JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2022, 23(4), 75–84
https://doi.org/10.12911/22998993/146352
ISSN 2299–8993, License CC-BY 4.0

Received: 2022.01.11
Accepted: 2022.02.14
Published: 2022.03.01

Comprehensive Assessment of the Impact of the Almaty Wastewater Storage System on the State of Groundwater

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ABSTRACT

This article presents the results of studies on the comprehensive assessment pertaining to the peculiarities of nutrition, accumulation, transit and discharge of groundwater in the adjacent territory of the Sorbulak reservoir. The information about the waste water storage was presented. The results of the analysis and decryption of satellite images, as well as the results of aerial photography of the territory of the Sorbulak were presented. The results of field route studies of the work area were presented to identify the external manifestations of directional filtration, areas of exits to the daytime surface of groundwater. The results of the calculation of the filtration flow controlled by the Sorbulak storage lake, unloading through the western side of the plateau into the Kurty River, were presented.

Keywords: water disposal, waste water, storage system, impact on groundwater, filtration, stability of loose massif, pollution.

INTRODUCTION

Requirements and activities related to the rational use and protection of water resources and the prevention of their pollution are among the most important tasks in the environmental protection system [Code of Environmental Protection, Directive 2000/60/EC]. At the same time, the issue of accumulation, storage and disposal of industrial waste and wastewater is one of the most pressing environmental problems today [Millennium Ecosystem Assessment 2005, American Academy of Environmental Engineers 2009]. Wastewater storage is applied in artificial or natural storage tanks, as well as recharge groundwater aquifers with subsequent use for various needs [Isabel et al. 2010]. Underground wastewater disposal is widespread in the UK, France, Canada, and Japan [Racault et al. 2005, Japan Ministry of Environment 2012]. The waste disposal scheme developed by Union Carbide (USA) includes: a waterproof layer; permeable layer; retaining embankment; waste water collection [Masbey 1987].

The systems that use large natural reservoirs for the collection and disposal of wastewater can have a negative impact on the environment. A significant part of the anthropogenic load on surface water bodies is wastewater containing synthetic surfactants Synthetic surfactants, and especially anionactive surfactants, are among the most common pollutants. Anionic surfactants accumulating in water bodies have a strong toxic effect on flora and fauna and worsen the organoleptic properties of water [Ying 2006]. Other hazards are related to the presence of nutrients in wastewater, which constitute one of the main pollutants that can lead to eutrophication [Smith 2003]. For this reason, sewage ponds should be the subject of special attention during the environmental impact assessment, both at the stage of designing new ones, as well as during the reconstruction and operation of existing plants [Kovalenko et al. 2012].

The wastewater in the Republic of Kazakhstan after mechanical and biological treatment is discharged into storage ponds. In some areas, wastewater is discharged into storage ponds without pretreatment. The real threat in the Republic of Kazakhstan are sewage storage ponds located near large cities and industrial centers, as there are 540 wastewater storage facilities. Given that such treated wastewater accumulators are often filled to the limit, there is a constant threat of an emergency breakthrough of enclosing dams for water bodies and settlements. At the same time, most of the sewage storage ponds located on the territory of Kazakhstan have a high degree of wear, their equipment is obsolete, there is no current and major repairs and, most importantly, almost complete exhaustion of storage capacity are the main causes of accidents and catastrophes that negatively affect the environment and human life.

At the same time, according to leading international and regional experts in the field of ecology, finance, tourism and construction, Kazakhstan will face the issue of national security and independence in the near future. It will happen because of water pollution and its uneconomical use. According to the data, Kazakhstan needs 3–10 times more water for production. Moreover, of all our large rivers and lakes, less than 10% are classified as clean. The rest are classified as polluted from "moderate" to "extremely high levels" [Draft Program of the Integrated Water Resources Management]. Meeting the growing demand for food and ensuring food security under the conditions of water scarcity can be realized through the widespread use of wastewater from the reservoir in irrigated agriculture.

The aim of this paper was to assess the ecological conditions as well as the nature and degree of impact of the sewage storage ponds from the city of Almaty in Kazakhstan on the water environment in their vicinity.

As a result of the ever-increasing anthropogenic influence, the ecological situation on the Karoy plateau is changing. On the basis of this fact, the purpose of this work was determined – the study of the complex effect of the wastewater storage system on the state of groundwater under the influence of anthropogenic activity.

