RESEARCH PAPER

PROBLEMS OF SUSTAINABLE MANAGEMENT OF WATER RESOURCES OF LAKE SEVAN AND ITS BASIN

Trahel G. Vardanyan[1*]

[1]Yerevan State University, Yerevan, Alex Manoogian 1, 0025, Yerevan, Armenia

***Corresponding author:** tvardanian@ysu.am

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ABSTRACT. Numerous rivers, lakes and other water features have suffered significant alterations as a result of human economic activity. As a result, hydrometric, hydrological, biological, ecological conditions, as well as morphometric elements of these objects were violated.

In this regard, Lake Sevan and its basin might be used as a well-known example. There has never been any instance in the history of limnology where a lake's level was artificially lowered by 18 meters over 3 to 4 decades (1930–1970), and by another 2 meters at the end of the 20th century (1990–2000). Additionally, the lake's water volume dropped from 58 billion m^3 to 32 billion m^3.

The Sevan problem first surfaced in the late 19th and early 20th centuries and is still a problem today. However, it has many meanings/soundings at different times. Based on this, we usually divided the entire study period into several stages.

It should be noted that the ecosystem has suffered irreparable losses as a result of the use of the Lake Sevan resources, inadequate water resource management, and both positive and negative effects of these factors.

We disagree with the assertions of many experts that problems can only be prevented or solved by raising the lake level. Therefore, extensive actions must be taken in the Sevan basin management area, regardless of the lake's level.

KEYWORDS: Lake Sevan, level fluctuations, hydrological regime, water balance, water resources management, anthropogenic transformation

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INTRODUCTION

A great deal of rivers, lakes, and other water features have changed significantly as a result of man's economic activity. As a result, hydrometric, hydrological, biological, ecological conditions, as well as morphometric elements of these objects were violated.

There has never been another case where a lake level was artificially lowered by 18 meters for 3–4 decades (1930–1970), and by another 2 meters at the end of the 20th century (1990–2000). The volume of water in the lake also decreased from 58 billion m^3 to 32 billion m^3, making Lake Sevan and its basin a classic example in this regard in the field of limnology. The quantitative change of the lake water has also brought about a qualitative change. Well before the artificial change in lake level (in 1893), the total mineralization reached 714 mg/l. After 1980 the mineralization sharply decreased, reaching lows of 660.2 mg/l and 647.8 mg/l at the moment. The massive outflow of salty water, which removed the salts that had been accumulating in the lake for ages, is significantly related to the decrease in the total general mineralization of the lake water. Only the sulfate ion (SO_4) increased about 1.8 times from the examined ionic composition, which had an impact on the flavour of the water and might encourage bacterial growth. And Water transparency decreased from 14.3 meters to 4.5 meters (Vardanian et al. 2021).

It should be mentioned that the lake's hydrological regime changed as a result of the lake's level dropping and the economic growth of the basin. The latter caused the disruption of the hydrochemical and hydrobiological regimes of the lake. The quality of water deteriorated and water turbidity increased. Both the inner water substances circulation and the biological substance circulation were altered.

The Sevan problem, which first surfaced in the late 19th and early 20th centuries, is still a problem today. However, it has many meanings/soundings at different times. Based on this, we divided the entire study period into several stages (Fig. 2).

In the last fifty years, thousands of scientific articles and theses have been published, and hundreds of theses have been successfully defended in Armenia and many other countries. Government decisions and programs have been adopted regarding saving the lake (the latest one is The "2022-2027 Management Plan of the Sevan Basin Management Area" [1] is the most recent government decision and program involving

[1]https://www.irtek.am/views/act.aspx?aid=119092

lake preservation. Numerous foreign funding initiatives have also been executed.

Despite all of this, I believe the Sevan problem will continue to be a concern for a very long time.

RESEARCH AREA, MATERIAL AND METHODS

Research area

The transformation of lake ecosystems, one of hydro ecology's most significant research fields, is represented by Lake Sevan as a dramatic example. Sevan is one of the high-mountainous freshwater lakes in the world and the largest lake in Caucasus. Sevan is thought to be a large freshwater reservoir that supplies not just Armenia but also other nations in the area (Fig. 1).

Lake Sevan is regarded as a miracle of nature, an ecologically and economically significant water body, and a national treasure for Armenia. At 1900 meters above sea level, it is one of the highest lakes in the world and is located in the dry subtropical climate area. But because it is a freshwater lake situated in the arid subtropical climate area, it is very uncommon. Other lakes in the same area, such as Van and Urmia (in the Armenian Highland), the Dead Sea, Tuz (Middle East), Lobnor (Central Asia), Issik-Kul (Central Asia), are all salty and their water is unfit for irrigation and drinking (Vardanian 2012). The salinity of Lake Sevan water is only 600-700 mg/l (Parparova 1979, Vardanian 2009).

Thus, it is a major source of water for Armenia, and potentially for other countries in the region.

Since antiquity, people have been aware of Lake Sevan; knowledge about it may be found in the works of Greek chroniclers and geographers. On the map that Ptolemy drew, Lake Lychnites, according to the French traveler Saint-Martain, is actually Lake Sevan (Gabrielian 1980). There are several theories explaining the creation of the lake, with the tectonic-retaining idea being the most logical (Sargsian 1962). According to this theory, the lake was formed in a tectonic depression as a result of dams created by lava flows from the Geghama mountains. Lake Sevan is divided by the Noratus and Artanish promontories into two major basins, Big and Small Sevan. In the upper Pleistocene volcanic outflows finally blocked the valley of the Hrazdan River, between 150-200 thousand years ago (Paffenholtz 1950).

