PhD Nemtsova A.A.

National University of Pharmacy, Ukraine

Impact assessment of runoff on river water quality

Land runoff is one of the main diffuse pollution sources for water bodies. In Ukraine about 80% of total amount of pollutants are discharged water bodies with runoff. Most of settlements do not have storm-water sewage systems or these systems cover only some parts of cities As result not only agriculture runoff and runoff from natural lands are coming into surface waters, but urban runoff is entered into them directly too. Unsatisfactory sanitary state of urban areas leads to high level of runoff pollution. E.g. average content of suspended solids reaches up to 1000 g/m^3, average content of oil products 16 g/m^3, and average content of organic substances (in units of BOD_{20}) 150 $g0_2/m^3$. In Ukraine, mainly small rivers represent surface waters. In this case, the negative influence is doubled, especially for anthropogenic impact of runoff. Compounds variability and particularly high level of pollutants are characteristic features of runoff. Runoff characteristics are depended on watershed area use. E.g. high level of pesticides, nutrients and high dissolved solids content feature agricultural runoff. Urban runoff usually contains oil-product additionally However all kinds of runoff are characterized by high level of organic matter and suspended solids. Suspended solids are the most characteristic pollutants of land runoff. They exert the major influence on water quality and on ecological conditions of water bodies. Essential increase of oxygen consumption by bottom deposits and change of living conditions for microorganisms in water and deposits reflects this influence. Therefore, impact assessment of runoff using suspended solids content in watercourses is necessary.

At the same time suspended solids content in water body is determined not only by their impact from external sources, but by sediment transport capacity as well. There is permanent exchange of suspended solids between water body and bottom deposits. This fact stimulates specific requirements to calculation methods. At present, the methods used for impact assessment of runoff on water quality do not allow taking into account this peculiarity of suspended solids. The aim of this paper is development of mathematical model, which allow evaluating impact of non-point sources of pollution on suspended solids content in watercourses.

The mathematical model is based on the mass conservation principle. One-dimension statement of the problem is considered. This approach can use for relatively non-wide watercourses.

Consider an elementary section of watercourse in the shape of prism. (See Fig. 1)

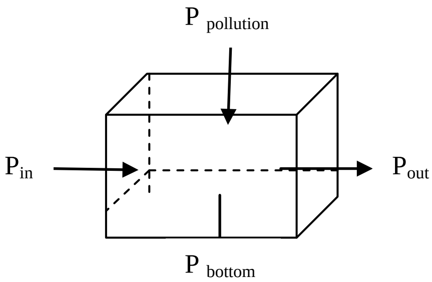

Figure 1. Scheme of mass balance in elementary section of watercourse.

The mass balance of suspended solids in the section can be written in the form:

$$P_{in} - P_{out} + P_{pollution} - P_{bottom} = 0 \qquad (1)$$

$\boldsymbol{P_{in}}$ = mass of suspended solids is entered into section through left lateral face per second, g/s.

$\boldsymbol{P_{out}}$ = mass of suspended solids is coming out section through right lateral face per second, g/s.

$\boldsymbol{P_{pollution}}$ = mass of suspended solids is entered into section through top face with runoff per second, g/s.

$\boldsymbol{P_{bottom} = P_{down} - P_{up}}$.

$\boldsymbol{P_{down}}$ = mass of suspended solids is settling through bottom face per second, g/s.

$\boldsymbol{P_{up}}$ = mass of suspended solids is entered into section through bottom face in process of re sedimentation per second, g/s.

Hydraulic characteristics of stream flow for section are assumed to be constant.

Consider every term in expression (1) separately.

a. Mass of suspended solids is entered through left lateral face of section. $\boldsymbol{P_{in}}$ can be determined as:

$$\boldsymbol{P_{in} = Q \cdot C} \qquad (2)$$

Q = flow rate, m^3/s.

C = average concentration of suspended solids on the left lateral face of section, g/m^3.

b. Mass of suspended solids is entered into section by runoff per second. $P_{pollution}$ can be determined as:

$$P_{pollution} = f \cdot L \tag{3}$$

f = specific (per the unit of length of watercourse) entrance of suspended solids into water body per second, g/(m·s).