MATERIALS AND METHODS

The wastewater treatment facilities of the city of Almaty, Republic of Kazakhstan are located 12 km northwest of the city border, in the Ili district of Almaty region, southwest of the village of Zhapek Batyr, along the banks of the Bolshaya Almatinka River. The design capacity of mechanical and biological treatment facilities is 640 thousand m^3 per day. The actual annual volume of wastewater treated in 2020 amounted to 13,2287,737 thousand m^3/year, that is, an average of 362,432 thousand m^3/day. Mechanical and complete artificial biological wastewater treatment is carried out at the treatment facilities. Biologically treated wastewater is diverted through the discharge channel to the Sorbulak storage lake or system of storage reservoirs of the Right-Bank Sorbulak Canal (RBSC), from where part of the wastewater through the emergency discharge channel, through bioprudes can be discharged into the Ili River.

Figure 1 shows the appearance of the wastewater discharge of the Almaty aeration station. Since 2005, the treated wastewater of Almaty has been used for irrigation of industrial crops. With the increase in the volume of treated wastewater intake for irrigation of industrial crops, the tightly controlled water balance of the Sorbulak storage lake enables to avoid discharges into the Ili river. The last discharge of part of the treated wastewater into the Ili River was carried out in 2006. That is, at present, the treated wastewater of Almaty is used for irrigation of industrial crops during the growing season, and the rest of the time it is diverted to the Sorbulak storage lake.

The Sorbulak storage reservoir is located 35 km southwest of Almaty in the Ili district of the Almaty region. By area, it is the largest wastewater storage facility in the former Soviet Union and one of the largest in the world [Technological regulations for the operation of the Aeration Plant in Almaty]. At the mark of the normal retaining level of the Sorbulak storage (620.5 meters), the mirror area is 58 km^2, the maximum length is 35 km, the width is up to 15 km, the maximum depth is up to 31 m. The capacity of the Sorbulak storage unit at the maximum level of the MPU (622.5 meters) is about 1000 million m^3 [Technological regulations for the operation of the Aeration Plant in Almaty].

The main functions of the Sorbulak storage lake are deep long-term regulation of wastewater in Almaty, ensuring their natural self-purification. The Sorbulak storage lake is a natural closed basin of the north-western city of Almaty, used for the collection, post-treatment and storage of urban wastewater.

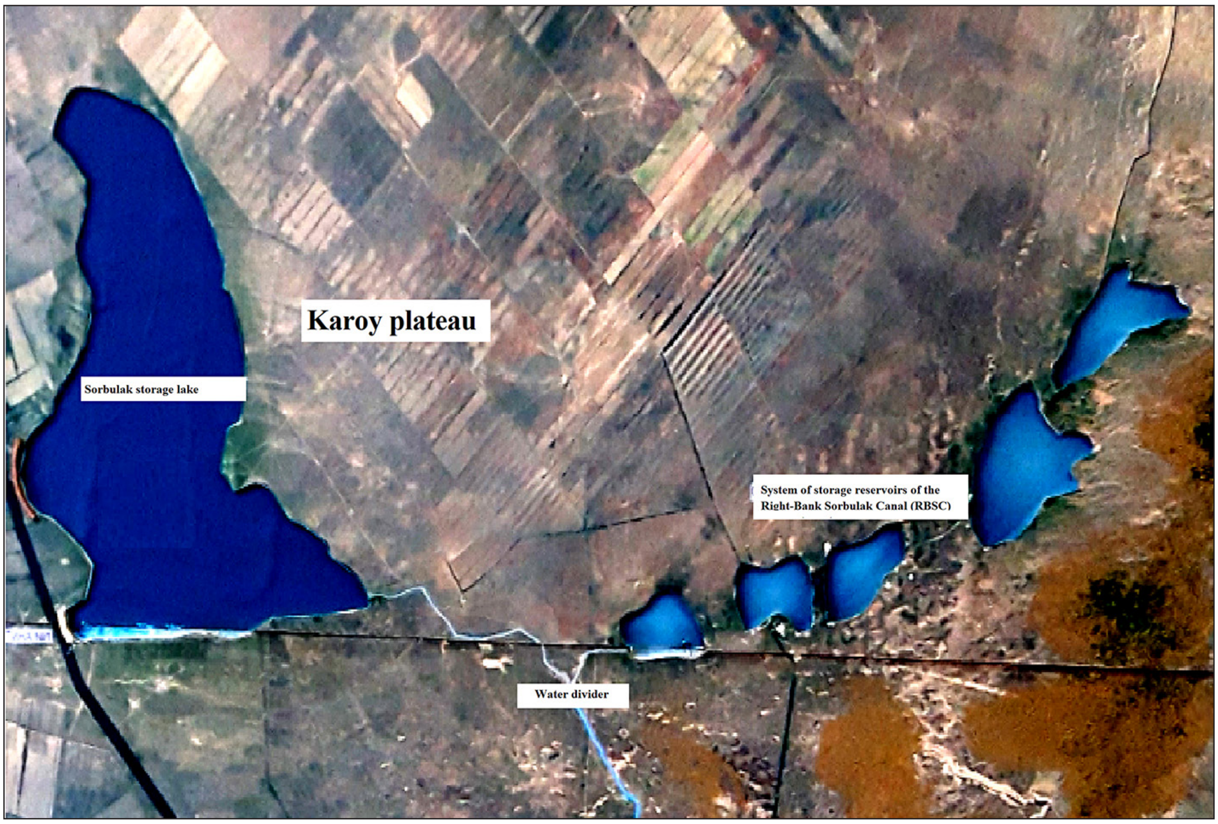

Figure 1. External view of wastewater discharge of Almaty the aeration station

In the southwestern and western parts, the Sorbulak basin does not have high banks. There are clearly two lowered sections, one 3.3 km long, the other 2.0 km. The Almaty-Karaganda highway runs along these sections along the storage (on its western side).

