another, adversely affect the quality of surface water sources, the greatest burden being borne by small rivers, which are often used by the rural population for drinking and household water supply. Nitrogen compounds represent a serious danger to human and animal health, especially nitrate nitrogen, the concentrations of which in water bodies are limited to 10 mg/l N-NO$_3^-$, nitrites to 0.08 mg/l N-NO$_2^-$, ammonium to 0.5 mg/l N-NH$_4^+$ [V]. The content of these substances above the specified amount, in both surface and groundwater is impermissible. Phosphorus does not directly affect the life of aquatic organisms, but is a limiting factor for anthropogenic eutrophication and secondary pollution of water bodies [VII].

The purpose of the present study is to develop a methodology for assessing diffuse runoff in a regional context and to calculate the washing out of biogenic substances by surface and drainage runoff into the water bodies of the Upper Volga basin from reclaimed lands, which will allow identifying the main sources of pollution and developing measures to protect the Volga from diffuse pollution.

II. Methods and Materials

The analysis of the main approaches to the assessment of diffuse runoff has shown the complexity of modeling the processes of mass and energy exchange in the agrogeo system, associated both with the need to create spatial hydrological models and the insufficiency and unreliability of the initial information. Therefore, the work focused on the analysis of the results of the long-term field observations performed and experimental data obtained in the Nonchernozem Zone (nonblack earth zone) by various researchers in different years [XIV, XV, XVII, XXIV, III, IV, XX, II, VI, XII, XVI]. The study also used empirical dependencies obtained in the course of field observations and calculation formulas that establish the relationship between natural climatic factors and diffuse runoff [XVII, XVIII, XX, XXI]. Based on the analysis carried out in the present study, a methodical approach was proposed to determine the diffuse runoff based on fairly simple dependencies, which makes it possible to calculate the module of surface and drainage runoff and determine the amount of biogenic pollution caused by the drainage systems to the water bodies of the Upper Volga basin using minimal and available information (see Figure1).
The calculation of the average annual washout of biogenic substances with surface and drainage runoff was carried out differentially in similar natural reclamation areas, and then summed up for each subzone of natural reclamation zoning.

To determine the module of surface runoff, reclamation zoning of the Nonchernozem Region, developed by All-Russian Research Institute of Hydraulic Engineering and Land Reclamation named after A. N. Kostyakov, was used on the basis of generalization and analysis of materials on the physical-geographical and natural-economic conditions of the territory [XIII]. Taking into account the requirements of drainage amelioration and the directions of agricultural development, the ameliorative subzones and provinces with characteristic values of radiation balance, precipitation, evaporation, the sum of active temperatures and the length of the vegetation period are were identified on the zoning map. All existing drainage systems were grouped by zones and areas of the drained agricultural land currently used in agricultural production were identified. At the same time, the structure of the crop rotation, the main agricultural crop, the doses of applied mineral and organic fertilizers in accordance with the zonal recommendations were taken into account. In the calculations, the averaged characteristics were taken for the predominant soil type of the runoff area in question. The characteristic soil types for reclamation subzones were identified: the northern taiga - peat-and peat-podzolic-gley; middle taiga - sod-podzolic loamy; southern taiga - gray forest and podzolizedchernozem; deciduous forest and forest-steppe - leached loamy chernozem.

**Fig. 1:** Schematic diagram of the estimated calculation of diffuse runoff

Referring of the territories under consideration to the areas of reclamation

Determination of runoff indicators by reclamation zones

Calculation of volumes of uncontrolled runoff from drained areas

- **drainage runoff**
- **surface runoff**

Estimated calculation of the washout of biogenic substances (N, P, K) with drainage runoff

Estimated calculation of the washout of biogenic substances (N, P, K) with surface runoff

Estimated qualitative and quantitative calculation of the total diffuse load from the drainage and surface runoff to a water body.
The amount of the surface runoff from the drained territory was estimated by the runoff coefficient ($\sigma$) depending on the amount of precipitation for a particular subzone of reclamation zoning [XVIII] using the formula:

$$\sigma = \frac{W_{\text{surf.runoff}}}{W_{\text{precip}}},$$

where $W_{\text{surf.runoff}}$ is the amount of surface runoff, $m^3$, and $W_{\text{precip}}$ is the average annual amount of precipitation, $m^3$, determined by the formula:

$$W_{\text{precip}} = 10 \cdot H_{\text{av. annual precip}} \cdot F, m^3,$$

where $H_{\text{av. annual precip}}$ is the average annual precipitation for spring and autumn, mm; $F$ is the water collection area, ha. It was taken into account that the surface runoff from adjacent territories enters the water intake. A river or pond, having a discharge into the river was considered as a water intake.

