GEF project “Enabling Transboundary Cooperation and Integrated Water Resources Management in the Dniester River Basin”

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ANALYSIS OF THE EFFECTS OF THE DNIESTER RESERVOIRS ON THE STATE OF THE DNIESTER RIVER

Report of the Moldovan-Ukrainian expert group

Thematic supplement to the Transboundary Diagnostic Analysis of the Dniester River Basin

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INTRODUCTION

This analysis of impact of construction and operation of the cascade of reservoirs of Dniester HPPs and PSPPs on the hydrological regime and ecosystem of the lower part of the basin of the Dniester as well as on provision of basic water management functions was produced by a mixed expert group of specialists of scientific, design, economic and environmental organizations and institutions of the Republic of Moldova[1], and Ukraine within the framework of the GEF project "Enabling Transboundary Cooperation and Integrated Water Resources Management in the Dniester River Basin”.

This analysis is based on the available evidence, including published sources, data of hydrological, hydro-chemical and hydro-biological observations by governmental agencies of Moldova and Ukraine, as well as historical data and information of scientific and industrial organizations of both countries.

The activities of the group followed the common principles of collaboration established at the meeting on the hydropower issues held in the frames of the GEF project in Chisinau on April 15, 2018:

- good faith;
- desire for dialogue;
- avoiding politicizing problems;
- respect for the position of colleagues;
- patience;
- flexibility in the definition of processes to negotiate issues and opinions.

In analyzing the data and drawing conclusions, the expert group strove as much as possible to achieve consensus among the members. To ensure more open discussions, the meetings of the group followed Chatham House rules: to maximize dissemination of information about the progress and results of the work, without reference to its members and specific sources of the views expressed[2].

Over the course of 2018-2019, the group had three working meetings. At the first meeting held on 18 - 19 June 2018 in Kyiv,[3] the general methodological issues regarding the group’s work were discussed and, in principle, agreed upon, including the periodization of the analysis (consideration of the periods before the construction of reservoirs and after filling and commissioning), the identification of the main sections for analysis (the near-dam transboundary section, the middle and lower reaches of the Dniester), the choice of observation posts and the periodicity of hydrometeorological data for analysis, as well as preliminary list of hydrological, hydro chemical and hydrobiological indicators for analysis, taking into account EU recommendations and evidence. Based on the results of the meeting, a final composition and structure of the group was established and its Terms of Reference prepared.

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[1] Hereinafter referred to as Moldova

[2] "When a meeting, or part thereof, is held under the Chatham House Rule, participants are free to use the information received, but neither the identity nor the affiliation of the speaker(s), nor that of any other participant, may be revealed”: https://www.chathamhouse.org/ chatham-house-rule.

[3] Project of the Global Environment Facility “Enabling Transboundary Cooperation and Integrated Water Resources Management in the Dniester River Basin”. Working meeting of the expert group to analyze the impact of reservoirs of Dniester HPPa on the state of the Dniester River Basin: city of Kyiv, Ukraine, 18 - 19 June 2018. Summary of the meeting.

At the second working meeting held on 14 September 2018 in Chisinau[4], the group discussed the results of the preliminary exchange of data and its analysis in respect of changes in the runoff, temperature and oxygen regimes, the state of macroinvertebrate communities, long-term dynamics, and current water needs in the basin. According to the results of the meeting, it was proposed to supplement the hydrological analysis with respect to intraday fluctuations in flow rate and water level, the characteristics of the spring flood regime and the water balance of reservoirs. It was also suggested to use complementary information in hydro chemical analysis and supplement the database of hydrobiological information for analysis with the data of the Institute of Zoology of Moldova and the available materials on the state of fish communities of the Dniester, avifauna and ecosystems of the Dniester floodplains. Finally, it was agreed to expand the analysis of water use by reconstructing long-term data on water consumption of Moldova and Ukraine in the middle and lower reaches of the Dniester and its expert forecast.

At the third working meeting held on April 3, 2019 in Kyiv, the leaders and deputies of expert subgroups discussed and clarified the draft of this report.

The draft results of the analysis were presented at the first and second sessions of the Commission on Sustainable Use and Protection of the Dniester River Basin in Chisinau 18 September 2018, and in Kyiv 4 on April 2019, as well as at the second meeting of the Steering Committee of the project "Enabling Transboundary Cooperation and Integrated Water Resources Management in the Dniester River Basin" in Odessa on December 18, 2018 .