The dams of the Sorbulak storage lake are made of sandy loamy soils with a laying density of 1.67 – 1.75 t/m^3 and have high seismic resistance. According to the content of water-soluble salts, gypsum and organic impurities, the soils meet the requirements for cohesive soils laid in the body of dams. The crest mark of the dam is 624.00 meters, the maximum height is 6 meters. The dams belong to Class IV in terms of capital.

According to the Institute of Zoology, the Sorbulak reservoir and its water area is a reservoir in which many representatives of fauna (fish, waterfowl, crustaceans, etc.) live and reproduce in abundance, and a variety of plants grow. During the summer period, 39 species of algae were found in water samples, as well as 23 species of zooplankton; 6 different species of fish live in the waters of the reservoir. Various species of waterfowl and near-water birds, including cormorants, gulls, herons, ducks, nest and feed en masse along the banks of the storage. Birds are most numerous during spring and autumn migrations, and many species winter here. The improvement of environmental conditions near the reservoir contributes to the growth of biomass of plants, insects, animals and birds. Many species of amphibians and crustaceans are an indicator of the purity of the reservoir.

The Karoy plateau is part of the semi-desert zone and is located on the border of the South Balkhash and Ili depressions. The climate of the area is sharply continental, with relatively cold winters and rather long summers, with little precipitation. In the area of the Sorbulak storage lake, loams are predominant, and sandy loams have a subordinate development. The thickness of the deposits varies between 1–3 m, sometimes reaching 6 m.

RESULTS AND DISCUSSION

In 2017 and 2018, the research work on a comprehensive assessment of the feeding, accumulation, transit and discharge of groundwater was carried out in the adjacent territory of the Sorbulak storage lake. In the process of assessing the impact of the wastewater storage system in the city of

Almaty on groundwater, the analysis and decoding of space images of the territory of the Karoy plateau were carried out. The ortho-transformed satellite images of the Landsat-8 satellite of various resolution were used for analytical studies.

The remote sensing method, along with direct methods, makes it possible to judge the geological structure of the work sites and the hydrogeological conditions by external visible signs. The interpretation of hydrogeological conditions in aerial photographs is based on the identification of direct and indirect geological and hydrogeological indicators.

The research is based on the fact that: a) the feeding of deep-lying aquifers, which have developed in the southern part of the Karoy plateau, is carried out due to the inflow of groundwater from the side of the foothill plume of the Zailiyskiy Alatau; b) 73% of the groundwater supply of the Moyunkum sandy massifs is provided by filtration of wastewater, which leads to the formation of an artificial aquifer. The satellite images of the work area are shown in Figures 2 and 3.

In Figure 4, loose sandy massifs are highlighted both on the topographic map and on the LC8 20160416 NDWI 30 satellite image. According

