Entry to the Stockholm Junior Water Prize 2012

Development of the device for water reservoirs monitoring

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Abstract

Conservation of Moscow’s water bodies is one of the most important tasks and conditions for sustainable development of our city. There exists a system of State monitoring of water bodies in Moscow. However, only major water bodies are monitored and most small rivers, lakes and ponds are not under monitoring. Meanwhile, the value of small water bodies is exceptionally high. The disappearance of such water bodies greatly impoverishes the biodiversity of any natural complex.

Currently, there is no routine small water body monitoring within the framework of State monitoring. However, these water reservoirs can and must become objects of public environmental monitoring.

In order to make an integrated assessment of a water body ecological state it is necessary to make its primary examination first. The aim of our project is to develop a device for primary examination of the state of small water bodies.

The work was carried out in several stages. An autonomous automatic laboratory (AAL) was designed during the first and second stages. It was designed originally using laboratory ROBOLAB and then using laboratory ‘Archimedes’. The second stage was devoted to the field testing of AAL. We have chosen as objects of our study two small water reservoirs in the south-eastern part of specially protected natural area of regional significance ‘Natural and historic park ‘Kuzminki-Lyublino’ in Moscow.

On the ground of the data obtained with the help of AAL the preliminary assessment of the state of the water reservoirs was made and a plan for their follow-up research was shaped.

The third stage was devoted to hydrochemical and bioindicative researches, which proved the correct nature of primary conclusions made using AAL.

Finally, we have made an assessment of the environmental state of the study objects. According to the results of our work the following conclusions can be made: the device designed for monitoring of water reservoirs on the platform shoe of the radio-controlled speed boat, model ‘AVANT-COURIER’, and the stateful device of the tablet PC NOVA 5000 has proved its value to the full. The device allows to collect primary data about a water reservoir easily, quickly and accurately and it makes it possible to shape a follow-up plan for research.

We can recommend the device of an autonomous automatic laboratory designed by us for school public monitoring of small water reservoirs.

The schools in Moscow are fitted with sets of research equipment (laboratory ‘Archimedes’, ‘ROBOLAB’), which can be used for the arrangement of public school monitoring system of small water reservoirs, which are not on the list of the State environmental monitoring.

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A list of the acronyms used in the project

SPNA- specially protected natural area
MAC- Maximum Allowable Concentration for household water reservoirs
A set 'DO-BOC'- a set 'Dissolved Oxygen-Biochemical Oxygen Consumption'
A school field laboratory 'WCS'- school field laboratory 'Water Control Set'

Acknowledgements

We would like to thank the teachers of our lyceum for the support given us while we were working over this project. We are grateful to the teacher of Biology and Ecology Sinegaeva Svetlana Nikolaevna who visited the place with us to conduct field testing of the laboratory and who helped us greatly to carry out a chemical water analysis. Also, we would like to thank the teacher of Informatics and Biology Brozdetskiy Vladimir Semenovich who taught us to operate the school digital laboratory 'Archimedes' and supported the idea of developing an autonomous laboratory for ecological research.

Personal Background

I, Denis Merkulov, am a student of Moscow lyceum № 1547. I am keen on physics and mathematics and I like going in for sports. My teacher of Informatics suggested that I should take part in the competition of water projects. I liked the idea of combining information technologies and Ecology greatly and I have taken up the following work. I am going to enter to National Research Nuclear University (Moscow Engineering and Physics Institute 'MIFI') with a specialization in electronics and nanoelectronics.

I, Kirill Ilyin, am a student of Moscow lyceum № 1547. My dream is to become a biologist and to do ecological research using up-to-date equipment that's why this project was interesting for me. I am going to enter to University in order my dream will come true.

1. Introduction.

A natural reservoir is a multilevel and autonomous to a considerable degree ecosystem, which includes dozens and hundreds of species of living organisms, which are closely related to one another. It is especially important to mention that such water reservoirs are a kind of self-balancing system. Any change in the environment makes the components of this system react in such a way so that the system could be maximally restored to its original state. Moreover, only natural aquatic ecosystems can sustain the existence of outstanding species of the living organisms listed in the Red Data Book.

The main reasons for the reservoir degradation are uncontrolled pollution and excessive recreational loading. Water reservoirs become disposal sites for household rubbish and industrial waste.