L = length of section of watercourse, m.

The value f is obtained as:

$$f = Q_{pollution} \cdot C_{pollution} \tag{4}$$

$Q_{pollution}$ = specific (per unit of watercourse length) discharge of runoff from watershed area, m^3/s.

$C_{pollution}$- concentration of suspended solids in runoff, g/m^3.

c. Alteration of suspended solids mass as a result of water body and bottom deposits exchange per second. P_{bottom} can be determine as:

$$P_{bottom} = q \cdot B \cdot L \tag{5}$$

q = sediment discharge in the vertical direction, $g/(m^3 \cdot s)$.

B = width of watercourse, m.

d. Mass of suspended solids is coming out from section per second. P_{out} can be determined as:

$$P_{out} = Q \cdot (C + \Delta C) \tag{6}$$

ΔC = change of average concentration of suspended solids along watercourse, g/m^3 It can be positive or negative.

The method to obtain the sediment discharge in the vertical direction depends on degree of saturation of water flow by suspended solids. The value of resedimentation concentration is usually used as criteria of saturation by suspended solids. Stream flow is sediment over laden if the average concentration of suspended solids in water body is more than concentration of sediments. Otherwise, the stream flow is normal.

The value of resedimentation concentration can be determined by Karaushev's empirical formula (Karaushev, 1977):

$$C_{res} = 150 \cdot N \cdot \eta^2 \cdot v^2 / h \qquad (7)$$

N and ***η*** are non-dimensional parameters. They can be determined as:

$$N = \frac{M \cdot Sh}{g}; \quad \eta = 1 - \frac{M}{3 \cdot Sh}; \quad M = 0,7 \cdot Sh + 6 \quad if \quad Sh \le 60; \qquad M = 48 \quad if \quad Sh > 60 \qquad (8)$$

Sh = Shezi's coefficient, $m^{1/2}/s$.

g = the acceleration due to gravity, m^2/s.

Sediment discharge in the vertical direction for normal stream is formed under influence of two major factors: sedimentation of suspended solids and resedimentation as result of turbulent exchange between water body and bottom deposits.

Mass of suspended solids that settle out from volumetric element of water body to unit area of bottom is determined as product of two factors: settling velocity of suspended fractions and average concentration of suspended solids.

Mass of suspended solids that rise from bottom deposits to water body under the influence of the turbulent exchange can be assumed proportionate to difference between concentration of resedimentation and average concentration of suspended solids in water body (Karaushev, 1987).

Thus, the value of sediment discharge in vertical direction is evaluated from formula

$$q = u \cdot C - k \cdot \left(C_{res} - C\right) \qquad (9)$$

u = settling velocity, m/s.

k = dimensional coefficient of proportion, m/s.

Value of the coefficient ***k*** is found from relationship

$$k = u \cdot \frac{\Gamma}{1 - \Gamma} \qquad (10)$$

Γ = non-dimensional hydro mechanical parameter of sediments. Value of this parameter depends on value of Shezi's coefficient (***Sh***) and non-dimensional parameter ***G = u/v***. Values of hydro mechanical parameter are indicated in **Table 1.**

Table 1. Values of hydro mechanical parameter ***Γ***

G	***S_h***				
	20	30	40	50	60
0,0001	0,998	0,9950	0,9600	0,98600	0,9800
0,0010	0,960	0,9340	0,9000	0,86000	0,8160
0,0020	0,927	0,8740	0,8120	0,74200	0,6690
0,0050	0,827	0,7160	0,6010	0,48400	0,3870
0,0100	0,687	0,5200	0,3730	0,25900	0,1770
0,0200	0,479	0,2900	0,1690	0,09900	0,0660
0,0300	0,337	0,1680	0,0840	0,04400	0,0260
0,0400	0,254	0,1100	0,0520	0,02600	0,0150
0,0600	0,041	0,0490	0,0188	0,00890	0,0045
0,0800	0,079	0,0231	0,0084	0,00330	0,0015
0,1000	0,044	0,0123	0,0038	0,00143	0,0005

Substituting relationships (2) - (6), (9) to (1) and approaching the limit as L $\to$ 0 we obtain the following equation

$$QdC = \left(f - \left(u \cdot C - k \cdot \left(C_{res} - C \right) \right) \cdot B \right) dL \qquad (11)$$

The boundary conditions are $\boldsymbol{C = C_0}$ at $\boldsymbol{L} = 0$.