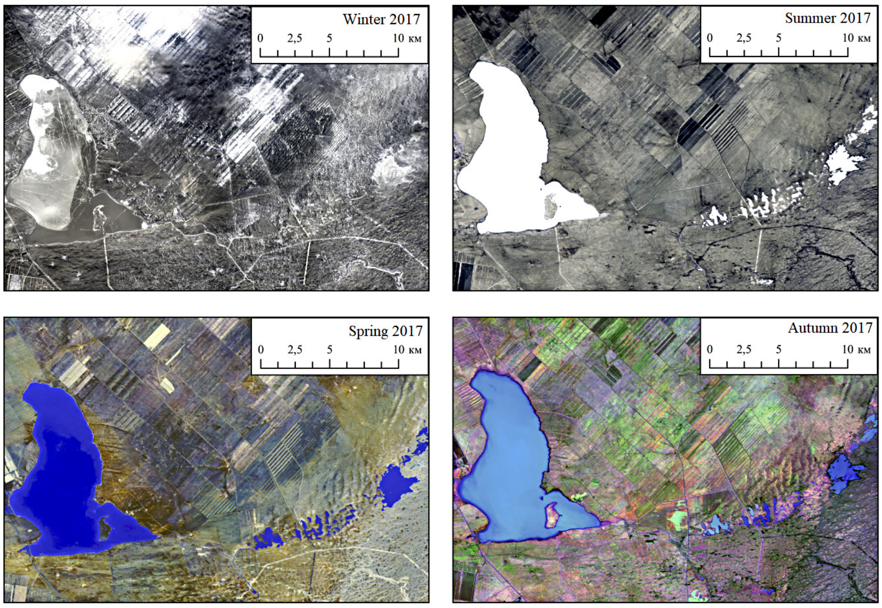

Figure 2. Satellite images of the work area for 2017

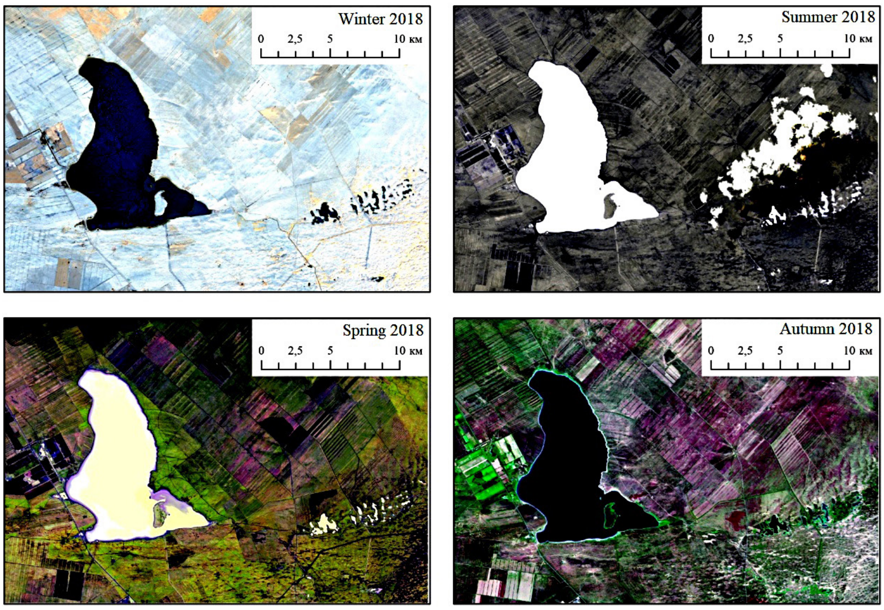

Figure 3. Satellite images of the work area for 2018

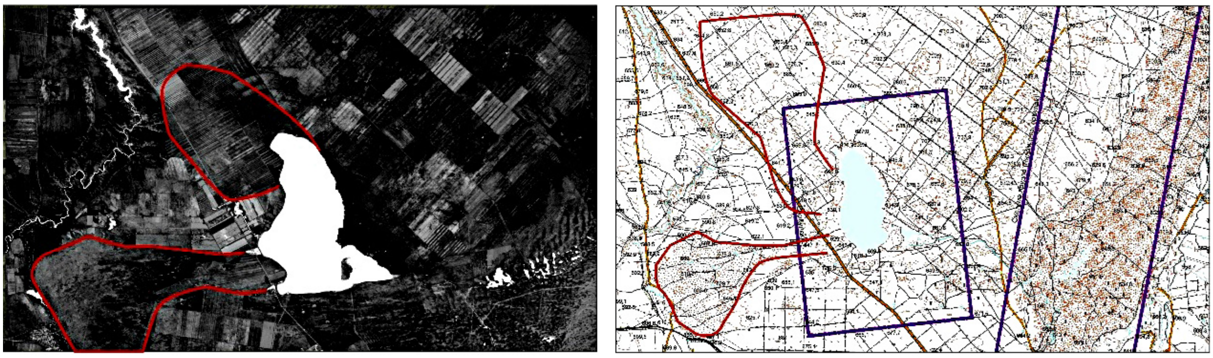

Figure 4. Location of loose massifs

to the results of earlier studies, the southern massif has a permanent, first from the surface, aquifer with absolute marks of the groundwater level of 550–620 m. The direction of movement of groundwater is predominantly western. The second massif, spread in the northwestern direction, contains practically waterless, well-permeable, loose sediments and a permanent aquifer does not contain mid-quaternary sediments distributed here in places to a depth of 100 m.

The zone of formation of an insignificant surface and weak underground runoff is highlighted on the LC8 20160416 15 6-7-1 satellite image in the form of a purple area south of the reservoir, capturing the southern massif of the hummock and areas adjacent to the eastern bank of Sorbulak, as well as in the basin of the river Kurty. The zone of absorption of waters of temporary streams and atmospheric precipitation by Neogene and middle-upper-Quaternary sediments is located to the west of the reservoir, extends in the western and north-western directions, corresponding to the second loose massif. Groundwater supply areas with waste and irrigation water are located to the south and southwest of the reservoir. Areas of open groundwater discharge are identified near the southwestern coast of the storage pond, in the forest-park zone, in the Kurty river basin. Zones of hidden discharge of groundwater, zones of vertical filtration of groundwater into the overlying horizons, the area in which the groundwater is connected with surface waters, appear in the image below the reservoir, to the north of the feeding area.

