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ANALYSIS AND MODELLING OF POLLUTANTS MIGRATION (CS-137) IN CASCADE OF DIDORIVSKY PONDS IN THE HOLOSIIVSKYI PARK

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Abstract. *The basic model of radionuclide content of Cs-137 in the cascade Didorivsky ponds was constructed. The cascade monitoring data were obtained. Base model extrapolation was made up on the base of the observed data and accurate model of the cascade was obtained. Model extrapolation resulted in conclusions concerning accumulation of Cs-137 radionuclide in the cascade of Didorivsky ponds for 50 years.*

Keywords: box model; radioactivity; radionuclides migration.

1. Introduction

Kyiv is the largest city of Ukraine, overloaded with hundreds of enterprises. Their activity is usually accompanied by the emission into the environment that adversely affect the biota. This is primarily heavy metals, pesticides, nitrates, dioxins. In addition, Kyiv suffered from contamination, caused by the Chernobyl accident in 1986.

Like a city, Holosiivskyi forest has been exposed to various of contaminants. Moreover, as any forest, being a barrier to the spread of contamination, acting as a defender of the environment, it is a scope of various substances, including toxic ones.

Reservoirs constitute an integral part Holosiivskyi forest. Holosiivsky ponds are subjects of strengthening eutrophication, due to discharges of pollutants. Thus, today there is an urgent need to study ecological processes that occur in ponds. . We offer the use of radionuclides as trasers because cesium -137 is an analogue of potassium, which clearly shows the status of the biota in ponds and its concentration can be easy determined in reservoirs. Moreover, cascades of Holosiivsky ponds are an excellent test object for the modeling of radionuclides like Cs137, because all three cascades belong to the park area and this allows to build more accurate models. They are also characterized by slow water income sufficient to establish equilibrium between water, biota and sediment budget. These models may be used to study the distribution of pollutants such as Pb, Zn and other heavy metals, behavior of which may be similar to the behavior of cesium in the cascade of ponds.

Holosiivskyi forest ponds, which are formed as a result of river barrage or stream valleys, can be attributed to three main groups. They are primarily Gorihovatski Ponds (at pp. Gorihovatka), Didorivsky Ponds (Didorivsky stream) and Kitaevski Ponds (Kitaevskyi stream) [1].

Each of the three cascades is formed by four interconnected ponds. Each pond at the bottom is limited by dam. Next to the dam there is a well thtough which in case of certain level of water it flows into the pond situated below [2].

In this study we will consider Didorivsky cascade. This cascade is located entirely within the Park "Holosiivskyi", the most distant from the city.

Holosiivskyi (Didorivsky) stream originates in Golosiiv forest to the north of the Main Astronomical Observatory of NAS of Ukraine. Then the natural boundary runs northeast and form near the desert Golosiyivska number of ponds, which are called "Holosiivskyi" (the largest of them – Didorivsky). Then the stream turns southeast and by flowing through the trap, creates several ponds. Near Kytayivska str. it merges with another stream – Kitaevska and Mysholovsky collector, which goes to the east which flows into the Dnieper Galley Bay [3].

The total area of of Didorivsky ponds is 10.3 hectares. The depth of the ponds in the central part ranges from 50-100 to 250-300 cm, while their filling occurs predominantly due to atmospheric and spring water. The predominant soil is muddy sand, detritus.

These reservoirs are of drainage or art and recreation type. All of them are affected by eutrophication (biegenic enrichment of water) [4].

2. Analysis of the latest research and publications

Radioactive contamination of aquatic ecosystems may occur as wide variety of shapes and composition of substances containing radionuclides. When radioactive materials intake in the form of aerosols into water surface and the catchment area through surface runoff, they disperse in the water column and subsequent distribute in components of aquatic ecosystems with the establishment of a dynamic equilibrium, which is determined by the sorption and desorption processes between liquid (water) and solid (sediments, suspended solids) phases, as well as the accumulation of radionuclides by living organisms.

It should be noted that in case of the short-term intake into the reservoir, radionuclides are absorbed enough quickly by bottom sediments and aquatic organisms, resulting in their specific activity rapid decrease in water. High concentration of many radionuclides in aquatic plants, animals and bottom sediments can be supported for a long time exceeding their concentration in water at orders of magnitude [5, 6].