The volume of runoff was determined by the formula:

$$W_{\text{surf.runoff}} = K_{\text{runoff}} \cdot \sigma \cdot 10 \cdot H_{\text{av. annual precip}} \cdot F, m^3$$

where $K_{\text{runoff}}$ is the correction factor for the runoff of artificially drained territory. Other symbols are given above. The calculation results were compared with the data of field studies for the zone under consideration and, if necessary, were corrected [XX, XXI].

The washout of pollutants by surface runoff, including solid runoff, was determined by the dependencies outlined in the regulatory document [V]. The estimated dependencies take into account almost all sources of biogenic inputs into the soil, including the specific composition of mineral and organic fertilizers applied, the content of dissolved and absorbed biogenic substances in the soil by using appropriate correction factors. The residual amount of biogenic substances in the soil after it was consumed from the soil by the crop was also taken into account.

The annual washout of absorbed and dissolved nitrogen by surface runoff ($\text{Washout N solid runoff}$) was calculated by the formula [V]:

$$\text{Washout N solid runoff} = \omega \left( K_2 N_y + 0.002 N_0 + 0.66 N + N_{\text{total}} \right) + \phi \left( K_1 N_y + 0.002 N_0 + 0.07 N_n \right),$$

kg/ha

where $K_i$ is the coefficient determining the residual amount of mobile nitrogen forms of mineral fertilizers after consumption by agricultural plants (for ammonium nitrate - 0.02, ammonium sulfate - 0.03, ammonium chloride - 0.06); $K_2$ is the coefficient determining the amount of nitrogen fixed in soil and absorbed by soil microorganisms from fertilizers (for ammonium nitrate - 0.65, ammonium sulfate - 0.35, sodium nitrate - 0.18, lime ammonium nitrate - 0.065); $N_y$, $N_0$, stand for the rate of application of mineral (y) and organic (o) fertilizers, respectively, kg/ha; $N_n$, $N_{\text{total}}$ stand for the content of mineral (n) and total nitrogen in the arable layer of soil (taken according to the survey, in this case for sod-podzolic gley soils $N_n = 4,000$ kg/ha, $N_{\text{total}} = 66$ kg/ha, for sod-podzolic loamy soils $N_n = 5,800$ kg/ha, $N_{\text{total}} = 128$ kg/ha, for gray
forest soil $N_a = 5,400$ kg/ha, $N_{total} = 81$ kg/ha, for leached chernozem $N_a = 13$ kg/ha, $N_{total} = 195$ kg/ha); $\omega, \gamma$ are coefficients characterizing the washout of absorbed nitrogen by solid runoff and of dissolved nitrogen from the soil surface (for peat soils $\omega = 3.1 \times 10^{-5}$, $\gamma = 4.8 \times 10^{-3}$, for gray forest soil $\omega = 1.8 \times 10^{-4}$, $\gamma = 1.4 \times 10^{-2}$, for leached podzolized chernozem $\omega = 4 \times 10^{-5}$, $\gamma = 2.4 \times 10^{-2}$).

The washout of absorbed phosphorus with solid runoff ($B_{P_{solid runof}}$) over the year was determined as follows [V]:

\[
W_{P_{washout}} = \omega \cdot (n_2P_y + n_3P_o + n_4P_n + P_{total}), \text{ kg/ha}
\]

where $P_y, P_o$ stand for the rate of application of mineral and organic fertilizers, respectively, kg/ha; $P_n, P_{total}$ stand for the content of mineral and total phosphorus in the arable layer of soil (for sod-podzolic gley soils $P_n = 300$ kg/ha, $P_{total} = 1,820$ kg/ha, for sod-podzolic loamy soils $P_n = 210$ kg/ha, $P_{total} = 3,380$ kg/ha, for gray forest soil $P_n = 420$ kg/ha, $P_{total} = 3,600$ kg/ha, for leached chernozem $P_n = 260$ kg/ha, $P_{total} = 3,900$ kg/ha); $n_2, n_3, n_4$ are coefficients characterizing the residual amount of phosphorus in mineral, organic fertilizers and soil, respectively ($n_2$ for light soils -0.8; for heavy soils – 0.26; for peat soils -0.32; $n_3 = 0.0014$; 0.0004; 0.0005, respectively; $n_4 = 0.85$; 0.28, and 0.34, respectively).