The numerous streams that run into the lake are fed by mountain ranges that are more than three thousand meters high, which surround the lake. Along the main axis of the lake, to the north-east, are the folded block mountains of the Areguni, Sevan, and East Sevan, while the Geghama and Vardenis volcanic mountains encircle the area to the south-west (Fig. 1). The Hrazdan River currently provides the natural outflow, and the river's waters are used downstream for irrigation and hydropower generation.

The Lake Sevan basin is characterized by a continental mountain-steppe landscape. The coastal zone of the Lake Sevan is characterized by a temperate climate with warm long summers and relatively cold winters. The climate changes slightly in higher elevations, with summers becoming cooler and winters becoming colder. The basin's high elevation and the air's relative dryness are what cause the region to get more than 2500 hours of sunshine annually (in Martuni, about 2800 hours). The warmest month is August, when the average monthly temperature ranges from 8.8°C (Yeratmber) to 17.6°C (Shorzha). The coldest month is January with an average monthly temperature of -4.6°C (Shorzha) to -12.3°C (Yeratmber). The average annual temperature ranges from -2.3°C (Yeratmber) to 6.4°C (Shorzha). A stable snow cover develops in the winter. The precipitation in the basin ranges from 386 (Tsovak) to 857 (Yeratumber) mm. During the year, the maximum amount of precipitation is observed in spring, mainly in May, and the minimum - in winter (Climate Bulletin of the Republic of Armenia 2011).

Water from inflowing rivers, surface precipitation, and groundwater influx supply Lake Sevan with water. Water is

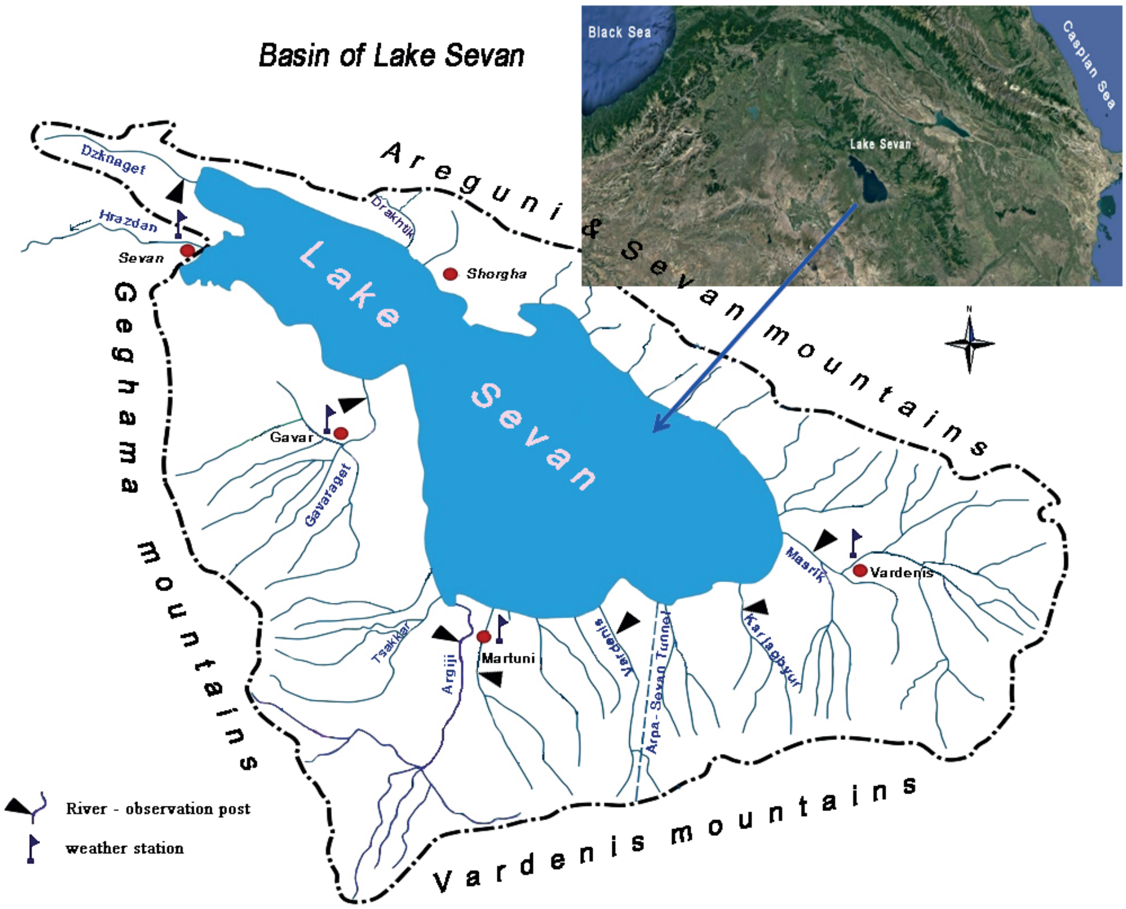


Fig. 1. The river network of Lake Sevan

removed from the lake by evaporation, infiltration, and flow out through the Hrazdan river.

The primary source of water is rivers. There are 28 rivers and streams are longer than 10 km (Table 1). The river network is rather dense in the south and south-western parts of the basin, which has the largest rivers, the Argiji, Gavaraget, Masrik, and Vardenis (Fig. 1).

The scientific study of Lake Sevan started at the end of the 19th century. The first relatively comprehensive survey was undertaken by (Markov 1911). In 1928 Davidov established the Hydro-Meteorological Bureau of Sevan, installed hydrological and meteorological stations, and commenced routine observations. Eventually the lake's water balance (Davidov 1938), and salinity balance (Lyatti 1932) were estimated. Since then, a variety of alterations in these balances have occurred as a result of human activity added to natural occurrences, most noticeably seen in variations in lake levels.