There exists a system of State monitoring of the state of water bodies in Moscow. The monitoring of water bodies within the city boundaries is conducted in thirteen monitoring sections of the Moskva river directly and in another fourteen monitoring sections of the mouths of small rivers, feeders of the Moskva river. Monthly, samples are taken and an analytical control in 29 indicators is conducted: pH, transparency, dissolved oxygen, suspended solids, BOD, COD, dry residues, chlorides, sulphates, phosphates, ammonium ions, nitrites, nitrates, total iron, manganese, copper, zinc, total chrome, nickel, lead, cobalt, aluminum, cadmium, petroleum products, phenols, formaldehyde, SAS anionic, hydrogen sulfide and sulfides, toxic level.

However, only major water reservoirs are monitored and most small rivers, lakes and ponds are not under monitoring. Meanwhile, the value of small water reservoirs is exceptionally high. The disappearance of such a water reservoir greatly impoverishes the biodiversity of any natural complex.

Currently, the State doesn’t have funds to arrange an effective monitoring system of small water reservoirs. There is no routine small water reservoir monitoring within the framework of State monitoring. It is these ‘blank spots’ which can and must serve as objects of public environmental monitoring.

Moscow schools are fitted with sets of research equipment (laboratory ‘Archimedes’, ‘ROBOLAB’), which can be used in order to arrange the system of public school monitoring of small water reservoirs, which are not on the list of the State environmental monitoring.

Therefore, we have made an attempt in our project to demonstrate the possibility of using school equipment to arrange the system of public school monitoring of small water reservoirs in Moscow metropolis.

The goal and stages of the project

The goal of the project is to develop a device for primary examination of the state of small water reservoirs.

The stages of the project

1. To design an autonomous automatic laboratory (AAL) for primary examination of small water reservoirs;
2. To conduct field testing of the autonomous automatic laboratory;
3. To evaluate some physical and chemical parameters, which reflect the ecological state of the study water reservoirs;
4. To assess the ecological state of the study water reservoirs.

Objective 1.

To design an autonomous automatic laboratory for primary examination of small water reservoirs. To conduct field testing of the autonomous automatic laboratory on small water reservoirs- the Mishkin Pond and the Round Lake.

The autonomous automatic laboratory should have enough wireless productivity, stability on water, a high range of operation, mobility and it should be easy to use.

Objective 2.

To evaluate physical and chemical parameters-pH, water temperature, dissolved oxygen concentration in the study water reservoirs using the autonomous automatic laboratory.

Based on these indicators direct and indirect data on the state of a water reservoir can be obtained.

Hydrogen (pH) index serves as an indicator of general metabolism speed in the community and has a great meaning for chemical and biological processes, which take place in natural reservoirs.

Dissolved oxygen concentration influences greatly the life in a water reservoir, for the most part sets the direction and speed of the chemical and biochemical oxidation processes of organic and inorganic compounds. Oxygen deficiency is more often found in water reservoirs where there is high concentration of organic pollutants and in disturbed water resevoirs, which contain a great quantity of biogeneous and humic substances.

Water temperature (ºC) is a very important indicator, which influences physical, chemical, biochemical, and biological processes in a water reservoir. Oxygenated conditions and the intensity of self-purification processes depend on this indicator to a considerable extent.

Objective 3.

Using school field laboratory 'WCS' and the set 'DO-BOC' of 'Christmas+', CJSC, to conduct a more thorough (extra) chemical water analysis for nitrites, nitrates, phosphates, total iron, copper, ammonium/ammonia, total hardness, carbonate hardness and the determination of organoleptic indicators.

Objective 4.

To assess trophic properties of the study water reservoirs via the biometric identification method by using higher plants.

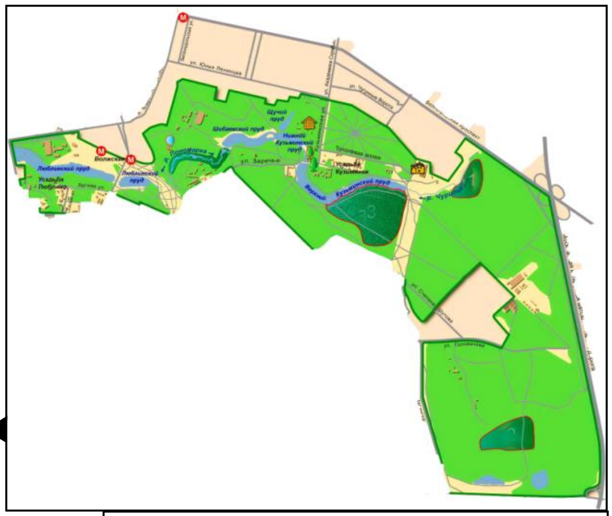
Objective 5.