Taking into account (10), the solution of the equation (11) can be formulary as

$$C = C_{tr} + \frac{f}{B \cdot (u+k)} + \left(C_0 - C_{tr} - \frac{f}{B \cdot (u+k)} \right) \cdot \exp\left(-\frac{B \cdot (u+k)}{Q} \cdot L \right) \qquad (12)$$

$\boldsymbol{C_0}$ = suspended solids concentration on the left boundary of watercourse section, g/m^3.

$\boldsymbol{C_{tr}}$ = concentration, corresponding to sediment transporting capacity of stream flow (Rodziller, 1984).

$$C_{tr} = \Gamma \cdot C_{res} \qquad (13)$$

For sediment overladen streamflow ($C_0 > \boldsymbol{C_{res}}$) only intensive gravitational settling of suspended solids is characteristic. In this case, sediment discharge in the vertical direction is introduced in form:

$$q = u \cdot C \qquad (14)$$

The balance equation (11) is reduced and can be written in the form

$$QdC = -\left(u \cdot B \cdot C - f \right) \qquad (15)$$

Its solving is

$$C = \left(C_0 - \frac{f}{u \cdot B} \right) \cdot \exp\left(-\frac{u \cdot B \cdot L}{Q} \right) + \frac{f}{u \cdot B} \tag{16}$$

Expressions (12) and (16) were obtained under assumption that all suspended solids have same settling velocity. The superposition principle can be used to extend these expressions on real streamflow conditions.

The developed mathematical model was used for calculation of suspended solids content in the Lopan River (Ukraine). This river flows through the city of Kharkov (with population about 1,5 million). Part of runoff non-collected by storm-water drain system discharges river. The discharge from urban wastewater treatment plant is located at distance 3 km upstream mouth of river. The Lopan River is the small one. Average long-term flow rate Q = 2,4 m^3/s, stream velocity v = 0,13 m/s, depth of stream h = 1 m. Wastewater entered into water body leads to increase of suspended solids content downstream. The average concentration of suspended solids is 30 mg/l. The average discharge of a runoff is 0,43 m^3/s. The concentration of suspended solids in a runoff from urban area is about 1000 mg/l. Granulometric composition of suspended solids is heterogeneous. They presented by fine-dyspersated sediments mainly. About 80 % of suspended solids have a size no more than 0,05 mm, including about 15% of sediments with diameter less than 0,005 mm. Eight the most representative fractions can be selected on the basis of long-term observations. Characteristic of suspended solids granulometric composition is shown in Table 2.

Table 2. Granulometric composition of suspended solids.

Diameter, m	10^{-3}	$5\cdot10^{-4}$	$2\cdot10^{-4}$	10^{-4}	$5\cdot10^{-5}$	10^{-5}	$5\cdot10^{-6}$	10^{-6}
Hydraulic size, m/s	10^{-1}	$6\cdot10^{-2}$	$2\cdot10^{-2}$	$8\cdot10^{-3}$	$2\cdot10^{-3}$	$8\cdot10^{-5}$	$3\cdot10^{-5}$	$8\cdot10^{-7}$
Content for river, %	25,3	15,8	28,9	10,2	4,6	4,2	5,0	6,0
Content for runoff, %	0	5	5	10	25	40	7	8

The main hydromechanical characteristics of streamflow for each fraction - concentration of resedimentation C_{res} and concentration, corresponding to sediment transporting capacity of stream C_{tr} - were calculated by relationships (7), (13) respectively. Results of calculation are presented in Table 3.

Table 3. The main hydromechanical characteristics of streamflow by fractions.