MATERIAL AND METHODS

The Armstatehydromet official observations (Climate Bulletin of the Republic of Armenia 2011; Fourth National Communication on Climate Change 2020), the Hydrometeorology and Monitoring Center state non-commercial organization, data from various departments (Institute of Hydro ecology and Fisheries; Yerevan State University; et al.), and currently available scientific sources were used to implement the article (Bagdasaryan 1990).

The fundamental concepts and techniques of spatial-temporal analysis (general geographic, physical-geographic, hydrometeorological, socio-economic, hydro ecological), as well as the synthesis of pertinent data and generalizations, were utilized to analyze the initial data (Mann 1945; Rusinov 1970; Shelutko 2007; Gagarina 2012; Chichasov 2013).

We used field expeditionary observations, processing techniques of specialised databases, geographic information systems, empirical-statistical and genetic theoretical models, methods of mathematical statistical analysis, and other methods and techniques used in practise in the study of hydrometeorological and hydrochemical information (Aliokhin 1970; Rozhdestvensky et al. 1974; Kendall 1975; Shelutko 1984; Trofimov et al. 2001).

RESULTS AND DISCUSSION

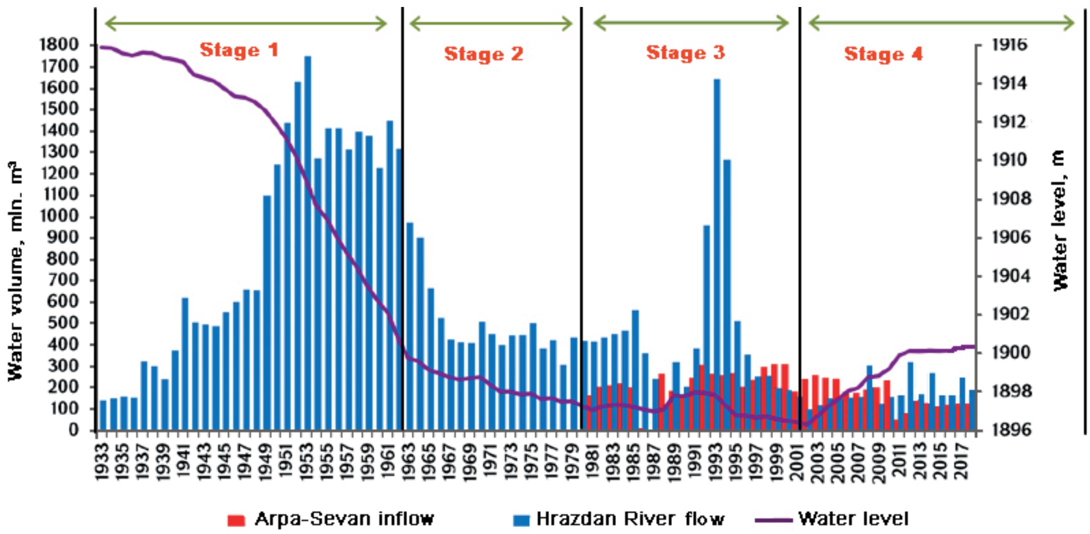
The transformation of hydrometric and hydrological regime and existing problems

As previously said, we divided the duration of the Lake Sevan problem study traditionally into a number of stages (Fig. 2), which we will talk about in detail below:

- Problem presenting stage (beginning of the 20th century)
- Implementation stage of the main problem (1930 – 1950s)
- Emergence stage of a new problem (1960 – 1970s)
- New problem prevention stage (1980 – 2000s)
- Current stage issues

Table 1. Some hydrometric and hydrological characteristics of relatively large rivers of the basin of Lake Sevan (Vardanian et al. 2021)

River-observation post	River length, km	Size of watershed basin, km²	Mean height of watershed, m	Mean annual discharge, m³/sec	Runoff , l/sec km²
Argiji-V. Getashen	51	384	2470	5.55	14.5
Gavaraget-Noraduz	41	467	2430	3.51	7.5
Masrik-Torf	45	685	2310	3.42	4.9
Vardenis-Vardenik	24	116	2680	1.64	14.1
Karchaghbjur-Karchaghbjur	26	117	2650	1.15	9.8
Martuni-Geghovit	20	85	2760	1.41	16.6
Dzknaget-Tsovagjugh	21	85	2220	1.06	12.5



Stage 1. Implementation stage of the main problem (1930 - 1950s) Stage 2. Emergence stage of a new problem (1960 - 1970s)	Stage 3. New problem prevention stage (1980 - 2000s) Stage 4. Current stage issues

Fig. 2. The graph of perennial fluctuation of Lake Sevan level: annual total water outflow volume and Arpa-Sevan inflow (According to Hydrometeorology and Monitoring Center of RA)

Problem presenting stage (beginning of the 20th century)

The concept of using Lake Sevan water in a practical way appeared at the beginning of the 20th century. Because of Armenia's dry subtropical climate, potential evaporation considerably exceeds the amount of precipitation. A limited resource for agriculture is water. There are hundreds of thousands of hectares of fertile land in the Ararat valley, which is south of and 1000 m lower than Lake Sevan. But their annual precipitation is close to 250-300 mm, and potential evaporation is above 1000 mm. In the meantime, the lake's evaporation caused millions of cubic meters of water to evaporate.

A water resources management project for the lake was designed to ensure the efficient use of Sevan's water and fish resources, and it calls for the annual discharge of 1025 million cubic meters of water from the lake's centuries-old water reserves through the Hrazdan River: 375 million cubic meters for irrigation and 650 million cubic meters for energy (Musaelian 1993; Gabrielian 1980).