The annual washout of absorbed and dissolved potassium by surface runoff ($W_{K_{surf runof}}$) was calculated by the formula [V]:

\[
W_{K_{washout}} = \omega \cdot (n_2K_y + n_3K_o + n_4K_n + K_{total}), \text{ kg/ha}
\]

where $K_y$ is the rate of application of the mineral fertilizer, kg/ha; $K_{total}$ is the total amount of potassium in the arable layer of soil, kg/ha (for sod-podzolic gley soils $K_{total} = 50,000$ kg/ha, for sod-podzolic loamy soils $K_{total} = 58,000$ kg/ha, for gray forest soil $K_{total} = 50,600$ kg/ha, for leached chernozem $K_{total} = 51,250$ kg/ha).

The calculation of the drainage flow ($W_{dr}$) volume was performed on the basis of the known dependencies of the average annual module drainage flow [XXI]:

\[
W_{dr} = \frac{q \cdot F \cdot t}{1000}, \text{ m}^3
\]

where $q$ is the average annual module of drainage flow, l/s ha; $F$ is the area of the drained area, ha; $t$ is the number of seconds in a year, s.

In determining the washout of biogenic substances with drainage runoff, a correction factor for the washout of biogenic substances for the water content of the long-term average annual was introduced.

Nitrogen annual washout by drainage runoff ($W_{N_{washout}}$) is determined by the formula [V]:

\[
W_{N_{washout}} = \frac{(K_1 \cdot N_y + 0.0002N_0 + 0.007N_n)W_{dr}}{W_{limit} + W_{dr}}, \text{ kg/ha}
\]

where $W_{limit}$ is moisture reserve in the considered soil layer to the depth of groundwater level or to the depth of drainage at maximum moisture capacity of soil.
m³/ha (for peat soils W_{limit} = 4,500 m³/ha, for sod-podzolic loamy soils W_{limit} = 2,682 m³/ha, for gray forest soil W_{limit} = 2,138 m³/ha, for leached chernozem W_{limit} = 2,765 m³/ha); See other symbols above.

The annual washout of dissolved phosphorus by drainage runoff (Washout_{P}^{dr}) is determined by the formula [V]:

\[
\text{Washout}_{P}^{dr} = \frac{n_{i}W_{\text{arable, limit}}^{limit} \cdot W_{dr}}{W_{\text{limit}}^{limit} + W_{dr}}, \text{kg/ha}
\]  

(9)

where n_{i} - the value characterizing the content of dissolved phosphorus in the soil (for light soils \(= 0.002 \); for heavy soils =0.00017; for peat soils\( = 0.0015 \); W_{\text{arable, limit}}^{limit} is moisture in the topsoil,m³/ha (for peat soils W_{\text{limit}}^{limit}=1,350 m³/ha, for sod-podzolic loamy soils W_{\text{limit}}^{limit}=537 m³/ha, for gray forest soil W_{\text{limit}}^{limit}=428 m³/ha, for leached chernozem W_{\text{limit}}^{limit}= 553 m³/ha).

The annual washout of dissolved potassium by drainage runoff (Washout_{K}^{dr}) is determined by the formula [V]:

\[
\text{Washout}_{K}^{dr} = \frac{((0.2 K_{o} + 0.0012 K_{o} + 0.008 K_{\text{total}})) \cdot 0.018 \cdot W_{dr}}{W_{limit}^{limit} + W_{dr}}, \text{kg/ha}
\]  

(10)

where K_{o} is the rate of application of organic fertilizer, kg/ha,

The total volume of biogenic compounds washout was determined by the following formula:

\[
B_{\text{total}}^{i} = \sum B_{i}^{dr} + \sum B_{i}^{surf} = B_{N}^{dr} + B_{P}^{dr} + B_{K}^{dr} + B_{N}^{surf} + B_{P}^{surf} + B_{K}^{surf}, \text{kg/ha}
\]  

(11)

where B_{i}^{dr}, B_{i}^{surf} stand for the washout of i biogenic element (nitrogen, phosphorus, potassium) by the drainage and surface runoff, respectively.