The final results and conclusions of the analysis conducted by the expert group were included in a short form in the Dniester Transboundary River Basin Management Plan, as well as prepared and published in the form of this report.

In the substantial part of this report, the effects of the construction and operation of reservoirs are divided into two categories: caused mainly by structural modifications (physical rearrangement of the drainage network, channel and floodplain of the Dniester – chapter 2); and caused by changes in the runoff due to its redistribution and regulation by storage reservoirs (explored in chapters 3 and 4). Conclusion contains an overview of the major changes brought about by the construction and operation of the Dniester reservoirs, as well as the recommendations of the group regarding future studies and remedial measures.

It should be noted that the task of the expert group was to analyze the impact of the operation of hydropower facilities. However, this is not the only reason for changes in the hydrological regime and biotic communities of the Dniester. They are also influenced by climate change, industrial and domestic pollution, construction, coastal protection, changes in the status of the catchment basin, the spread of invasive species, and other factors. The Dniester Transboundary River Basin Management Plan, amongst other things, considers the impact of those factors. .

[4] Global Environment Facility Project "Enabling Transboundary Cooperation and Integrated Water Resources Management in the Dniester River Basin". Working meeting of the expert group on the analysis of the impact of the Dniester reservoirs on the state of the Dniester basin: Chisinau, the Republic of Moldova, September 14 , 2018. Summary of the meeting.

1. CHARACTERIZATION OF RESERVOIRS AND HYDROMORPHOLOGICAL EFFECTS OF THEIR CONSTRUCTION

Source: Strategic Directions ... 2015

Fig. 1.1. Physical map of the Dniester basin

The reservoirs of the Dniester hydropower stations are multipurpose and provide for the irrigation needs, water supply, flood control, electricity generation, shipping, recreation, etc. Three river reservoirs and a reservoir of a pump-storage power plant (PSPP) were built along the length of the river.

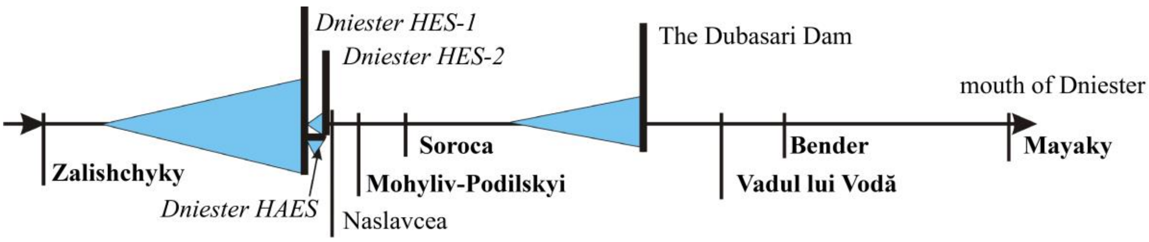

Fig. 1.2. Linear layout of hydropower stations and reservoirs

Table 1.1 Morphometric characteristics of Dniester reservoirs

<table>
<tr><th rowspan="2">Indicator</th><th rowspan="2">Dniester reservoir</th><th colspan="2">Buffer reservoir</th><th rowspan="2">The upper pond of the PSPP</th><th rowspan="2">Dubossary Reservoir</th></tr>
<tr><th>Before PSPP commiss.</th><th>After PSPP commiss.</th></tr>
<tr><td>Normal retaining level (NRL), m</td><td>121,0</td><td>72,0</td><td>77,1</td><td>229,50</td><td>28,0</td></tr>
<tr><td>Forced retaining level, m</td><td>125,0</td><td>82,0</td><td>82,0</td><td>-</td><td>30,0</td></tr>
<tr><td>Dead volume, m</td><td>102,5</td><td>67,0</td><td>67,6</td><td>215,50</td><td>24,2</td></tr>
<tr><td>The area of the water table at NRL, km^2</td><td>136,0</td><td>5,9</td><td>7,3</td><td>2,61</td><td>67,5</td></tr>
<tr><td>The volume of the reservoir at NRL, mln m^3</td><td>2657</td><td>31,0</td><td>58,1</td><td>41,43</td><td>266,0</td></tr>
<tr><td>Useful volume, mln m^3</td><td>1907</td><td>23,4</td><td>31,8</td><td>32,70</td><td>163,4</td></tr>
<tr><td>Length, km</td><td>194,0</td><td>19,8</td><td>19,8</td><td>2,90</td><td>127,5</td></tr>
<tr><td>Average width, m</td><td>701,0</td><td>298,0</td><td>369,0</td><td>900,0</td><td>529,0</td></tr>
<tr><td>Maximum depth, m</td><td>54,0</td><td>9,0</td><td>17,1</td><td>29,75</td><td>19,5</td></tr>
<tr><td>Average depth, m</td><td>19,5</td><td>5,3</td><td>6,7</td><td>15,90</td><td>4,54</td></tr>
</table>