The Hrazdan River's bed was first suggested to be deeper, and the discharge was intended to be artificially increased. This would reduce the lake level by 55 m and increase the outflow of the Hrazdan river by 14-15 times, draining Big Sevan but using the water to irrigate 120 thousand ha immediately downstream and in the Ararat valley. Additionally, it would permit the development of a series of hydroelectric facilities on the Hrazdan River (Vardanian et al. 2007).

Before 1930, Lake Sevan's surface was 1916 meters above sea level in its natural state. The surface of the drainage area of the lake before its artificial drop (1930s) was 3475 km^2, that is larger than the surface of the lake by 2.5 times (1416 km^2), and the volume of lake water was 58.5 billion m^3 (Table 2).

In its natural state, the water balance of Sevan was stable (Table 3). The largest component of the balance was evaporation, 1210 million m^3 per year, and the outflow through the Hrazdan River was only 50 million m^3.

The Hrazdan River's bed was first suggested to be deeper, and the discharge was intended to be artificially increased. This would drain Big Sevan but use the water to irrigate 120 thousand ha directly downstream and in the Ararat valley, lowering the lake level by 55 m and raising the Hrazdan river's outflow by 14–15 times. Additionally, it would enable the development of a series of hydroelectric facilities on the Hrazdan river. But, the First World War came into play (Vardanian et al. 2007).

In our opinion, this decision was correct and realistic for the given period. It was based on the socio-economic situation of the country. Armenia was an agrarian country, it did not have any fuel and energy resources. In other words, the country partially addressed a number of crucial economic difficulties with the help of this approach of water resource management.

Implementation stage of the main problem (1930 - 1950s)

The concept wasn't given another thought until the Soviet times. In 1931, after partial changes, the project was approved by the government and construction started. After building Kanaker and Yerevan hydropower stations, the construction of Sevan-Hrazdan hydropower cascade (Fig. 3) was interrupted by the Second World War. Work re-started in the early 1950s, and further power stations were built.

The water balance of the lake underwent the greatest change at this stage (Fig. 2, Table 3). The outflow of water through the Hrazdan River in 1950-1953 reached its historical maximum volume of 1.7-1.8 billion m^3 (Fig. 2).

Table 2. Some hydrometric and hydrological indicators of Lake Sevan

Indices	Unit of Measurement	In natural state (Davidov, 1938)	At the lowest level (2001)*	Present-day Condition*
Drop of lake level	m	0.0	19,43	15,48
Height above sea level	m	1915.89	1896.46	1900.41
Watershed surface	km^2	3475	3649	3613
Lake surface	km^2	1416	1242	1278
Maximum depth	m	98.7	79.3	83.2
Water volume	km^3	58.5	32.8	38.3
* According to Hydrometeorology and Monitoring Center of RA				

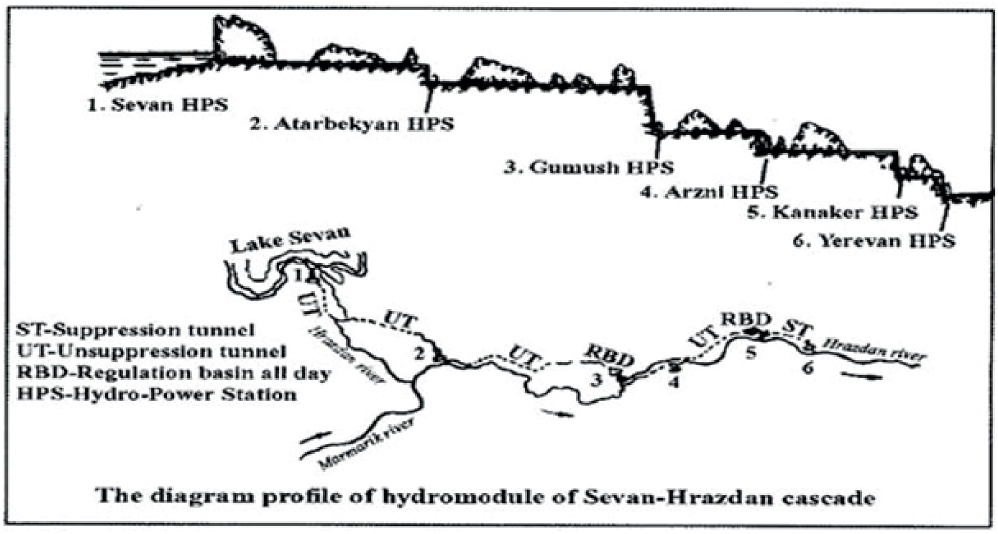


Fig. 3. The Plan of Sevan-Hrazdan Hydropower Cascade (Vardanian et al. 2007)

In this respect, Sevan is the only lake, which is considered to be a large natural laboratory, where one can observe all those processes, connected with the decrease of erosion basis of flowing into the lake rivers, and which cannot be studied under laboratory conditions. Among these processes, the hydrological, thermal, hydro-chemical, carbon regime of the lake, as well as biological conditions, which have served as a rich material for scientific researches, are rather important.

The activation of channel processes that flow into lake rivers was brought on by a decrease in erosion basis. It caused the river valleys' balanced profiles, which were created over thousands of years, to be violated. The active down-cutting erosion destroyed the foundations of bridges and caused their collapse.

Down-cutting erosion is characteristic of all the rivers which flow into Lake Sevan. But at the mouth of the Argiji, the main inflowing river, where the river has deepened its riverbed by 10-15 m, the erosion is quite visibly exhibited (Fig. 4).

Some of the irrigation, electricity, and industrial issues were already partially resolved at this point. However, the government realized that it is necessary to make some changes in the water resources management plan of Lake Sevan. Examine the topic of additional level reduction in particular.

