Surface run-off as a factor of water quality in water-supply sources formation

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Abstract. The paper describes the source water characteristics, obtained at Samara pump-filtration station № 1 according to the following indicators: permanganate oxidizability, turbidity, suspended substances, colour, manganese, as well as the quality of surface run-off, which is discharged upstream into the source of water supply within the boundaries of the third sanitary protection zone. Surface run-off is characterized according to $\text{BOD}_{5}$, suspended substances, nitrogen group, phosphates, iron (total), oil products, Anion Synthetic Surfactants (ASS). The researchers applied mathematical statistics methodology to determine regressional dependencies between separate variables of source water. It is established that out of all variables, only turbidity and colour are connected with separate qualitative variables of surface run-off. The authors assess degree of this connection and introduce calculation dependencies. Keywords: surface run-off, water treatment station, water supply sources, water quality indicators.

1. Introduction
Surface run-off is considered to be one of the main sources of pollution. It has an effect on formation of water bodies qualitative composition [1,2], including those water objects which serve as sources of drinking water supply [3].

The qualitative composition of surface run-off is studied sufficiently enough [4-6]. It is characterized by certain seasonal regularities [7-11], typical for a certain region. In quantitative terms, the formation of surface run-off depends on climate conditions [12,13] and on water catchment area characteristics [14,15]. Besides, in modern cities, researchers observe an increase in run-off rate of discharge together with the growth of their urbanization [16,17].

The existing technical solutions aimed at protection of water objects from surface run-off pollution are mostly based on their techno-economic and environmental efficiency [18]. They do not take into account the direct impact of the sources under consideration on water supply systems. At the same time, the choice of technological schemes of surface run-off purification is mainly made on the basis of dictating ingredients selection [19]. Sometimes, they do not include indicators, which are most important in water treatment technology.

Studies of the source water composition conducted at pumping-filtration stations show the need to increase their barrier role [20] as well as to introduce new technological processes [21,22].

It is obvious, that optimization of measures to protect water objects from surface run-off pollution and to increase a barrier role of waterworks water treatment facilities is possible only after detailed
consideration. This paper identifies basic patterns of water quality formation under the impact of surface run-off with account of determined technological parameters.

2. Problem specification

Water supply of the city of Samara is carried out both from surface sources, and by way of groundwater withdrawal. The main source of water supply is the Saratov water reservoir of the Volga river.

There are several pumping-filtration stations (PFS-1, PFS-2 and hot water supply stations known as HWS) in Samara. The total capacity of the Samara City water supply system is more than 1 mln. m³/day.

The largest station is PFS-1 (it was constructed and put into operation in 1931-1978) The station consists of three channel river intakes, combined with three pumping stations of the first ascent. According to Paper [12], water treatment technology used at this station is a two-stage purification scheme (consisting of horizontal flow sedimentation basins and quick filters). The station is located on the bank of the Volga river (the Saratov water reservoir) in the northern part of Samara (Soviet Army str., 298). The design capacity of sewage treatment plants here is 550 thous. m³/day.

Table 1 shows main variables used to select the technological scheme of water treatment at this station. They are turbidity (T) and colour (C).

The scheme also includes suspended substances (SS), permanganate oxidizability (PO) and manganese content. Permanganate oxidizability is a variable characterizing the total contamination of water by organic substances. When their content is changed, the work of wastewater treatment facilities is also affected.

Manganese as an important variable is also considered because in recent years its concentration in the region is constantly increasing (usually in summer). It is necessary to determine if this process connected with untreated surface run-off from urban areas flowing into water bodies.

Table 1 shows characteristics of the initial water coming to PFS-1.