Data Sources: Draft Rules, 2017; Certification, 1983

Restructuring of river ecosystems and following ecosystem changes in the mouth of the Dniester started in 1955 with the construction of Dubossary HPP. Filled in 1954 - 1956, Dubossary reservoir, according to its design (Certification, 1983), is used to carry out seasonal runoff regulation, weekly runoff regulation during the low-flow period, and during flood period - the daily runoff regulation. The purpose of the reservoir is to meet the needs of hydropower, irrigation, fisheries, and water supply. It is a medium sized reservoir with shallow depths.

The second wave of significant changes in the 1980s is linked to the commissioning of the Dniester hydropower complex (modern name – the Dniester cascade of HPPs and PSPPs) (Fig. 1.1).

The Dniester reservoir, commissioned in December 1981, carries out seasonal (with multi-year elements) regulation of the Dniester runoff (Rules, 1987). Characteristic features of the reservoir are its large length and depth, relatively small width and significant tortuosity. According to the main morphometric characteristics (Table 1), it belongs to a category of large riverbed foothill deep water bodies (Avakyan, 1987). The purpose of the reservoir is flood control, water consumption, hydropower, irrigation.

The buffer reservoir, a technical reservoir, commissioned in 1987 by building an overflow dam 20 kilometers downstream of Dniester HPP-1, is used for alignment of the flow rate of water, coming from Dniester reservoir (Regulation 1987). In the late 1990s - early 2000s, the reconstruction of the buffer hydropower complex was carried out in order to commission Dniester HPP-2. In the early 2000s the construction of PSPP resulted in changes of morphometric characteristics of the buffer reservoir (Table. 1 .1). Following the launch of the first PSPP unit in 2009, the reservoir has been used as the lower pond of the PSPP. The buffer reservoir provides daily and weekly regulation and belongs to the small, shallow channel reservoir category.

On the right bank of the buffer reservoir, a *PSPP upper pond* was created. During nighttime, when power demands are low, water is pumped up from the buffer reservoir, while during morning and evening peak demands the water is discharged back, passing through hydropower units. According to morphometric characteristics, the reservoir can be classified as a fillable reservoir with average depths.

2. THE IMPACT OF STRUCTURAL CHANGES ON THE AQUATIC ENVIRONMENT AND BIOTIC COMMUNITIES

Insert 2.1 Methodology issues of the analysis of the impact of structural changes

The analysis of hydrochemical and hydrophysical changes was focused on studying the content of oxygen dissolved in water, its temperature, and - as a characteristic of changes in solid runoff - the flow rate of suspended sediment. For analysis, we used information from the Hydrometeorological Center of Ukraine, the State Hydrometeorological Service of Moldova and the Hydrometeorological Center of Tiraspol:

- on the average monthly and average annual flow rate of suspended sediment – from the observation posts in Zalishchyky, Mogilev-Podolsky, Grushka, the upstream of the Dubossary hydropower plant;
- on average monthly temperatures of water – from the observation posts at the upstream of HPP-1 (buffer reservoir), Mogilev-Podolsky, Grushka, Camenca, and the upstream of Dubossary HPP;
- on water dissolved oxygen – from the observation posts at the upstream of the Dniester HPP-1, Naslavcea, Otach, Soroki.

Two periods are considered in the study: before the construction of the HPP-1 dam (1951–1980) and the period of operation (1990–2015). The period from 1980 to 1990 is excluded from the analysis due to the filling of the Dniester reservoir during these years, the construction and commissioning of HPP-2, and also based on the characteristics of the climate cycle. The period of 1990–2015 coincides with the current phase of climate warming, which is directly reflected in hydrophysical changes.