Emergence stage of a new problem (1960 - 1970s)

At this point, it was evident that the physical, chemical, and biological characteristics of Lake Sevan and its surroundings had been significantly impacted by the lake's level fall. The water balance of the lake continued to remain negative. The difference between water inflow and outflow was -845 mln. m^3, and the level dropped to 17-18 m (Fig. 2, Table 3).

The changes that have created better circumstances for algae development and the early warning indicators of eutrophication are the most visible. The first signs of the lake's eutrophication were recorded in 1964, when green and blue algae blossomed in the lake. The ecosystem as a whole has deteriorated as a result of changes in lake conditions, as have changes in a number of lake-related processes (including bio-degradation, sedimentation and diffusion). Despite the waters still having oligotrophic lake conditions, the quantity of bacteria per liter was more than twice what it had been prior to the lake's level reduction in the 1960s. However, starting in the 1980s, the number of

Table 3. The water balance of Lake Sevan in different years (million m^3)

Balance Component	In natural state, Davidov V. K. (1927-1934)	Hydro-meteorological Department of RA (1951-1970)	Hydro-meteorological Department of RA (1981-2000)	(2002-2009)*	Hydrometeorology and Monitoring Center of RA (2018)
Inflow					
Precipitation	550	498	507	593	497
River flow	720	749	777	735	725
Arpa-Sevan flow	-	-	236	219	142
Subsurface flow	50	78	80	94	94
Total	**1320**	**1325**	**1600**	**1641**	**1458**
Outflow					
Evaporation	1210	1053	1102	1045	1 203
Hrazdan River flow	50	1093	513	157	201
Subsurface flow	60	24	10	14	14
Total	**1320**	**2170**	**1625**	**1216**	**1418**
Inflow-Outflow	0	-845	-25	+425	+40

*Ecology of lake Sevan during the period of water level rise the results of Russian-Armenian biological expedition for hydroecological survey of lake Sevan (Armenia).

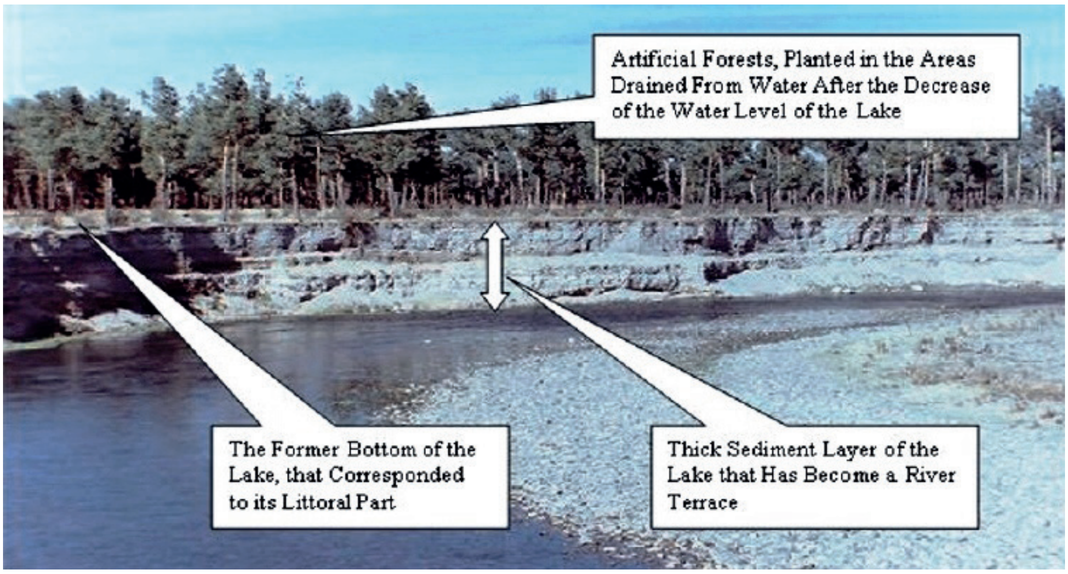


Fig. 4. The riverbed of the Argiji river, which [riverbed] has deepened as a result of the drop of Lake Sevan level

bacteria quadrupled once more, creating a concentration that currently reflects the elements of a mesotrophic lake.

The drainage of the lake also had important effects for the fauna. The primary trout breeding habitats were eliminated as parts of the lake's rocky bottom dried out. In addition, around 10 thousand ha of wetland and semi-wetland areas also dried out. These areas were previously used by up to 160 species of migratory birds, and only 50 of these species are currently recorded. The populations of mammal and reptile species in the area have also declined significantly, and there is evidence of changes in species composition (The Biodiversity of Armenia 1999).

As the deterioration of the lake environment became more apparent and better understood, restoration and increased lake levels became a consideration in any project involving the lake.

Concern for the preservation and restoration of Lake Sevan and its environment first became apparent in the 1960s. Water from nearby river basins has to be supplied to the lake in order to achieve restoration. In 1961 it was proposed to construct the Arpa-Sevan water-carrying tunnel. The planned tunnel was 48 km long, passed under the Vardenis mountain range (Fig. 1) and was supposed to carry 250 million m^3 of water annually from the Arpa river in Sevan (Fig. 5).

New problem prevention stage (1980-2000s)

After the construction of Arpa-Sevan tunnel in 1982-1990, a positive water balance was established in the lake and the level started to rise gradually (Fig. 2). As a result, biological and chemical changes and associated physical processes encouraged biological productivity and the lake rehabilitation became sustainable.

Despite the stabilization of the level and the average annual volume of water drained by the Arpa-Sevan tunnel (236 million m^3), the lake balance still remained negative (-25 million m^3) (Table 3).