To make an integrated assessment of the ecological state of the study water reservoirs based on the obtained data.

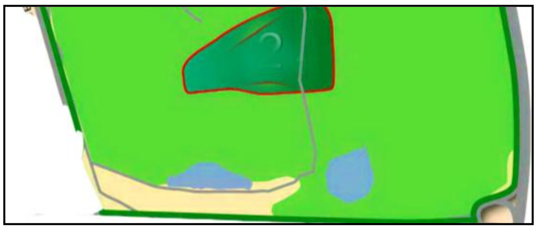
The object of research: two small water reservoirs in the south-eastern part of specially protected natural area of regional significance 'Natural and historic park 'Kuzminki-Lyublino' in Moscow. (pic.1)

2. Methods of research:

- ✓ Constructional engineering combined with information technologies.
- ✓ The evaluation of physical and chemical water parameters (school digital laboratory 'Archimedes').
- ✓ Chemical water analysis (the field laboratory 'WCS' and the set 'DO-BOC' of 'Christmas+', CJSC).
- ✓ Macrophyte bioidentification based on the species diversity statistics of water-inhabiting plants and their indicator importance.



Map of SPNA ‘Kuzminki-Lyublino’



Map of SPNA in Moscow

Study water reservoirs

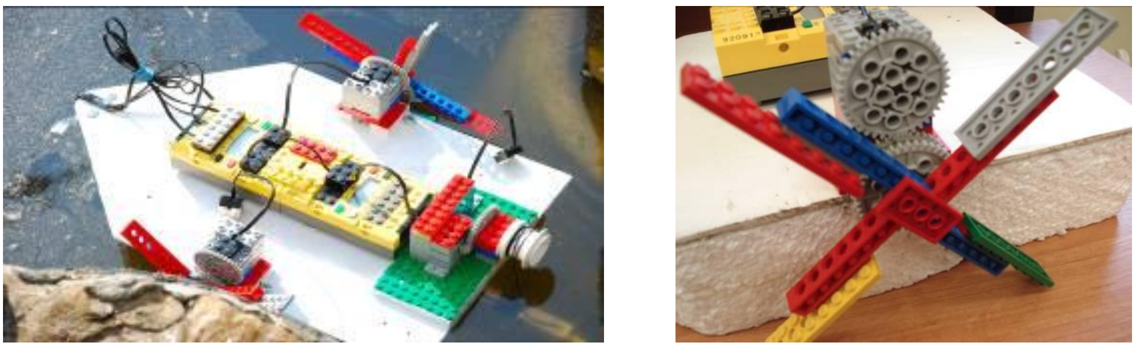
Pic.1. Map of Study District

3. Results and discussion

3.1. Development and testing of the autonomous automatic laboratory.

We used the set ROBOLAB at early stages of our work. Program Apparatus Complex ROBOLAB is a set from LEGO, which includes microprocessor RCX with a set of various sensors, IR port to connect RCX with PC and program ROBOLAB set up at PC. We used Program Apparatus Complex ROBOLAB based on LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench) for our research. LabVIEW is the leading tool of measurement and control, at the heart of which there is a conception of graphic programming that is a series type connection of operational units on the block-diagram.