The indicators presented in Table 1 have been accepted as the initial information.

Table 1: Baseline data for the calculation of diffuse biogenic runoff from drained lands

| Indicator | Type of subzone according to natural land reclamation zoning |
|-----------|-------------------------------------------------------------|
|           | North Taiga | Middle Taiga | South Taiga | Deciduous forest, forest-steppe |
| Prevaling soil type | peat and peat-podzolic-gley soils | sod-podzolic loamy soils | gray forest and podzolized soils | leached loamy chernozem |
| long-term average annual amount of precipitation for the spring and autumn period, mm | 190 | 177 | 198 | 172 |
| Average annual surface runoff module, l/s ha | 0.014 | 0.009 | 0.07 | 0.003 |
| Average annual drainage runoff module, l/s ha | 0.07 | 0.06 | 0.05 | 0.04 |

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III. Results and Discussion

Agriculture in the Upper Volga basin has regional differences in specialization due to the climatic and soil conditions characteristic of the designated areas of reclamation zoning. In view of the fact that not all previously drained lands are used in agricultural production, the areas used in agricultural production at the present time were identified, from which the surface and drainage runoff to the basin of the Volga river (see Table 2) was calculated. The largest territory of drained land of 766.38 thousand hectares is used in Moscow, Kirov, Tver, Kostroma and other areas belonging to the Southern Taiga zone. The smallest territory of drained land is in the North Taiga zone (0.41 thousand ha).

### Table 2: Distribution of drained land used in agricultural production in land-reclamation subzones and administrative regions

| No | Names of subzones as per reclamation zoning | Average values of the main indicators of the zone | Name of administrative areas | The area of drained land, ha (data of the Department of Land Reclamation of the Ministry of Agriculture of the Russian Federation) |
|----|---------------------------------------------|--------------------------------------------------|------------------------------|--------------------------------------------------------------------------------------------------|
| 1  | North Taiga                                 | - radiation balance 25 kcal/cm²;                | Komi Republic                | 410                                                                                             |
|    |                                             | - duration of the growing season – 65 days;     |                              |                                                                                                |
|    |                                             | - the sum of active temperatures – 1000°C;     |                              |                                                                                                |
|    |                                             | - amount of precipitation – 600 mm;            |                              |                                                                                                |
|    |                                             | - runoff coefficient – 0.5;                    |                              |                                                                                                |
|    |                                             | - drainage runoff coefficient – 0.21;          |                              |                                                                                                |
|    |                                             | - surface runoff coefficient – 0.45            |                              |                                                                                                |
| 2  | Middle Taiga                                | - radiation balance 29 kcal/cm²;               | Mari El Republic             | 17,310                                                                                          |
|    |                                             | - duration of the growing season – 100 days;   |                              |                                                                                                |
|    |                                             | - the sum of active temperatures – 1400°C;     |                              |                                                                                                |
|    |                                             | - amount of precipitation – 650 mm;            | Perm region                  | 22,990                                                                                          |
|    |                                             | - evaporation – 400 mm;                        |                              |                                                                                                |
|    |                                             | - runoff coefficient – 0.4;                    |                              |                                                                                                |
|    |                                             | - drainage runoff coefficient – 0.27;          |                              |                                                                                                |
|    |                                             | - surface runoff coefficient – 0.40            |                              |                                                                                                |
| 3  | South Taiga                                 | - radiation balance 35 kcal/cm²;               | TverOblast                   | 106,940                                                                                         |