Accumulation of radionuclides by biota is caused by the feature of mineral metabolism of all living organisms, in which the input of micronutrients and macronutrients in the body is much faster than their output. Bottom sediments deposit a bulk of radionuclides fall into the pond, due to the large mass and sorption capacity of absorption.

Further processes of vertical and horizontal migration and redistribution of radionuclides in aquatic ecosystems, biogeochemical cycles are related to movement of substances in nature and occur much more slowly. Thus, together with the superior sedimentation and sorption processes of deposing radionuclides in bottom sediments and sedimentation on suspensions, the importance of their migration and accumulation in the food network, and continued participation in the biotic cycle of life as a result of aquatic organisms.

Bottom sediments play important role in the fate of radionuclides in fresh water. Having a large sorption mass and absorption capacity, they deposit a bulk of emitting radionuclides that fall into the pond, and thus partially (often temporarily) remove them from the biotic cycle. In this regard, bottom sediments play significant role in the process of self-purification of water from various, including radioactive substances. This is due to the sorption of radionuclides by bottom surface, diffusion of water into the thickness of the bottom sediments, due to deposition of suspended particles to the bottom, carrying sorbed radionuclides, and as a result of settling to the bottom of the remnants of dead aquatic organisms (plants and animals), which also contain radionuclides in their tissues.

The highest sorption capacity and absorptive capacity is inherent in bottom sediments, consisting mainly of fine clay or silt particles. Therefore, in areas with large bottom deposits of silt, the greatest accumulation of radioactivity may be expected in comparison with the mouth of the river, the bottom of which is formed of clean, well-washed sand, gravel or rock [8].

3. The aim of the research

The aim of the research is to build the model of cascade of Didorivsky ponds and to conduct its analysis.

Due to the need to study ecological processes in Holosiivskyi ponds, several problems appear:

- to build the basic model of the cascade;
- to get natural monitoring data;
- to extrapolate the simulation results;
- to analyse obtained models.

4. Materials and methods

For this study we selected samples of bottom sediments, biota and soil of Didorivsky water bodies cascade. From each pond were selected 2 samples. Selected samples were dried and the content of ^{137}Cs was measured with the help of gamma spectrometer SEG-01.

To describe the transfer (transition) and migration of radionuclides in ecosystems, the method of box models is used. Whole their chain of radionuclides transfer is divided into chambers [7]. The interaction between the cameras is specified using transfer of radionuclides from one chamber to another per unit of time (usually a year). The coefficients are selected due to field research and calculations [9].

The calculations were made with the help of the Maple software on the base of differential equations. Behavior of 137Cs was analyzed, as they are the main isotopes in contaminated waters and their biotic components. Built models (fig. 1) included such boxes as "soil", "water", "bottom sediments","biota".

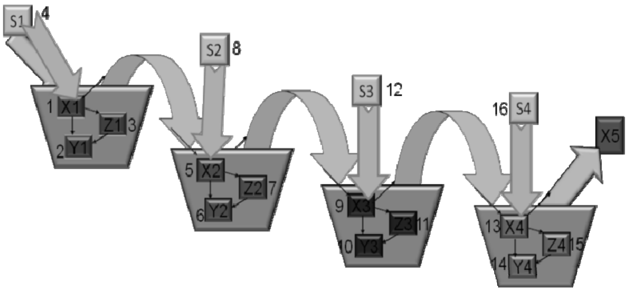

Fig. 1. Block diagram of Holosiivski ponds cascade: X - water, Y - bottom, Z - biota, S - soil.

5. Construction and analysis of the basic model of Didorivsky ponds cascade

The basic model of Holosiivskyi ponds is built on the base of flowcharts and it takes into account the speed of radionuclide transfer between the boxes and inside each chamber between water, biota and bottom sediments. Box model of ponds cascade as a system of ordinary differential equations of first order, is represented below:

$$\begin{cases} \frac{dX1}{dt} = a41 * S1(t) - (a13 + a12 + a15) * X1(t) \\ \frac{dY1}{dt} = a12 * X1(t) \\ \frac{dZ1}{dt} = a13 * X1(t) \\ \frac{dS1}{dt} = -a41 * S1(t) \\ \frac{dX2}{dt} = a85 * S2(t) - (a57 + a56 + a59) * X2(t) \\ \frac{dY2}{dt} = a56 * X2(t) \\ \frac{dZ2}{dt} = a57 * X2(t) \\ \frac{dS2}{dt} = -a85 * S2(t) \\ \frac{dX3}{dt} = a129 * S3(t) - (a911 + a910 + a913) * X3(t) \\ \frac{dY3}{dt} = a910 * X3(t) \\ \frac{dZ3}{dt} = a911 * X3(t) \\ \frac{dS3}{dt} = -a129 * S3(t) \\ \frac{dX4}{dt} = a1613 * S4(t) - (a1315 + a1314 + a1317) * X4(t) \\ \frac{dY4}{dt} = a1314 * X4(t) \\ \frac{dZ4}{dt} = a1315 * X4(t) \\ \frac{dS4}{dt} = -a1613 * S4(t) \end{cases}$$

where *a* radionuclide transfer coefficient between the cameras, X1-4 – water, Y1-4 – bottom, Z – biota, S1-4 – soil.

The average values of transfer speed were taken as the result of typical field research and results of calcutions:

$$a41 = 0,05;\ a12 = 0,6;\ a13 = 0,35;\ a15 = 0,05;$$
$$a85 = 0,03;\ a85 = 0,03;\ a56 = 0,6;\ a57 = 0,35;$$
$$a59 = 0,05;\ a129 = 0,03;\ a910 = 0,6;$$
$$a911 = 0,35;\ a913 = 0,05;\ a1613 = 0,02;$$
$$a1314 = 0,6;\ a1315 = 0,35;\ a1317 = 0,05.$$

Results of the study and the model are shown in Fig. 2-5, in the form of graphs, for the most important cells in the processes of distribution and redistribution of radionuclides.

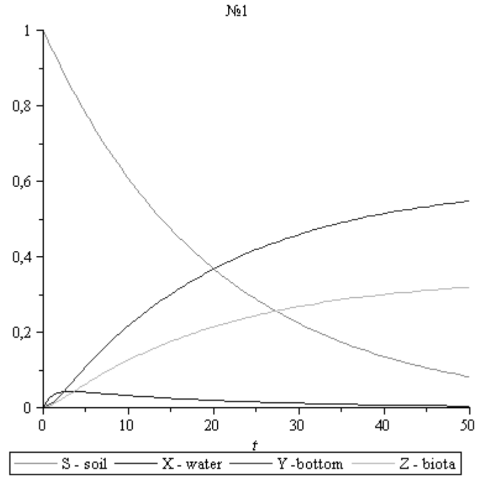

Fig. 2. Dynamics of the radionuclides concentration change for 50 years in the first pond

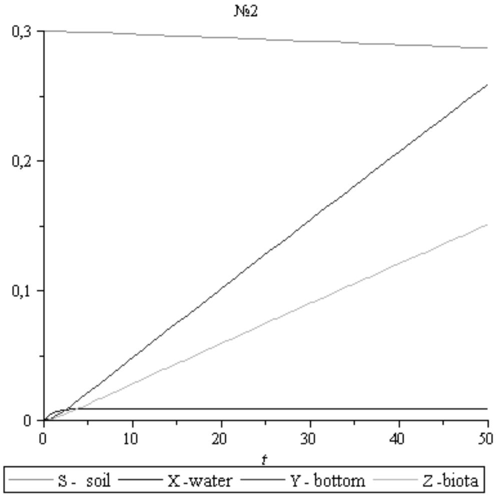

Fig. 3. Dynamics of the radionuclides concentration change for 50 years in the second pond

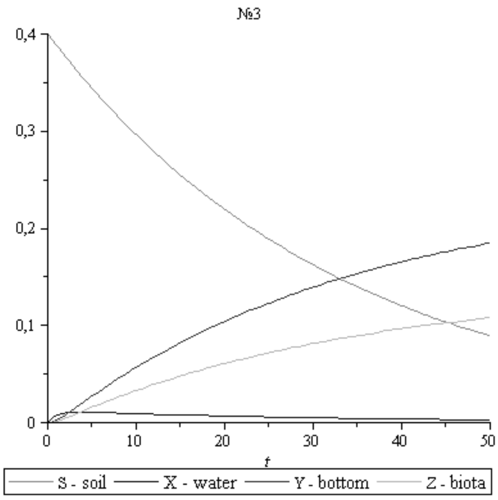

Fig. 4. Dynamics of the radionuclides concentration change for 50 years in the third pond