Meanwhile, design and construction started on a new water transfer project. This would obtain a supply of water from the Vorotan river basin, adjacent to the Arpa River. Annually 150-170 million m^3 would come through a 20 km tunnel into Kechut reservoir, built on the Arpa River. The water would then travel through the Arpa-Sevan tunnel and into Lake Sevan from there. At the same time, the outflow from the lake would not exceed 100-120 million m^3. These conditions would enable the lake to stabilize as well as gradually raise its levels. Construction started in 1990.

However, the sustainability was interrupted by the economic and energy crisis in Armenia (Disintegration of the USSR, Karabakh war, economic blockade), and since 1992, large water releases from the Lake restarted (1.6-1.7 billion m^3). Construction of the Vorotan-Arpa tunnel was also stopped.

Thus, the lake's secondary destabilization began, resulting in a further drop in level, which led to the buildup of organic materials in the lake, a trend towards eutrophication, and the reemergence of the serious issues. During this time, the level of the lake continued to decrease and in 2001 reached its historical minimum mark (1896.46 m) and the volume was only 32.8 km^3, instead of the previous 58.5 km^3 (Table 2).

Current stage issues

The biggest problem of the current stage is the effective management of the Sevan basin management area.

An increase in lake levels over the current value is required if Lake Sevan is to be restored as a viable freshwater lake. During the past 20-30 years, the status and processes within Lake Sevan has been investigated by a number of scientific- research institutes, scientific expedition groups, and scientists from Armenia, the former USSR, and foreign countries. They agree that a rise in lake level is needed in order to slow down or stop the eutrophication processes in the lake and reverse the deterioration of the lake environment. Most suggest that the lake level must be increased by at least 6 meters.

In order to raise the water level of the lake, to restore and preserve the ecosystem, a number of large-scale measures were taken. In particular, in 2001, the Law of the Republic of Armenia on measures for restoration, conservation, reproduction and use of the Lake Sevan ecosystem was adopted[2].

According to this law, in the field of raising water level of Lake Sevan, it was planned to put into operation the Vorotan-Arpa hydro junction, which construction was

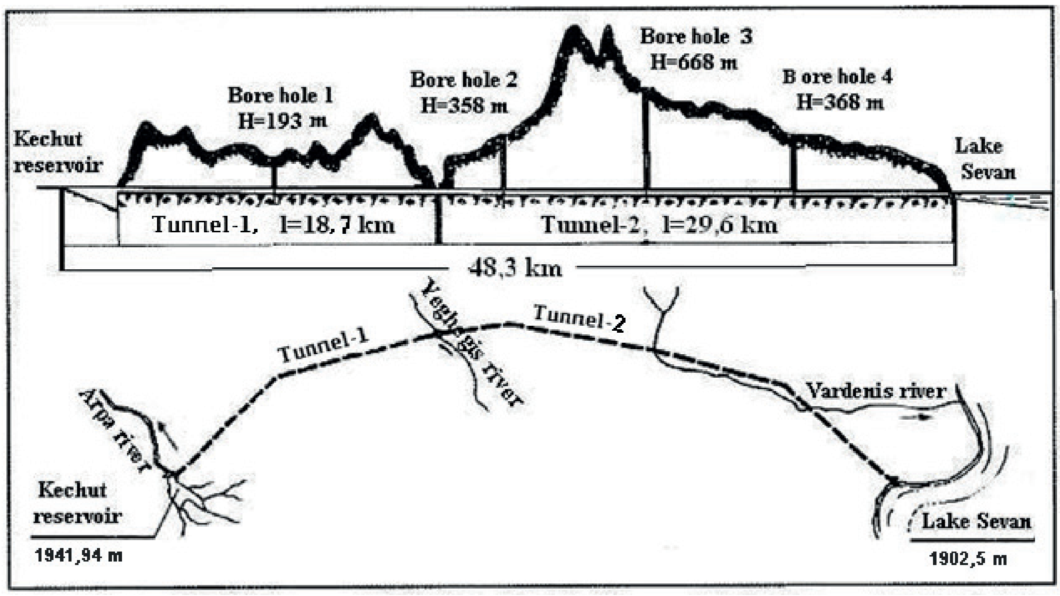


Fig. 5. The Plan of Arpa-Sevan Tunnel (Vardanian et al. 2007)

[2]https://www.arlis.am/DocumentView.aspx?docid=137373

stopped in the 1990s, and to ensure the stable operation of the Arpa-Sevan water pipeline.

As a result, an annual increase in the level of Lake Sevan was expected about 21.6 cm. According to these calculations, during the 30 years planned by the complex program, the volume of Sevan water would increase by around 8.8 billion m^3, which is equivalent to a 6.5 m increase in the lake level. According to the ecological balance, Lake Sevan will have an additional water supply following the required 6 m rise in lake level, which will be seen as a highly significant and strategically significant natural resource for energy and other economic branches.

The Vorotan-Arpa water tunnel was put into operation in 2004 according to the law, which was intended to transfer a part of the water of the Vorotan River to Sevan. Unfortunately, this aqueduct hasn't functioned in any way since the day it was launched for reasons that are unclear.

In 2008, the President of the Republic of Armenia issued a proclamation establishing the Sevan Lake Issues Commission for the supervision of the specified works, monitoring observations, and submission of new proposals[3].

This commission contributed significantly to later lake level stabilization. As a result, the level of Sevan rose by more than 3 m (Fig. 2).

However, due to ineffective management of the water basin, inaccurate estimates, and favorable meteorological conditions in those years, a double increase in lake level instead of the anticipated annual increase of 21.6 cm took place. The lake level increased by nearly 2.5 metres in just 6 years (2002–2007).