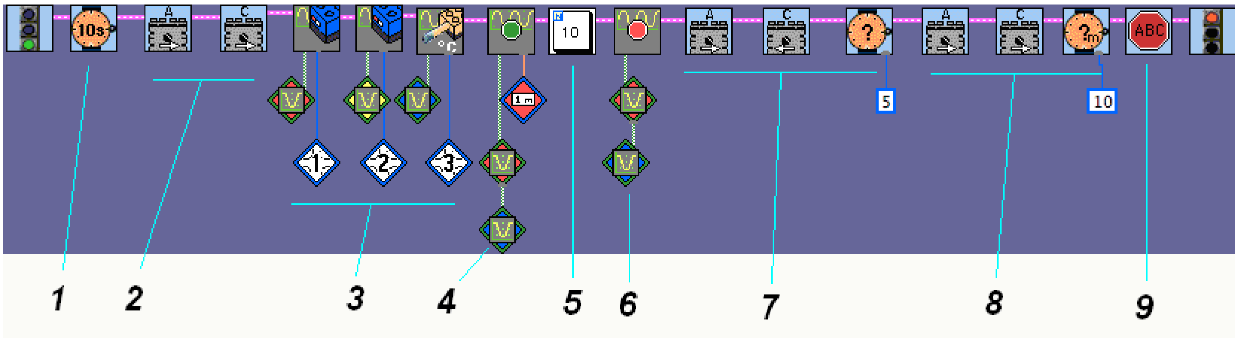
In order to provide a construction with flotation ability such materials as plywood and foam plastic were used (pic.2)



Pic 2. The boat made with a ROBOLAB set

We have compiled a program for microprocessor RCX-1 (pic.3). The program controlled the motors of the boat and collected data from the temperature sensor. Program Complex ROBOLAB, Section ‘Explorer’ was used for this purpose. It makes it possible not only to control the motors but also to collect data from sensors preserving and processing them by a user’s request. Each program element is designed as an icon with modifiers. The icons of which the program consists correspond to a specific action of the device. The operation description of the program is given below:

1. *Wait 10 seconds*
2. *Both motors are operated on one side*
3. *Start the data initialization*
4. *Start monitoring*
5. *Measure data for 10 minutes*
6. *Finish monitoring*
7. *Make a turn within 5 seconds*
8. *Both motors are operated in reverse for 10 minutes*
9. *Stop the program.*