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When performing calculations, the main factors affecting the volume of runoff and pollutant washout were taken into account. In the region under consideration, the amount of precipitation (on average 600–700 mm per year) significantly prevails over evaporation (425–475 mm), therefore during snowmelt, prolonged rains and heavy rains, the largest amount of surface runoff is formed, which provokes soil flushing and the coming of pollutants into the water bodies [1]. The analysis of field studies showed that surface runoff is directly proportional to the runoff coefficient and the amount of precipitation. With a constant amount of precipitation, the runoff coefficient depends on the permeability of the soil and underlying soils, the degree of natural drainage, the cultivation of the soil and the applied agrotechnical measures. The steepness and length of the slope affect the...
amount of surface runoff, which determines the runoff coefficient (Table 1). The washout of biogenic substances with surface runoff increases with the long-term application of large doses of mineral fertilizers, which contributes to their accumulation in the topsoil and washout with surface water. When fertilizers are applied over frozen soil, and especially in spring over melting snow, the diffuse runoff also increases significantly [XXIV, XIX]. Currently, the use of mineral and organic fertilizers has decreased and it was assumed in the calculation that the applied fertilizers are presented in the form of azophoska (N16P16K16) and fertilization is combined with the sowing of the agricultural crop. An important role in the washout of biogenic substances from the drained lands is played by agrochemical measures and the crop rotations used. Therefore, the calculations took into account the leading crop rotations and the applied agrotechnical methods of tillage. Calculations were performed for the long-term average annual. The results of calculations of the surface runoff and washing out of nutrients according to formulas 1-6 for reclamation subzones are given in Table 3.

Table 3: Average annual washout of biogenic substances with surface runoff into the water bodies of the per zones of natural reclamation zoning

| Names of subzone s as per natural reclamation zoning | Surface runoff, thousand m³/year | Annual washout of pollutants kg / ha | Annual washout of pollutants, kt |
|----------------------------------------------------|---------------------------------|-------------------------------------|----------------------------------|
|                                                    | Nitrogen (N) | Phosphorus (P) | Potassium (K) | Nitrogen (N) | Phosphorus (P) | Potassium (K) |
| North Taiga                                        | 183,19       | 0.67          | 0.06          | 4.26         | 0             | 0.002         |
| Middle Taiga                                       | 29,756.58    | 0.62          | 0.09          | 4.12         | 0.063         | 0.009         | 0.436         |
| South Taiga                                        | 177,613.21   | 0.54          | 0.06          | 3.84         | 0.326         | 0.047         | 3.055         |
| Deciduous forest, forest-stepp e                    | 9.1, 45.31   | 0.77          | 0.05          | 2.45         | 0.075         | 0.003         | 0.225         |
| Total:                                             | 216,698.29   | 0.464         | 0.059         | 3.718        |

As follows from the table, from 961.12 thousand hectares of drained land currently used in the Upper Volga basin, 216,698.29 thousand m³ of polluted surface run-off flow into the water bodies in the long-term average annual, containing 0.464 kt of nitrogen compounds, 0.059 kt of phosphorus, 3.718 kt of potassium. The increased washout of potassium is associated with its significant amount in sod-podzolic soils (58,000 kg/ha), compared to nitrogen (4160 kg/ha), and phosphorus (only 312 kg/ha) content in this soil.

The volume of drainage runoff also depends on climatic conditions: the amount of precipitation and air temperature. Long-term field observations of the
Drainage runoff have shown that it makes up from 20 to 38% of the annual precipitation depending on soil conditions and drainage parameters [XX]. Research has established that on heavy soils with water permeability of illuvial horizons <0.1 ... 0.05 m/day with an intermediate distance of 10, 20, and 40 m, the volume of runoff changes in the ratio of 3: 2: 1. The volume of runoff and the washout of biogenic substances increases dramatically during the moling of heavy soils (1.5 - 2 times), while deep ameliorative tillage can help reduce the washout [XXIII]. The intensity of the washout of biogenic substances with drainage runoff is determined by the parameters of drainage and related activities. However, it should be borne in mind that the depth of the drains and the distance between them significantly affect the volume of drainage runoff. Thus, according to experimental studies, the depth of drains equal to 0.6 m on loamy soils increases the amount of drainage runoff by about 30%, and an increase in the distance between drains, for example from 14 to 30, helps to reduce drainage runoff from 10 to 15% [XXI].

The calculation of the drainage runoff is made using aggregate indicators. When calculating, it was assumed that drainage is carried out by closed horizontal drainage, with a depth of 0.6–0.9 m with distances between drains of 20–30 m in combination with regional agromeliorative measures.