Diameter, m	10^{-3}	$5{\cdot}10^{-4}$	$2{\cdot}10^{-4}$	10^{-4}	$5{\cdot}10^{-5}$	10^{-5}	$5{\cdot}10^{-6}$	10^{-6}
C_{res}, mg/l	11,62	7,26	13,28	4,69	2,11	1,93	2,30	2,76
C_{tr}, mg/l	$1{,}2{\cdot}10^{-4}$	$1{,}4{\cdot}10^{-4}$	0,20	0,66	1,01	2,09	2,10	2,89

The calculations of suspended solids concentration by the relationships (12), (16) were carried out for each of eight fractions separately. They have shown that the sedimentation and resedimentation processes to exercise a significant influence on suspended solids content. Sedimentation processes dominates for fractions with a diameter of particles from 0,05 mm to 1,00 mm. Resedimentation processes is more typical for fine-dyspersated sediments with a diameter from 0,001 mm to 0,005 mm. The process becomes stabilize at the distance about 200 m from initial point. The results of calculations for some fractions are shown on Fig. 2.

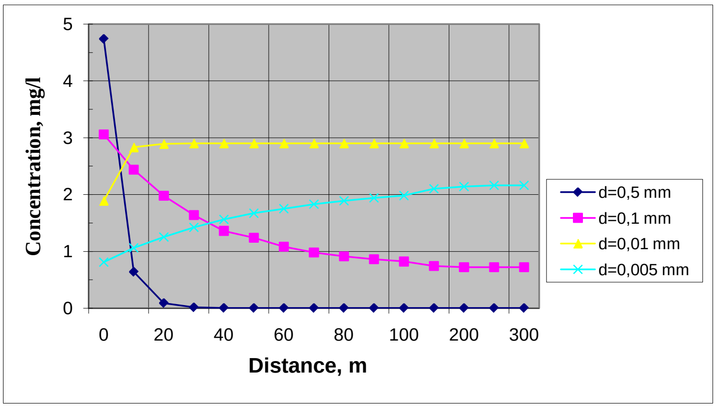

Figure 2. Change of suspended solids concentration for different fractions.

Total concentration of suspended solids, obtained on the basis of the superposition principle, shown that incoming of runoff leaded to increasing of suspended solids content on 10,8% in compares with sediment transporting capacity of stream. The results of calculation were compared with five-year field data. (See Fig. 3) and confirmed adequacy of the model.

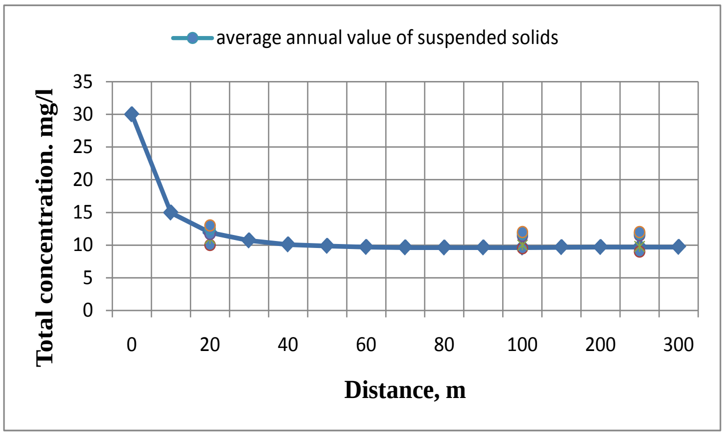

Figure 3. Comparison of calculated suspended solids concentration with field data

REFERENCES

Karaushev A V (1977). Theory and methods of calculation of river sediments, Gidrometeoizdat, Leningrad, 272 p. (In Russian).

Karaushev A V (1987). Metodological fundamentals of assessment and reglamentation of anthropogenic impact on surface water quality, Gidrometeoizdat, Leningrad, 250 p (In Russian).

Rodziller I D (1984). Forecasting of water quality of water bodies, Strojizdat, Moskow, 263 p. (In Russian).

Nemtsova A.A., Ponomarenko E.G. (2012). Use of balance and one-component models for assessment of river water quality. Materials of International Scientifical-Practical Conference “The Science and education in 21 century”. Vol. 40. Ecology. Sofia. p. 3-8.