Next, aerial photography of the work area was carried out. Aerial photography was carried out by a DJI "Phantom 4 Pro" unmanned aerial vehicle. The areas covered by the survey are shown in Figure 5.

The purpose of the work was:

- identification and selection of the most informative and optimal routes for the survey of the territory of the planned works;
- identification of the areas of open discharge of groundwater on the ground;
- clarification of the position of research objects;
- clarification of the geoecological situation of the research area;
- refinement of cartographic data and the results of the analysis of satellite images.

In the course of the work, the orthotransformed satellite images of the Landsat-8 satellite of various resolution were studied, decrypted and analyzed. More than 1,000 aerial photographs and videos were produced by an unmanned aerial vehicle. The area of the surveyed territory exceeds 5000 km^2. Some aerial photographs are shown in Figure 6.

According to the data of remote sensing of the Earth, the following were determined:

- water absorption zones of temporary watercourses and atmospheric precipitation by Neogene and middle-upper quaternary sediments;
- areas of groundwater supply by sewage and irrigation water;
- areas of open discharge of groundwater;
- zones of hidden discharge of underground water;
- zones of vertical filtration of groundwater into the overlying horizons, the area in which groundwater is connected to surface waters.

Updated on the ground:

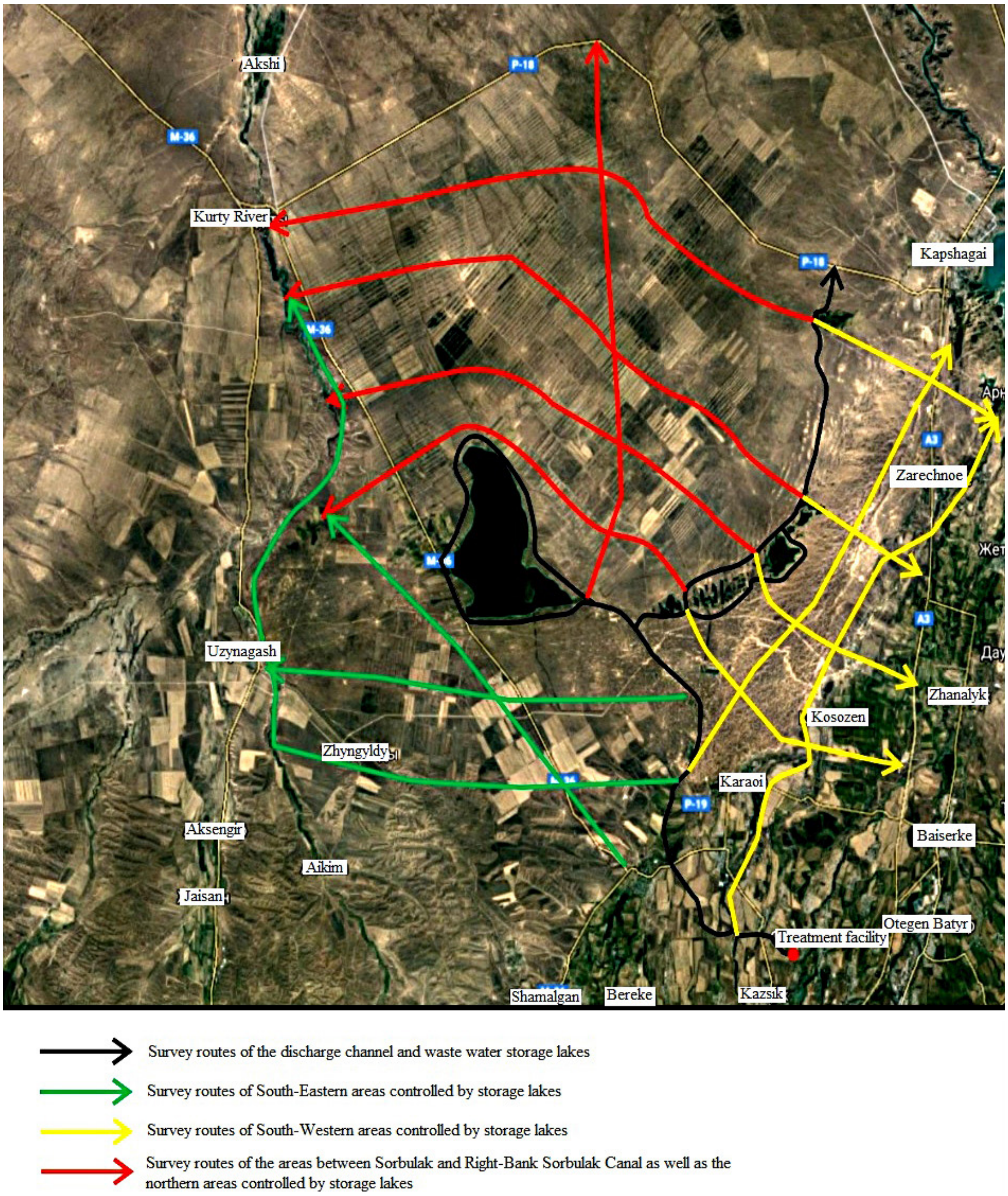

Figure 5. Schematic map of route surveys and aerial photography

- optimal directions and length of routes for the survey of the work area;
- location of research objects.

The field route surveys of the work area were conducted. The purpose of the surveys was to identify the external manifestations of directional filtration, areas of exits to the daytime surface of groundwater, and to survey the operating lines of observation wells. In 2017, comprehensive route surveys of the wastewater storage system and the territory of the Karoy Plateau were organized and conducted.

Four comprehensive route surveys were conducted throughout the study area (Figure 5), covering an area of 4,989 km^2. The areas of directional filtration are identified in the area of 1 and 2 dams of the Sorbulak reservoir, between ponds and storage reservoirs of the RBSC (Figure 7).

The filtration flow front controlled by the Sorbulak storage lake, which is discharged through the western side of the plateau into the Kurty River, is also determined and calculated. The length of the flow front was 7000 m.

The following conclusions can be drawn from the above. The filtration flow into the Kurty River from the Sorbulak reservoir has an average value of 2455.04 m^3/day. The maximum value of the flow was observed in the first

Figure 6. Aerial photographs of the work area

Figure 7. Photographs of surface areas of directional filtration