As a result, a new issue emerged, namely, the coastal green zone (tree-shrub vegetation) and recent constructions is under water (Fig. 6). Significant water levels rose quickly and unexpectedly, leaving no time to clean the shoreline of vegetation, putting the lake at risk of eutrophication once more.

Based on this situation, in the years that followed, the lake's quick increase was slowed, mostly by increasing outflows through the Hrazdan River, making it possible to clear the buildings and coastal green zone. In addition, climatic conditions became more unfavorable (precipitation decreased, droughts increased). Even now, this process is still in motion. As a result, the lake became frequently covered with blue-green algae (Vardanian et al. 2021).

Changes in the shoreline of Lake Sevan in 1973-2015 were analyzed more thoroughly in the paper (Hovsepyan et al. 2019), using the spectral index NDWI (Normalized Difference Water Index).

The bloom event in 2018 reached unprecedented levels, and therefore, stirred intense media attention (Gevorgyan et al. 2020). The lake continued to bloom in 2019-2022 too (Fig. 7).

Our studies have shown that only raising the lake level is not enough. In order to effectively manage the water resources of the lake and develop the Ecosystem, it is necessary to ensure a stable level of the lake during the year. Drastic fluctuations during the year, such as the level of Lake Sevan, should not be subjected. Utilizing historical data from the Armenian Monitoring Center's measurements for the most recent year (2022), we can observe that the lake level varied by 42 cm in just four months (Fig. 8), or roughly 511 million m3 of water volume. That is, as much water as the approximate combined flow

Fig. 6. The coastal green zone is under water (https://blog.168.am/blog/251490.html; https://www.ecolur.org/hy/news/sevan/2039/)

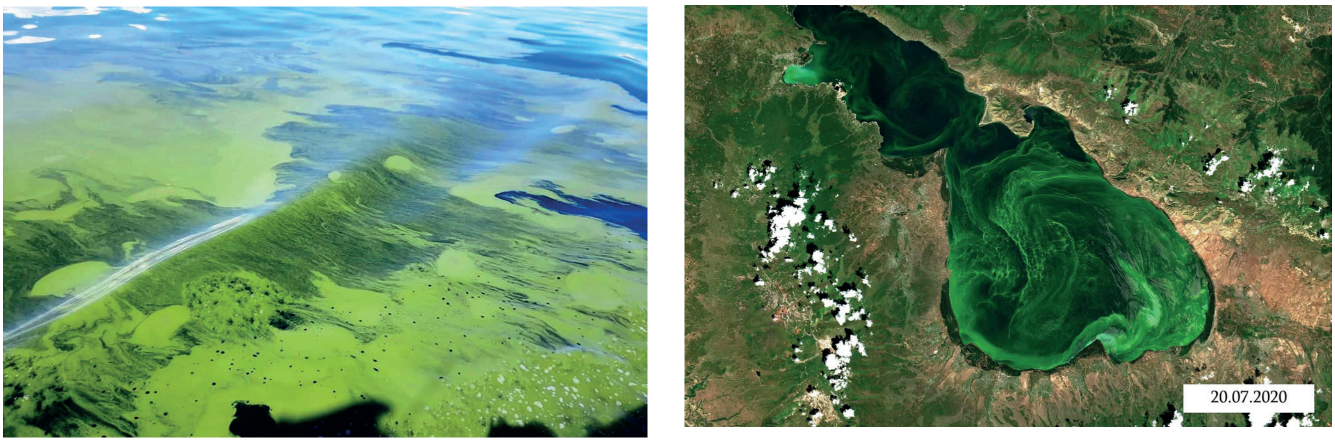


Fig. 7. Satellite images of Lake Sevan blooming in 2020 (https://hetq.am/en/article/146637)

[3]https://www.arlis.am/DocumentView.aspx?DocID=48718

of all rivers entering the lake during a year with low water levels.

It is hard to predict the future developments of these processes. However, the issue of lake Sevan is not entirely settled, the ecosystem of the lake is damaged, undergoing the process of eutrophication. The flora and fauna of the water and coast underwent serious and irreversible changes.

The last document adopted by the government regarding Lake Sevan was the adoption of the decision on the "2022-2027 Management Plan of the Sevan Basin Management Area"[4].

The document's primary goal is to strike a balance between the interdependent relationships among water users, including agriculture, fisheries, industry, energy and the environment, in order to assist the bodies in charge of managing water resources, administrative bodies, and the general public in making decisions regarding the wise and effective use of water resources. Hopefully this program will help to improve the ecosystem.

The main ways of solving current problems

The following methods of ecosystem regulation are provided as a result of our investigation into and analysis of the history and present issues of the Sevan Basin Management Area.

1. It is known that the management of natural resources in the direct influence zone of the Sevan catchment basin is carried out by various state administration bodies, governorates and communities. From the analysis of the management system, it follows that there is no single governing body in the region, as a result of which the ecological condition of Lake Sevan and its catchment continues to deteriorate. Therefore, in order to address the issue, new legislation must be passed, existing water law must be improved, institutional capacity must be increased, and a water monitoring system must be put in place.

2. In the management of current problems, it is extremely important to clarify the quantitative indicators of the water balance components of the Sevan Lake basin. Specifically, the amounts of available dynamic water resources' inflow and outflow. However, our monitoring observations and studies show that the indicators of these components do not have sufficient reliability. The cause is that there aren't enough evaporators, the calculation methods for groundwater flow entry and exit aren't specified, and hydro-meteorological measurement and testing equipment is frequently out of date.