Table 1. Average monthly values of variables (taken in 2013-2016).

| Month | Permanganate oxidizability (PO), mgO/dm³ | Turbidity (T), mg/dm³ | Suspended substances (SS), mg/dm³ | Colour (C), grad. | Manganese (Mn), mg/dm³ |
|-------|----------------------------------------|----------------------|----------------------------------|------------------|----------------------|
| 1     | 6.350                                  | 0.605                | 3.100                            | 25.0             | 0.020                |
| 2     | 7.010                                  | 0.615                | 3.100                            | 28.0             | 0.052                |
| 3     | 6.625                                  | 0.615                | 3.300                            | 30.0             | 0.035                |
| 4     | 7.217                                  | 2.470                | 4.800                            | 32.7             | 0.092                |
| 5     | 6.700                                  | 1.823                | 5.400                            | 32.0             | 0.079                |
| 6     | 7.200                                  | 0.960                | 3.677                            | 36.3             | 0.069                |
| 7     | 7.100                                  | 0.790                | 3.467                            | 32.0             | 0.053                |
| 8     | 7.100                                  | 0.947                | 3.000                            | 25.0             | 0.038                |
| 9     | 6.767                                  | 0.990                | 3.067                            | 26.0             | 0.028                |
| 10    | 6.800                                  | 0.690                | 3.133                            | 25.0             | 0.034                |
| 11    | 5.900                                  | 0.630                | 3.933                            | 19.5             | 0.017                |
| 12    | 6.176                                  | 0.717                | 3.000                            | 20.2             | 0.047                |

Water disposal in Samara is carried out mainly by a complete separate sewage system.

Depending on the topography of the terrain, Samara is divided into 15 sewerage basins to collect and divert surface run-off from the territory of the city [23].

Through the system of rainwater drainage, surface run-off flows from I, II, III, IV, V sewerage basins into the Saratov reservoir. There are no surface run-off treatment facilities [23].

Upstream, within the boundaries of the third line of PFS-1 water intake sanitary protection zone, the discharge of surface run-off is carried out through "Proseka 8" wastewater outlet. The main trunk
permanganate oxidizability and water colour (both parameters characterize organic substances). The content of suspended substances is connected with water turbidity. The parameters which are selected at pumping-filtration stations. As a result, they defined regressional according to its main variables.

In this research, the authors used quantitative chemical analysis data and employed mathematical dependencies between the quality of surface run-off and water variables at PFS-1, but also to estimate multiplicity of dilution in Papers [24,25], statistical methods allow not only to determine the impact really exists, it is important to determine what variables prevail and to develop mathematical models of raw water parameters connection with the quality of the surface run-off.

### 3. Research results

In this research, the authors used quantitative chemical analysis data and employed mathematical statistics methods for its analysis. In contrast to the calculation methods used to determine the multiplicity of dilution in Papers [24,25], statistical methods allow not only to determine the dependencies between the quality of surface run-off and water variables at PFS-1, but also to estimate the degree of impact of each source of pollution on the qualitative composition of water supply source and its formation.

At the first stage the researchers assessed the dependence between the main technological parameters which are selected at pumping-filtration stations. As a result, they defined regressional dependencies (see Table 3) which allow to characterize the inter-influence of individual parameters and determine their significance, especially in conditions when initial information is not complete.

The analysis of the obtained models (see Table 3) shows that there is a dependency between permanganate oxidizability and water colour (both parameters characterize organic substances existence in the water). The content of suspended substances is connected with water turbidity. The turbidity itself is characterized not only by the presence of suspended substances, but also by the

| Month | BOD<sub>total</sub> | BB | NH<sub>4</sub><sup>+</sup> | NO<sub>2</sub> | NO<sub>3</sub><sup>-</sup> | P | Fe | HII | ASS |
|-------|-----------------|----|----------------|--------|----------|---|----|-----|-----|
| 1     | 7.500           | 17.450 | 2.000       | 0.350  | 5.600    | 0.320 | 0.320 | 0.053 | 0.075 |
| 2     | 6.600           | 6.600  | 1.115       | 0.155  | 2.550    | 0.205 | 0.290 | 0.038 | 0.059 |
| 3     | 5.750           | 7.200  | 1.600       | 0.165  | 1.020    | 0.215 | 0.305 | 0.050 | 0.090 |
| 4     | 7.200           | 35.233 | 1.717       | 0.270  | 1.203    | 0.197 | 0.607 | 0.113 | 0.110 |
| 5     | 7.900           | 8.633  | 2.367       | 0.267  | 1.170    | 0.257 | 0.383 | 0.104 | 0.083 |
| 6     | 6.433           | 19.700 | 2.097       | 0.197  | 1.210    | 0.193 | 0.373 | 0.105 | 0.070 |
| 7     | 5.467           | 9.500  | 0.563       | 0.153  | 1.320    | 0.101 | 0.323 | 0.060 | 0.070 |
| 8     | 8.867           | 11.700 | 2.287       | 0.375  | 1.000    | 0.233 | 0.447 | 0.060 | 0.098 |
| 9     | 5.867           | 9.333  | 1.820       | 0.387  | 1.450    | 0.127 | 0.293 | 0.059 | 0.111 |
| 10    | 7.533           | 8.367  | 2.527       | 0.293  | 1.083    | 0.287 | 0.310 | 0.057 | 0.111 |
| 11    | 5.267           | 10.467 | 1.710       | 0.174  | 0.913    | 0.263 | 0.340 | 0.081 | 0.071 |
| 12    | 5.600           | 11.800 | 1.757       | 0.163  | 1.700    | 0.173 | 0.283 | 0.065 | 0.100 |