quarter of 2018, and the minimum at the beginning of the 4th quarter of 2017. This dynamics is explained by the mode of operation of the drive, the discharge to which stops at the beginning of the warm period, and filling begins at the beginning of the cold period.

The reverse pattern is observed for the filtration flow formed by ponds and storage reservoirs of the Right-Bank Sorbulak Canal (RBSC).

The volume of manifestations of directed filtration on the daytime surface was calculated as follows: from a satellite image linked to a digitized map m 1:100000, the areas of manifestations on the map were taken according to the Argis 10 program, the average height of the area occupied by water was calculated, which was taken as the average depth, the volume was considered as the product of the area S by the average depth h and the coefficient k.

According to this algorithm, all manifestations located on the territory controlled by the storages were calculated (Table 1, Figures 8, 9).

Table 1. Area and volume of surface manifestations of directional filtration

Min. level	Max. level	Average level	Average power of manifestation	The power of manifestation taking into account the empirical coefficient	Area, m^2	Volume, m^3
636	640	638.6	4	0.32	44555,75317	14257,84
637	641	639.4	4	0.32	11989,16628	3836,533
623	628	625.4	5	0.4	111881,6029	44752,64
623	628	625.0	5	0.4	49889,23018	19955,69
626	630	627.8	4	0.32	16177,63022	5176,842
627	633	629.5	6	0.48	42197,66504	20254,88
628	632	629.4	4	0.32	38185,56024	12219,38
623	625	623.5	2	0.16	29419,86171	4707,178
623	625	623.5	2	0.16	10394,28602	1663,086
620	622	621.5	2	0.16	5934,641685	949,5427
620	624	622.5	4	0.32	7366,892464	2357,406
623	624	623.2	1	0.08	3989,70332	319,1763
623	625	623.7	2	0.16	1464,84668	234,3755
616	620	617.8	4	0.32	14919,7347	4774,315
618	621	619.8	3	0.24	1732,614352	415,8274
626	627	626.8	1	0.08	1189,518508	95,16148
625	627	625.7	2	0.16	950,102707	152,0164
630	634	632.1	4	0.32	5183,982142	1658,874
616	622	618.0	6	0.48	290152,566	139273,2
618	621	619.1	3	0.24	17057,16728	4093,72
617	620	618.7	3	0.24	68125,57118	16350,14
617	620	618.3	3	0.24	41949,01474	10067,76
617	620	618.3	3	0.24	48521,3389	11645,12
617	621	619.4	4	0.32	61666,30933	19733,22
620	623	621.7	3	0.24	18568,98427	4456,556
618	622	619.7	4	0.32	75220,17669	24070,46
619	622	619.9	3	0.24	70761,70003	16982,81
616	619	618.0	3	0.24	226674,0751	54401,78
615	620	617.4	5	0.4	109485,9564	43794,38
619	620	619.5	1	0.08	20727,18515	1658,175
616	620	618.0	4	0.32	51099,53503	16351,85
615	619	617.7	4	0.32	50345,59286	16110,59
617	619	618.1	2	0.16	1783,652283	285,3844
617	619	618.3	2	0.16	8576,392512	1372,223
641	644	642.5	3	0.24	18135,69362	4352,566
641	643	642.1	2	0.16	4331,495135	693,0392
639	648	642.3	9	0.72	30095,20694	21668,55
626	627	626.1	1	0.08	103958,2392	8316,659
626	627	626.4	1	0.08	33865,46225	2709,237
627	630	628.4	3	0.24	2979,590418	715,1017
620	622	620.9	2	0.16	6378,711902	1020,594
623	625	624.1	2	0.16	14719,36581	2355,099
622	623	622.8	1	0.08	4658,238002	372,659
622	622	622.0	0	0	1862,41133	0
622	624	623.3	2	0.16	21835,03641	3493,606
624	626	625.0	2	0.16	4477,660656	716,4257
636	639	638.1	3	0.24	16675,62199	4002,149
					1822110,744	568843,8