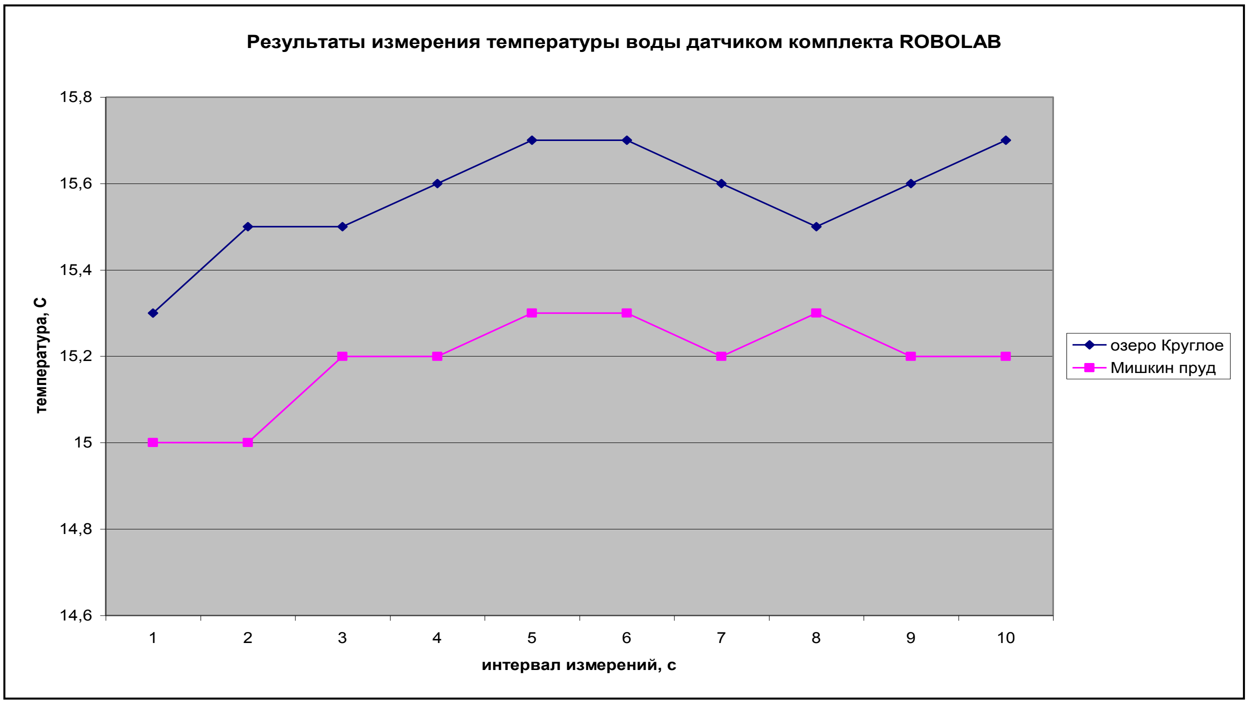


Pic 3. Program based on LabVIEW

The testing of the construction in question was conducted on small water reservoirs (The Round Lake, The Mishkin Pond) situated in specially protected natural area ‘Natural and historic park ‘Kuzminki-Lyublino’ in Moscow in June, 2011.

The ROBOLAB set has a set of sensors, from which only the temperature sensor can be used for water reservoir monitoring.

The first construction of ours under control of the program went offshore at a distance of three meters and measured the water temperature. Then obtained data were transmitted to PC for further manipulations. (pic.4) The built-in functionality of ‘ROBOLAB-EXPLORER’ was used for a visual data display.



temperature, C measurement interval The Round Lake, The Mishkin Pond

Pic.4. The results of water temperature measurement using a sensor ROBOLAB

A number of deficiencies were found while in operation. The remote control was performed via infrared channel. But under bright summer light the contact with the boat was lost at a distance of a meter and a half or three meters. Water plants were wound on the propeller blades while the boat was moving and the boat got sluggish in its movement. The abovementioned fact restricted the application of the laboratory on water reservoirs, which were overgrown with water plants. If the weather was windy the boat was too much above water and that led to the 'sailing effect'. If the overall travel speed was not high the head wind or the cross wind whisked the boat away from its course.

Despite the restricted abilities of our first construction while testing it we conceived the requirements which were necessary to develop an autonomous automatic laboratory.

While developing an autonomous automatic laboratory we decided to use a radio-controlled speed boat as a platform shoe.

While selecting the model of a speed boat we were guided by the following requirements to its characteristics:

A speed boat should have

- the remote control via the radio channel at a distance of 100-150 meters (a relative size of small water reservoirs);

- load-lifting capacity of some 2 kilograms (for accommodation possibility of the measurement equipment)

- two separate motors and quite a high travel speed (more than 1 meter per a second)

According to the abovementioned a reasonably-priced model of speed boat 'AVANT-COURIER' was selected with the following characteristics:

- Signals: via the radio channel at a distance of 150-200 meters.
- Functional control capabilities of two motors separately
- Size: 710x250x150 mm.
- Equipment (the radio unit, the motors and the battery) of not great size and weight (approximately 1 kilogram)

As a device of fixation measurement parameters we used school digital laboratory ‘Archimedes’, which includes tablet PC NOVA 5000 with a software and a set of measure sensors, while designing an autonomous automatic laboratory.

The model of the speed boat ‘AVANT-COURIER’ was upgraded by us:

1. Parts of both boards were deleted and holes for the sensors were made.
2. Shores for PC were set inside of the speed boat. The shores were made from polystyrol and set under the PC in order to fix the PC horizontally and to remove it easily for data collecting.
3. The platform for the sensors was attached to the speed boat with the help of curved metal plates in order to be able to remove them for an easier transportation.
4. A protection waterproof lid was designed and fixed on the speed boat in order to prevent water from leaking on PC.
5. All the details were protected and polished.
6. The sensors on the stern of the speed boat were fixed.
7. The battery of the motors of the speed boat was fixed.
8. PC NOVA 5000 was fixed in the speed boat hull.
9. The sensor cables to the PC were wired
10. The sensors to the PC were connected.

As a result of upgrading the speed boat and establishing school laboratory ‘Archimedes’ on it, the autonomous automatic laboratory was ready for environmental monitoring of water reservoirs (pic.5)

Pic. 5. The autonomous automatic laboratory.

The school digital laboratory ‘Archimedes’, which we used while designing our device, allows to save a great deal of time, which is necessary for work organization and work performance, it also improves accuracy and illustrative sides of the experiments, makes it possible to process and analyze a great amount of data.