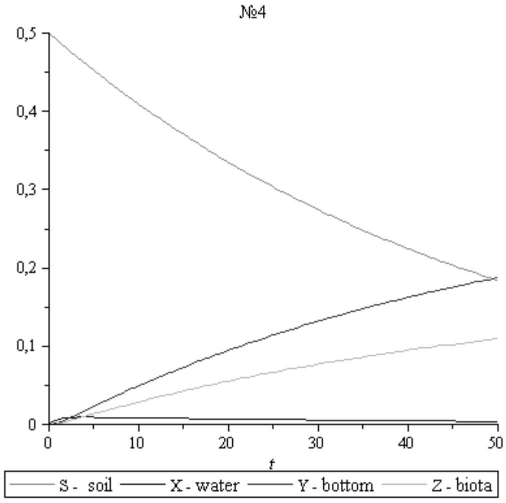

Fig. 5. Dynamics of the radionuclides concentration change for 50 years in the fourth pond

As a result, most of radionuclides accumulate in first pond. Noticeable gradual clearing from radionuclides was detected in cascade. In case of radionuclides accumulation in each pond, with time Cs-137 accumulating in the bottom sediments and biota was observed.

6. Extrapolation and analysis of the model according to the results of field studies

The results of field studies are presented in Table 1.

The basic model of the cascade is extrapolated so that at 29th year to get the model result close to the conducted monitoring. To do this, the coefficients were corrected by observed data monitoring:

$$a41 = 0{,}05;\ a12 = 0{,}104;\ a13 = 0{,}115;$$

$$a15 = 0{,}05;\ a85 = 0{,}03;\ a56 = 0{,}98;$$

$$a57 = 0{,}86;\ a59 = 0{,}05;\ a129 = 0{,}03;$$

$$a910 = 0{,}46;\ a922 = 0{,}38;\ a913 = 0{,}05;$$

$$a1613 = 0{,}02;\ a1314 = 0{,}647;\ a1315 = 0{,}564;$$

$$a1317 = 0{,}05.$$

Table 1. The content of Cs-137 in components Didorivsky cascade ponds

№ of lake	№ sample	A (Bq) Bottom	A (Bq) Soil	A (Bq) Biota
1	1	60,95	136,5	60,85
	2	51,75	195,5	63,85
	average	56,35	166	62,35
2	1	22,15	36,8	54,1
	2	64,1	65,85	21,1
	average	43,125	51,325	37,6
3	1	25,95	37,55	25,3
	2	51,25	109	50,45
	average	38,6	73,275	37,875
4	1	20,4	67,85	31,35
	2	40,45	54,6	21,6
	average	30,425	61,225	26,475

As a result, the following graphs (fig. 6-10) on Didorivsky cascade were obtained.

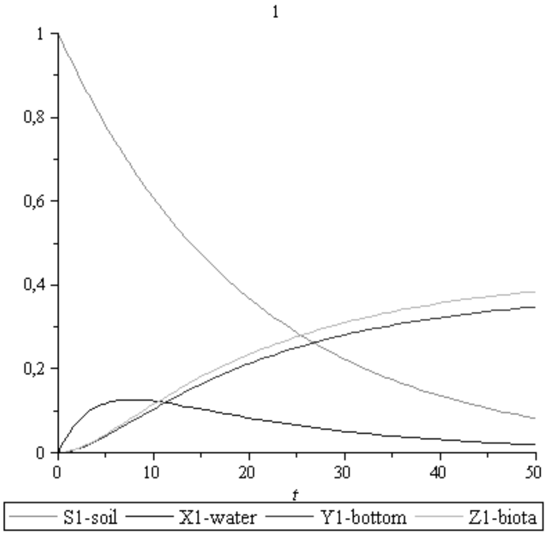

Fig. 6. Dynamics of the radionuclides concentration change for 50 years in the first pond

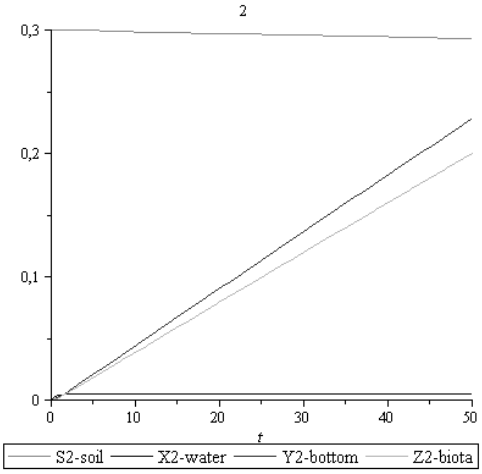

Fig. 7. Dynamics of the radionuclides concentration change for 50 years in the second pond