In the conditions of the Upper Volga, biogenic substances (nitrogen, phosphorus, and potassium) are washed out with drainage runoff. Nitrogen enters the drainage water most intensively from the soil, especially in spring during floods and in autumn when there is prolonged rain. The washout of potassium is very noticeable on acidic soils. Potassium is contained in the soil either in the form of ions of the soil solution, or is absorbed by mineral (clay) particles, which prevents its washing out into the drainage runoff. In addition, potassium is biologically actively absorbed by plants for carbohydrate metabolism [XI]. Phosphorus almost does not enter the drainage water even when phosphoric acid fertilizers are applied, because phosphoric acid is bound mainly to trivalent metals, especially aluminum. Analyzing the sources of phosphorus compounds entering drainage waters, it should be noted that phosphorus has a very low mobility in the soil. The washing out of phosphorus is significant only from light soils that contain little clay or iron and aluminum soluble in it, which are necessary for the sedimentation of phosphate ions. The calculation of the volume of drainage runoff from the drained areas of the Upper Volga and the annual washout of biogenic substances with drainage waters was carried out according to dependencies (7-10) and summarized for selected subzones per natural reclamation zoning (Table 4).
Table 4: The average annual washout of biogenic substances with drainage runoff into the water bodies of the Volga basin in ameliorative subzones

| Names of subzones as per natural reclamation zoning | Drainage runoff, thousand m³/year | Annual washout of pollutants kg / ha | Annual washout of pollutants, kt |
|-------------------------------------------------|----------------------------------|-------------------------------------|----------------------------------|
|                                                 |                                  | Nitrogen (N) | Phosphorus (P) | Potassium (K) | Nitrogen (N) | Phosphorus (P) | Potassium (K) |
| North Taiga                                     | 865.38                           | 4.16         | 0.20           | 3.71           | 0.002        | 0              | 0.002          |
| Middle Taiga                                    | 187,044.23                       | 7.37         | 0.18           | 3.88           | 0.791        | 0.019         | 0.416          |
| South Taiga                                     | 1,270,738.82                     | 7.29         | 0.17           | 3.76           | 3.347        | 0.133         | 2.604          |
| Deciduous forest, forest-steppe                  | 105,789.01                       | 5.22         | 0.14           | 2.45           | 0.53         | 0.012         | 0.225          |
| Total:                                          | 1,564,436.82                     |              |                |                | 4.67         | 0.164         | 3.247          |

The annual volume of drainage runoff in the long-term average annual from the operating drainage systems does not exceed 1,564,436.82 thousand m³, while nitrogen washout is 4.67 kt, phosphorus - 0.16 kt, potassium - 3.25 kt. The total annual washout of biogenic substances from drained lands amounts to 12.32 kt, of which 4.241 kt are carried with surface runoff and 8.08 thousand tons with drainage water (Table 5). Unlike the washout of biogenic substances with surface runoff, highly soluble nitrogen compounds prevail in drainage waters. In addition to the influence of the direct entry of nitrogen compounds into the water bodies due to the use of mineral fertilizers, the high content of ammonium nitrogen (NH₄⁺) can be explained by the decomposition of organic matter, especially in organically rich flooded soils.

Table 5: Average annual washout of biogenic substances from drained lands and drainage systems

| Names of subzones as per natural reclamation zoning | Average annual volume of diffuse runoff, thousand m³ | Average annual removal of nutrients, kt |
|-------------------------------------------------|-----------------------------------------------|----------------------------------------|
| North Taiga                                     | 1,048.57                                      | 0.01                                   |
Studies have shown that the main load on water bodies is determined by biogenic pollution with drainage runoff, which accounts for 65% of the total pollution from drained lands. In the surface runoff the concentration of the most dangerous pollutant - nitrogen is about 2 g/m$^3$, while in the drainage runoff it is 3 g/m$^3$. The obtained results of the calculation were compared with the scattered data of field studies of various authors, performed during the years of different estimated frequency on the mineral soils of the drained territories of the Nonchernozem Zone. There is a fairly good correspondence between the calculation and the actual data. All calculated data fall within the range of actual values for the prevailing loamy soils: the range of values for the average annual washout of nitrogen is 1.4 ... 65 kg/ha, potassium 3 ... 12 kg/ha, phosphorus - less than 1 kg/ha (Table 6).