Note: SS – suspended substances, NH<sub>4</sub><sup>+</sup> – ammonium ion, NO<sub>2</sub> – nitrite ion, NO<sub>3</sub><sup>-</sup> – nitrate ion, P – phosphates (phosphorus), Fe – iron (total), PP – petroleum products
presence of manganese compounds. It is interesting that according to the statistical parameter R-Squared, the change of turbidity is by more than 65% described by these two parameters.

**Table 3.** Dependence of source water parameter on PFS-1.

| Parameter                  | Regressional model                                                                 | R-Squared |
|----------------------------|-----------------------------------------------------------------------------------|-----------|
| Permanganate oxidizability | $4.3024 + 0.0886217 \cdot C$                                                      | 58.0520   |
| Turbidity                  | $-0.609559 + 0.258516 \cdot SS + 14.5004 \cdot Mn$                               | 66.2754   |
| Suspended substances       | $2.78348 + 0.816877 \cdot M$                                                      | 32.1272   |
| Colour                     | $-16.5876 + 6.55054 \cdot PO$                                                     | 58.0520   |

At the second stage, the researchers defined the dependences between the source water at PFS-1 and quality parameters of surface run-off flowing into the Saratov reservoir.

It is determined that the statistically significant dependence on the quality of surface run-off is characterized by only two parameters: Turbidity and colour (see Table 4).

**Table 4.** Dependence between water parameters on PFS-1 and surface run-off.

| Parameter                  | Regressional model                                                                 | R-Squared |
|----------------------------|-----------------------------------------------------------------------------------|-----------|
| Turbidity                  | $0.12146 + 0.0320927 \cdot SS + 0.212821 \cdot NH^+ - 2.02073 \cdot NO^- + 1.63389 \cdot Fe$ | 68.5328   |
| Colour                     | $21.2589 + 87.9562 \cdot NP$                                                      | 32.3365   |

The amount of turbidity is affected by the content of suspended substances in the surface run-off, as well as the content of iron (general), ammonium and nitrite nitrogen. It should also be noted that the increase of nitrite content reduces turbidity. This seems to reflect the interconnection of different forms of nitrogen in water. The increase in nitrites concentration is characterized by lower content of ammonium nitrogen.

The colour of water is affected by the content of oil products in surface run-off. They determine colour variability by about 30%.

### 4. Conclusion

The research shows that surface run-off discharge through "Proseka 8" wastewater outlet has a statistically significant effect on PFS-1 source water quality.

The obtained regressional dependencies between the main parameters of crude water at treatment stations give an opportunity to make forecast for different periods of the year as well as to link values of individual parameters among themselves.

The proposed regression models allow to predict the influence of applied technical solutions aimed at reduction of surface run-off discharge onto water treatment systems operation, with PFS-1 as an example.

Turbidity of initial water at PFS-1 is affected by suspended substances, ammonium, nitrite nitrogen and total iron. Water colour, in its turn, depends on oil products content.

The content of suspended substances, manganese and permanganate oxidizability have no statistically significant connection with the quality of surface wastewater flowing through "Proseka 8" wastewater outlet. Obviously, these parameters are mostly formed more under the influence of other natural and anthropogenic sources.

The lack of a statistical connection between manganese content and the quality of surface run-off indirectly confirms the opinion that its concentration in water bodies of the region is connected primarily with biological processes which take place in these water bodies (extinction of algae). It does not directly depend on external sources of pollution.
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