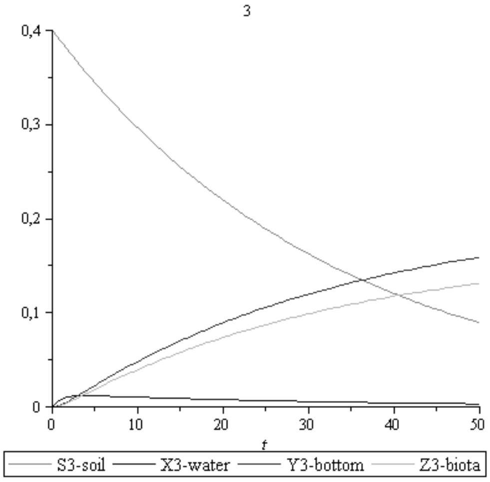

Fig. 8. Dynamics of the radionuclides concentration change for 50 years in the third pond

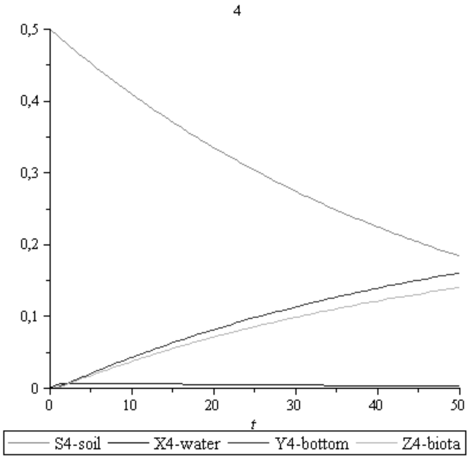

Fig. 9. Dynamics of the radionuclides concentration change for 50 years in the fourth pond.

As in the basic model, the greatest accumulation of Cs-137 was observed in the first pond and then decreased in the cascade. There is a significant role of biota in the accumulation of radionuclides in Didorivsky cascade. In the first pond more of it accumulates in biota. Then the key role belongs to sediments, but the role of biota remains significant.

7. Conclusions

As a result of the work, adequate model of of Cs-137 radionuclide accumulation in the cascade of Didorivsky ponds, was received. The basic model was extrapolated after obtaining observed data.

The model showed the crucial role of biota in this cascade. On the one hand, deposition of radionuclides in plant mass provides water purification, and on the other – the mass of plants is the basis of the first-term component of the trophic level and intake of radionuclides to animals and especially in fish-herbivores.

Moreover, the decrease of radionuclide concentrations when passing through the cascade was observed. Important natural factors of water masses self-purification are sedimentation processes – adsorption of radionuclides into the suspended solid particles and deposition in the bottom sediments.

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М.О. Кравець[1], Ю.О. Кутлахмедов[2], К.Л. Туленінов[3], А.Г. Салівон[4]. Аналіз і моделювання міграції полютантів (Cs-137) в каскаді Дідорівських ставків в парку «Голосіївський»

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Побудовано базову модель вмісту радіонукліду Cs-137 у каскаді Дідорівських ставків. Отримано дані моніторингу каскаду. На основі натурних даних, проведено екстраполяцію базової моделі і отримано точнішу модель каскаду. У результаті екстрапольованої моделі зроблено висновки щодо накопичення радіонукліду Cs-137 в каскаді Дідорівських ставків протягом 50 років.

Ключові слова: камерні моделі; міграція радіонуклідів; радіоактивність

М.А. Кравец[1], Ю.А. Кутлахмедов[2], К.Л. Туленинов[3], А.Г. Саливон[4]. Анализ и моделирование миграции полютантов (Cs-137) в каскаде Дидоровских прудов в парке «Голосеевский»

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Построена базовая модель содержания радионуклида Cs-137 в каскаде Дидоровских прудов. Получены данные мониторинга каскада. На основе натурных данных проведена экстраполяция базовой модели и получена точная модель каскада. В результате экстраполированной модели сделаны выводы относительно накопления радинулида Cs-137 в каскаде Дидоровских прудов в течение 50 лет.

Ключевые слова: камерные модели; миграция радионуклидов; радиоактивность,

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