3. There is a highly stressed water-economic balance in the Sevan basin management area. Water intake in the basin is carried out for drinking-domestic, irrigation, water desalination, industry, hydropower and fish farming purposes, in accordance with water use permits. However, there are many unauthorized water users. In other words, a specific amount of water is not taken into consideration or seen as a loss. As a result, the supply and demand of water require significant attention. Monitoring of the water use licenses issued by the competent department is required in order to ascertain the true demand for water. At the same time, improvement of water supply and irrigation networks is needed to reduce water losses. It is time for the state to define the priorities of the water use sectors in the basin and to implement the SCADA (Supervisory Control and Data Acquisition) system for the main water users, which will enable more efficient collection and processing of actual water use data.

4. Qualitative and quantitative pressures on the Sevan Basin Management Area have increased in the last decade. Anthropogenic load has increased. As a result, household waste and domestic sewage from the villages and industries in the basin can flow freely via the rivers or into the lake. There are only three mechanical wastewater treatment plants in the entire basin of Lake Sevan (Gavar, Martuni and Vardenis). Water does not undergo biological and chemical treatment.

5. For sustainable management of the ecosystem, it is necessary to clear the forests and bushes in the flooded areas, to build new wastewater treatment plants, to re-equip the old ones, to build a sewage system and a sanitary landfill. In addition, we propose to build modern phytoremediation plants in small communities in the basin (up to 2-3 thousand inhabitants), which are widely used all over the world.

6. The climate change scenarios show a negative impact on the conditions for life in the Lake, and the pessimistic (the worst) scenario suggests a decrease in the total river

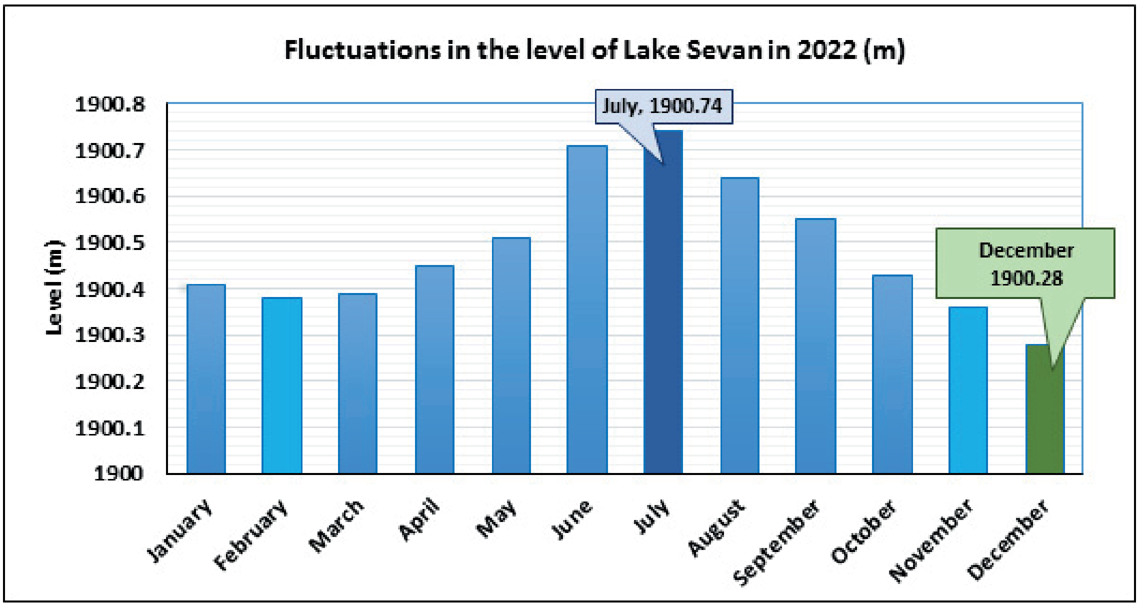


Fig. 8. Fluctuations in the level of Lake Sevan in 2022 (According to Hydrometeorology and Monitoring Center of RA)

[4]https://www.irtek.am/views/act.aspx?aid=119092

inflow into the Lake Sevan by about 34% (265 million m^3) and increase of Lake surface evaporation rate by 36.5% (292.6 million m^3) by 2100 as compared to the baseline conditions (1961-1990). The Lake level will decrease by about 16 cm in a year.

Considering this circumstance, we propose to diversify agriculture and industry in the effective and sustainable management of water resources. Create water-saving strategies, introducing drip irrigation in particular and diverse water billing schemes.

CONCLUSION

The ecosystem has suffered irreparable losses as a result of centuries-old fluctuations in the level of Lake Sevan and in general in the water, thermal, water-chemical, and water-biological regimes that created diverse issues at different eras and had both positive and bad features.

Although the RA Ministry of Environment has taken and is taking a variety of steps to stabilise the biological condition of the Lake, it is difficult to anticipate how these processes will develop in the future. However, the issue of lake Sevan is not entirely settled, the ecosystem of the lake is damaged, undergoing the process of eutrophication. The flora and fauna of the water and coast underwent serious and irreversible changes.

We believe that only raising the lake level cannot prevent or solve existing problems, as many experts claim. Given the fact that the lake level rise is limited (only 2 meters can be raised, because the entrance of the Arpa-Sevan tunnel to Lake Sevan is located at 1902.5 m. (Fig. 5) in height, and the lake level was 1900.28 m. (Fig. 8) in December 2022), the solution to the problem is unrealistic. In our opinion, raising the level can only provide a temporary solution to the ecosystem, contributing to the self-cleaning of the lake water. If the remaining issues are not resolved, the lake will soon encounter the same issue once more. Therefore, in the Sevan basin management area, which was covered in detail above, complicated actions must be implemented regardless of the lake's level.

Finally, a mathematical model for sustainable management of water resources should be developed and implemented for the entire basin.

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