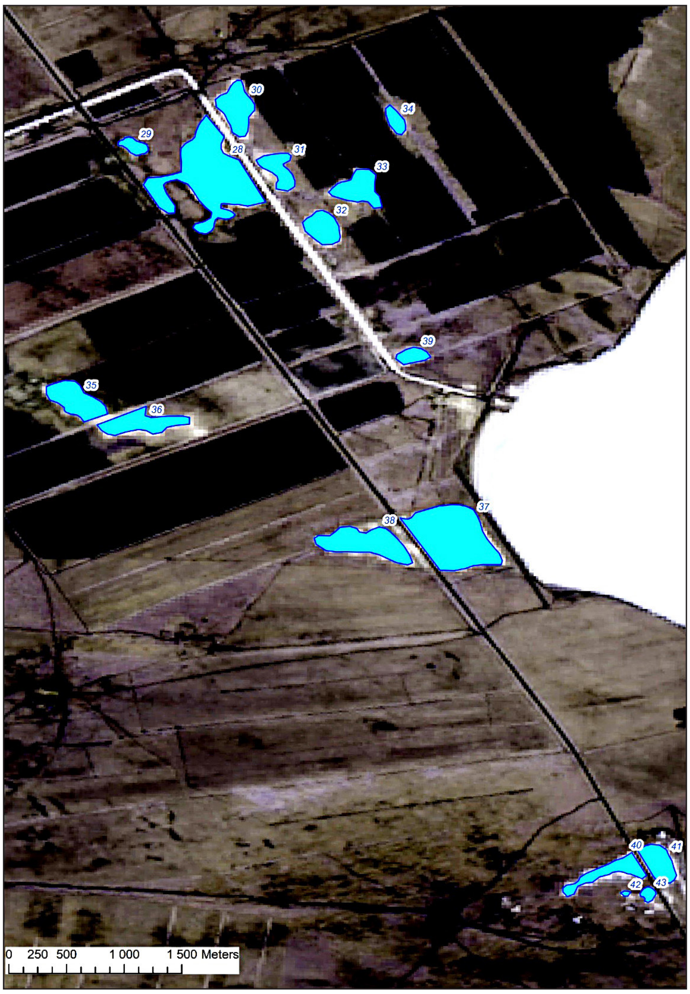

Figure 8. Water occurrences in areas controlled by the Sorbulak storage lake, used to calculate the volume of filtration water