The laboratory ‘Archimedes’ consists of PC NOVA 5000 with a software and a set of measurement sensors. (pic.6)

NOVA 5000


pH-метр DT016-A


Датчик кислорода DT222A


Датчик температуры DT029

NOVA 5000
Power indicator/ Loudspeaker/Pen(in its holder)
LCD monitor
On/off stand-by button

pH- meter DT016-A
Oxygen sensor DT222A
Temperature sensor DT029

Pic. 6. The outside appearance of PC NOVA 5000 and measurement sensors

The software of tablet PC NOVA 5000 consists of operating system Windows CE 5.0, inbuilt registrar FourierSystems and program MultiLab for control and processing of the obtained data. The sensor ports of Nova 5000 make it possible to connect several sensors. The data scanning can be fulfilled both in real-time mode and on completing the experiment. The data form is diagrams and tables. Diagrams and tables can be transmitted to PC for further operations with them.

Three sensors were used in our project: pH-meter DT016-A (measurement range is 0-14 units pH), oxygen sensor DT222A (measurement range is 0-14 mg/l of dissolved oxygen (DO_2) and 0-25% O_2), and temperature sensor DT029 (measurement range is – 25- +110 ºC).

The autonomous automatic laboratory designed by us was used for primary examination of two small water reservoirs- the Round Lake and The Mishkin Pond (pic.7).

Pic. 7. The measurement of physical and chemical water indicators on the Round Lake and the Mishkin Pond

While working we made calculations on economic benefits of using our device for environmental monitoring of water reservoirs. The autonomous automatic laboratory designed by us is easy to use and rather cheap in comparison with services of an expert whose survey trip in the Moscow area costs 4000 rubles. As we found out, water sample taking by an expert on a boat with a follow-up analysis and the conclusion on the state of a water reservoir costs 35000 rubles. The development of the laboratory cost us 10 000 rubles. And our device is easy to use and can be handled by schoolchildren for environmental monitoring.

3.2. Primary examination of small water reservoirs.

The study water reservoirs are small lakes –the Round Lake and the Mishkin Pond (pic.8) – are situated in the south-eastern part of SPNA ‘Kuzminki-Lyublino’. The water reservoirs are used by citizens for relaxation near the water and unprofessional fishing.

The Round Lake: the diameter is 190m, the square is 2ha, it has little islands called floating bogs. There are few convenient ways to water, the watersides resemble bogs of an intermediate type. The bottom is silty. The lake is of natural origin.

The Mishkin Pond has a narrowish shape- 400m to the west, its width is approximately 130m, its square is 2ha. There is a power transmission line along the south bank, then there is a plant of special mounting production, there is a sandy beach on the north bank, the south bank and the south-eastern banks are swampy. The pond is of artificial origin.

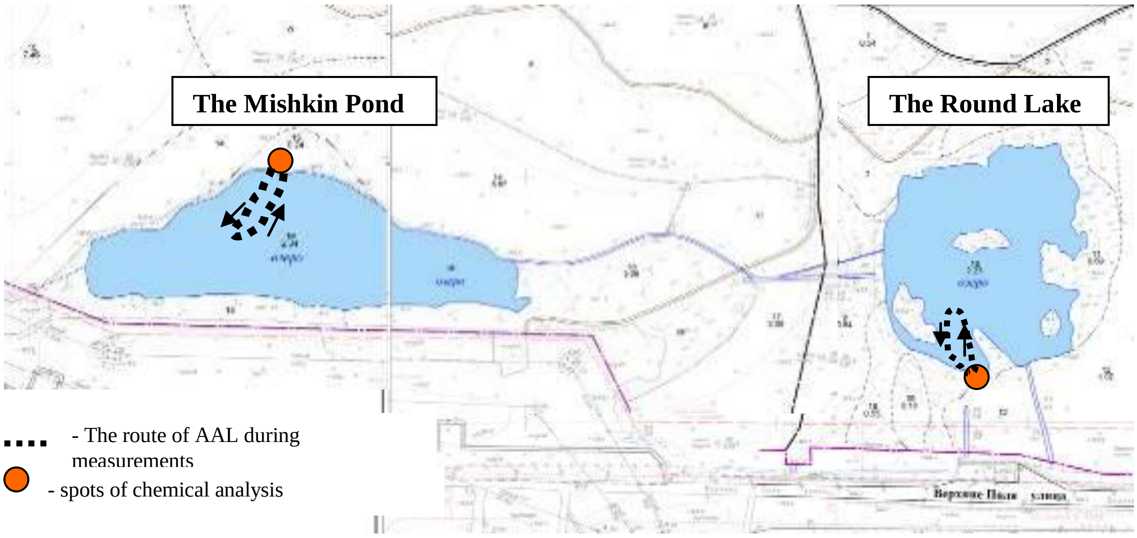
The forest area around the water reservoirs has mainly middle-aged birches and pines. Willows grow directly near the water.