Table 6: Comparison of calculated and actual data on the washout of biogenic substances (kg/ha) and the concentration of drainage flow (mg/l)

| Type of soil               | Indicator          | Calculated values of salt washout, kg/ha | The actual values of salt washout for drainage flow, kg/ha | References |
|----------------------------|--------------------|------------------------------------------|----------------------------------------------------------|------------|
|                            |                    | With surface runoff                       | With drainage runoff                                      |            |
|                            | LOAMY              |                                          |                                                          |            |
|                            | NO$_3^-$+NH$_4^+$   | 0.32-0.85                                | 1.96-23.84                                               | Komparskas, I.I., et al. [4]; Thomson, H., et al. [14]; Fedotova, Z.D., Strautynia, V.P. [16], Shkinkins, C.N. [19-20]; Betson, R. P. [22], O’Brien, W. G. [25]. |
|                            | P$_2$O$_5$         | 0.02-0.11                                | 0.16-0.2                                                 | up to 1 kg |
|                            | K$_2$O             | 3.53-4.28                                | 2.91-6.05                                                | 3-12       |
|                            |                    |                                          |                                                          |            |
|                            | GRAY FOREST        |                                          |                                                          |            |
|                            | NO$_3^-$+NH$_4^+$   | 0.44-0.77                                | 4.24-21.4                                                | 8-24       |
|                            | P$_2$O$_5$         | 0.06-0.11                                | 0.13-0.15                                                | 0.6-1.2    |
|                            | K$_2$O             | 2.87-3.87                                | 2.36-6.33                                                | up to 14   |

The assessment of the washout of biogenic substances from drained lands into the water bodies of the Upper Volga basin allows for the identification of measures to reduce the diffuse load on water bodies. In the conditions of the Upper Volga, it is recommended to pay special attention to reducing the volume and the treatment of drainage waters: when they are discharged into a water body or river network, it is recommended to use conventional reclamation technologies: bioplate (channel and infiltration); cascade of lagoons; cascade of drained areas;
bioengineering facilities that allow cleaning from anthropogenic pollution to the MPE. To reduce surface runoff, it is effective to apply organizational, economic, agrotechnical, and agromeliorative measures. The choice of measures does not have an unambiguous solution, since it is always possible to choose several different options that would ensure a reduction in diffuse flow. The main requirements to be met by the system of measures can be the following:

- comprehensive consideration of climatic factors and zonal patterns of formation of surface runoff;
- the optimal ratio of organizational, economic, agrotechnical techniques, forest-marsh melioration and hydraulic melioration;
- equivalence of all techniques and measures that make up the system. The same techniques and measures for different types of agricultural landscape may carry different functional loads, which will largely determine the likelihood of their use;
- the placement of system elements should be carried out taking into account the vertical microzonality;
- the coverage of the whole territory by the soil and water protection system. Only in this case it is possible to significantly reduce the diffuse load on water bodies.

IV. Conclusion

Thus, the relevance of the study is due to the need to assess the possible pollution of water bodies in the process of agricultural production in order to protect them and reduce the risks to the life and health of people. Therefore, this article is aimed at identifying the causes of diffuse pollution of water bodies from land reclamation activities and assessment of diffuse runoff from drained lands, including surface and drainage waters. The methodical approach considered by the authors to the assessment of regional diffuse pollution provides a solution to one of the priority tasks of environmental management and has practical significance in assessing the pollution of any water body by biogenic substances. The research methodology is based on a comprehensive and objective analysis of the results of field studies in the region under consideration. The revealed patterns of formation of surface and drainage runoff and the use of calculated dependences allow to comprehensively consider the formation of diffuse runoff from the surface of drained lands and drainage runoff from drainage systems depending on climatic, organizational and economic conditions and assess the amount of biogenic pollution entering the water bodies of the Upper Volga.

The article shows that in the Upper Volga basin, the estimated annual volume of surface runoff from the existing drained areas for the long-term average annual is 216,698 thousand m$^3$, of which nitrogen compounds make 0.46 kt, phosphorus - 0.06 kt and potassium – 3.72 kt. The annual volume of drainage runoff for the long-term average annual from the operating drainage systems is 1,564,436 thousand m$^3$, of which nitrogen washout is 4.7 kt, phosphorus - 0.16 kt, potassium - 3.25 kt. Total annual washout of biogenic substances from drained lands is 12.32 kt, of which 4.24 kt are carried with surface runoff and 8.08 kt with drainage water.
It was revealed that the main load on the water bodies is from the discharge of drainage waters, the volume of which is 7.2 times higher than the surface runoff, with the content of pollutants being 65% of the total diffuse pollution.

The materials of the article are of practical value for justifying the need to develop and apply effective measures and technical solutions that ensure the decrease of diffuse runoff from reclaimed areas due to its reduction and treatment.

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