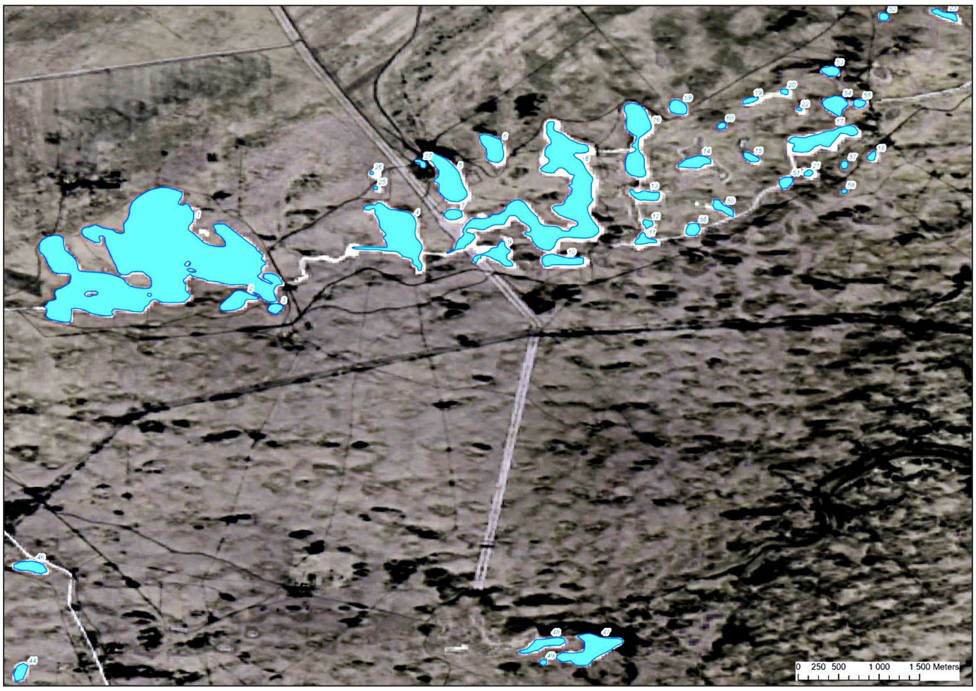

Figure 9. Water manifestations in areas controlled by reservoirs of the Right-Bank Sorbulak Canal used to calculate filtration water volumes

CONCLUSIONS

According to the research results, it was revealed that the main filtration flow from the Sorbulak storage lake is directed to the western side of the plateau. The average filtration coefficient of the western side at the front of the filtration flow was 1.37 m/day. Unloading is carried out in the Kurty River, there is no filtration in the northern and southern directions. From the south there is a zone of groundwater formation, and from the north there is a Paleozoic uplift of weathering crust rocks. These factors determine the absence of filtration processes from the storage in these directions. The filtration flow of the eastern side of the plateau is formed by storages. The discharge of the flow is carried out in the Kaskelen river. In the northern direction, the filtration flow is currently determined by the processes of subsurface filtration of the Sorbulak storage lake.

When analyzing the above, it can be stated that the filtration flow into the Kurty River from the Sorbulak storage lake has an average value of 2455.04 m^3/day. The maximum value of the flow was observed in the first quarter of 2018, and the minimum at the beginning of the 4th quarter of 2017. This dynamics is explained by the mode of operation of the storage, the discharge to which stops at the beginning of the warm period, and filling begins at the beginning of the cold.

Acknowledgements

We acknowledge the support of the Ministry of Education and Science of the Republic of Kazakhstan and the State Communal Enterprise “Almaty Su” of Almaty, the Republic of Kazakhstan. The work was performed within the framework of the projects “Comprehensive assessment of the impact of the Almaty wastewater storage system on the state of groundwater (2017–2018)” and BR10965134 “Assessment of fresh groundwater resources as the main source and long-term reserve of sustainable drinking water supply for the population of the Republic of Kazakhstan”.

REFERENCES

1. American Academy of Environmental Engineers (AAEE). 2009. Environmental Engineering Body of Knowledge. AAEE, the Environmental Engineering Body of Knowledge Task Force. Available at: www.aaees.org/publicationseebodyofknowledge.
2. Code of Environmental Protection of the Republic of Kazakhstan No. 212-III–SAM, Astana (rev. 26.12.2019). 2007. Available online: https://online.zakon.kz/document/?doc_id=30085593#pos=11;46 (accessed on 05 January 2022).
3. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. URL: http:// www.caresd.net/iwrm/new/doc/direct.pdf (reference date: 28.10.2013)
4. Draft Program of the Integrated Water Resources Management (IWRM) and the water use efficiency increase in the Republic of Kazakhstan until the year of 2025 (under the UN project), Astana 2006. http://www.voda.kz
5. Escobar I.C. 2010. Sustainable Water for the Future: Water Recycling versus Desalination /I.C. ES-COBAR, A.I. SCHÄFER. Amsterdam. Elsevier.
6. Japan Ministry of Environment. Solid Waste Management and Recycling Technology of Japan: Booklet / Minister's Secretariat, Waste Management and Recycling Department, Tokyo. 2012. Electronic resource: https://www.env.go.jp/ en/recycle/smcs/attach/swmrt.pdf
7. Kovalenko M.S., Polozentseva V.A. 2012. Stores of sewages and industrial wastes as potentially hazardous objects. East Eur. J. Enterp. Technol., 12, 27–29.
8. Masbey E.D. 1987. Chemical waste transportation: a status report / E.D. Masbey. Waste Age, 10, 90–94.
9. Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-being. Washington, DC: Island Press.
10. Racault Y. 2005. Waste stabilization ponds in France: state of the art and recent trends. Racault Y., Boutin C. Water, Science and Technology, 51(12), 1–9.
11. Smith V.H. 2003. Eutrophication of freshwater and coastalmarine ecosystems a global problem. Environ. Sci. Pollut. Res., 10, 126.
12. Technological regulations for the operation of the Aeration Plant in Almaty. 2013. Almaty, 251.
13. Ying G.G. 2006. Fate, behavior and effects of surfactants and their degradation products in the environment, Environment International, 32, 417–431.