During the preliminary inspection of the water reservoirs lots of household rubbish along the bank line was found.

Pic. 8. The Round Lake, the Lake 'Mishkin Pond'.

In order to define the water parameters, which reflect the ecological state of the small water reservoirs, monitoring sites were selected on the bank line along the Round Lake and the Mishkin Pond (pic.9).

The research of the physical and chemical water parameters (dissolved oxygen, pH, temperature) was done during first 10 days of July, 2011. The measurements were fulfilled in triplicate while the autonomous automatic laboratory was moving from the marked monitoring sites and all of them were recorded every 5 seconds.



Pic.9. The place of taking water samples in the study water reservoirs

As a result of the primary examination of the small water reservoirs we have obtained the following indicators of dissolved oxygen, pH, temperature (tab. 1).

Tab. 1. The results obtained using AAL(mean sample value).

The interval of measurement, 5 s	Dissolved Oxygen mc (mgO_2/l)		pH		Temperature (°C)	
	The Round Lake	The Mishkin Pond	The Round Lake	The Mishkin Pond	The Round Lake	The Mishkin Pond
1	7.45	8.41	6.51	8.11	18.88	18.12
2	7.55	8.42	6.52	8.12	18.89	18.17

3	7.54	8.41	6.54	8.11	18.91	18.18
4	7.50	8.41	6.55	8.10	18.89	18.20
5	7.52	8.39	6.59	8.12	18.87	18.20
6	7.52	8.42	6.54	8.13	18.87	18.21
7	7.52	8.41	6.54	8.14	18.88	18.19
Mean Value	7.51	8.41	6.54	8.12	18.88	18.18

Note: The tab contains arithmetic mean values from total amount of values obtained.

The obtained data made it possible to assess the ecological state of the water reservoirs on a preliminary basis. The water in the Mishkin Pond has a faintly alkaline reaction (pH = 8.12), and the water in the Round Lake has a neutral reaction (pH = 6.54). These parameters correspond to recreational water quality.

The water temperature in the Mishkin Pond is 18.88 °C, and it is 18.18 °C in the Round Lake (air temperature is 16°C). The temperature bears evidence that there is no thermal pollution in the water reservoirs.

The dissolved oxygen level in the Round Lake is 7.51mg $O_{2/}$ l and it is 8.41 mgO_2/l in the Mishkin Pond. According to these data the study water reservoirs are classified as moderately polluted (quality class 3 on the six-point grading scale).

Thus, preliminary data about the size of the water reservoirs, pH value, oxygen level make it possible to make a supposition about the ecological type of the water reservoirs: the Round Lake is both mesotrophic and eurtophic whereas the Mishkin Pond is a mesotrophic type.

3.3. Study of the water reservoirs on the organoleptic indicators and chemical analysis of water.

The environmental inspection of the water reservoirs was carried out from June, 2011 till August, 2011. After the preliminary assessment of the water reservoirs using the autonomous automatic laboratory some water samples for the chemical and organoleptical analyses were taken from the monitoring sites (pic.9).

The water samples were taken three times twice a month in July 2011.

The chemical analysis was performed using field laboratory ‘WCS’ and a set ‘DO-BOC’ of ‘Christmas+’, CJSC. The following indicators were taken into consideration: total hardness, carbonate hardness, total iron, copper, phosphates, ammonium/ammonia, nitrates, nitrites. Control measurements of pH and of dissolved oxygen were also performed. (tab.2)

Tab. 2. The results of organoleptical and chemical water analyses (mean sample value).

Measured indicators	Maximum Allowable Matter Concentration$_w$	The Round Lake	The Mishkin Pond
Chemical analysis			
pH	6,5-8,5	6,5	8
Carbonate hardness (mg-equiv/l)	10	6	6
Total hardness (mg-equiv/l)	7,0	4	7
Nitrites (mg/l)	3,0	0,5	0,5
Nitrates (mg/l)	45	10	10
Phospates (microgram/l)	3,5	0	0,3

NH_4/NH_3 (mg/l)	2,0	0	0
Total iron (mg/l)	0,3	0	0
Cu (mg/l)	1	0	0
Dissolved oxygen(mg O_2/l)	not below 4	7,5	8,5
Organoleptical analysis			
Colour		yellowish, brownish and yellow	yellowish
Odour (grades)	2	Putrefactive, 3	Putrefactive, 2
Suspended particles		present	Very few

Note: The tab contains arithmetic mean values from total amount of values obtained.

All the study chemical indicators correspond to maximum allowable concentration for household water reservoirs. The study water reservoirs can be classified as a mesotrophic type according to biogenic substances, water hardness and pH indicators as well as dissolved oxygen indicators.

3.4. Evaluation of the state of the water reservoirs on the species macrophytes diversity.

The state of the water reservoirs was assessed via the bioidentification method using higher water plants (macrophytes) at the next stage.

The species composition identification of water and semi-water vegetation of the study water reservoirs revealed the presence of plants-bioindicators (tab.3) with a follow-up assessment of their frequency (according to a nine-point grading scale) [7, 8].

Tab. 3. The results of the pollution level of the water reservoirs via the species of plants-bioindicators.

Species of a plant	Pollution level of the water reservoir (1)	Present		Frequency (2)		(1) × (2) = (3)	
		The Round Lake	The Mishkin Pond	The Round Lake	The Mishkin Pond	The Round Lake	The Mishkin Pond
Lesser bladderwort *(Utricularia minor)*	1	+	-	1	0	1	0
Meakin *(Myriophyllum spicatum)*	2	+	+	5	5	10	10
Cornstalk weed *(Potamogéton lucens)*	3	+	+	5	4	15	12
Canadian pondweed (*Elodea canadensis)*	4	+	+	3	2	12	8
Greater duckweed (*Spirodela polyrhisa)*	5	+	+	3	2	15	10
Little duckweed *(Lemna minor)*	5	+	-	3	2	15	10
Total of the							

indicator				Σ (2) =20	Σ (2) = 15	Σ (3) =68	Σ (3) =50
Overall pollution level Σ (3) : Σ (2) =						**3,4**	**3,3**

As a result of the obtained data these lakes can be classified as moderately polluted (quality class 3), of a mesotrophic type and this information doesn't contradict the data of the primary examination using the autonomous automatic laboratory and the data of the organoleptical and chemical water analyses.

One of the reasons for the deterioration of the ecological state of the study water reservoirs is the pollution along their bank line with household rubbish. The lack of information about the ecological state of small water reservoirs is a reason for their uncontrolled pollution. A water reservoir and surrounding area are used as a disposal site for household rubbish and industrial waste. While working on our project we arranged a few ecological actions connected with the collection of rubbish along the bank line of the study water reservoirs, for which schoolchildren were invited.

4. Conclusions.

1. The device designed for monitoring of the state of water reservoirs on the platform shoe of the radio-controlled speed boat, model 'AVANT-COURIER', and the stateful device of the tablet PC NOVA 5000 has proved its value to the full. The device allows to collect primary data about a water reservoir easily, quickly and accurately and it makes it possible to shape a follow-up plan for research.
2. Further research via the bioidentification method and the physical and chemical water analyses has confirmed tentative assumptions about the state of the water reservoirs.
3. 'The Mishkin Pond' and 'The Round Lake' are classified as moderately polluted (quality class 3) water reservoirs of a mesotrophic type, and that makes it possible to use them for swimming and fishing.
4. We can recommend the device of an autonomous automatic laboratory designed by us for school public monitoring of small water reservoirs in Moscow.

Afterword

The autonomous automatic laboratory designed by us is going to be fitted with new sensors for environmental monitoring of the small water reservoirs in SPNA 'Kuzminki-Lyublino'. We are also going to design a device for sampling of water on the route of the speed boat in order to make a further analysis under laboratory conditions. Simultaneously, we are going to arrange a constant plankton gathering from the autonomous automatic laboratory for further microscopic study.

We are going to share our experience of using school equipment for environmental research of Moscow metropolis water reservoirs, which are not on the list of the State environmental monitoring.

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