When analyzing hydrobiological changes, we used available information on species richness, dominant species, quantitative indicators of the presence of hydrobionts (abundance, biomass) along with additional indicators (biotic indices, saprobity indices, etc.). The sources of information were monographs and scientific studies summarizing the results of field hydrobiological studies before and after the creation of reservoirs, as well as data from the hydrobiological monitoring by the State Hydrometeorological Service of the Republic of Moldova (Naslavcea, Otaci, Soroca, Rezina, Dubossary reservoir upstream and downstream of Dubossary, Dubossary reservoir upstream, Vadul-lui-Voda and Bendery). To calculate the characteristics of the dominant macroinvertebrate groups, the ASTERICS software http://www.aqem.de/ was used.

2.1. Impact on the suspended sediment regime

A characteristic feature of the solid runoff of the unregulated upper and middle Dniester is its intra-annual variability, which significantly depends on water content (correlation coefficient 0.71–0.84) (Melnik, 2006, 2010). The bulk of suspended sediment is formed during the spring flood and rain floods. Monthly average values vary in a very wide range - from 0.21 to 2400 kg/s (State Cadastre, rivers). From the 1950s to this day, there has been a trend towards decrease of the amount of sediment in the unregulated river flow, according to some estimates – of up to 40% (Melnik, 2010; State Cadastre, rivers).

Prior to the regulation of the runoff, some 3.5–6 million tons/year of suspended solids arrived at the mouth of the Dniester (Hydrobiological, 1992; Ecosystem, 1990). With the commissioning of the Dubossary reservoir, about 90% of suspended sediments in the lower reaches of the river (Figure 2.1.) (Hydrological Yearbook) became intercepted, which resulted in active silting of the reservoir: from 1955 to 1981 its total volume decreased by 45%, useful volume - by 23% (Certification, 1983). The inflow of sediment to the transboundary section of the river and to the Dubossary reservoir was significantly reduced due to the construction of the Dniester reservoir (Fig. 2.2), and the current volume of solid runoff downstream of the dam of the Dubossary reservoir is practically unchanged throughout the year, regardless of water content (State Cadastre, rivers).

The Dniester reservoir also intercepts an average of 90% of the suspended sediment entering it (the Hydrological Yearbook), but its siltation is less intense: since 1981, the total volume has decreased by only 11%, useful - by 4.7% (Draft Rules, 2017). Along the length of reservoir sediment, deposition occurs in different ways: the maximum flow rate (up to 60% of the received suspensions) is observed within 120-150 kilometers upstream of the dam, the least deposition of sediments occurs in the tail and the dam sections (Gulyaeva, 2009).

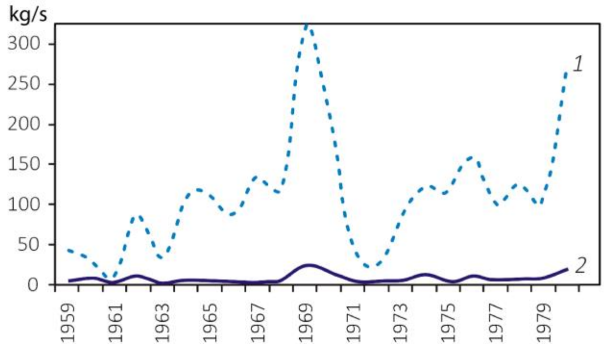

Fig. 2.1. The average annual flow rate of suspended sediment (kg/sec) at Zalishchyky (1) and the downstream of Dubossary HPP (2) in 1959-1980.

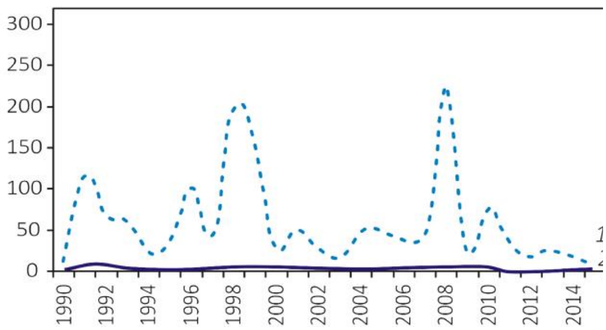

Fig. 2.2. The average annual flow rate of suspended sediment (kg/sec) at Zalishchyky o/p (1) and downstream of the Dniester HPP (Mogilev-Podolsky) (2) in 1990–2015.

Sources: Hydrological yearbook 1951–1977; State Cadastre, rivers 1978–2015.

Such a distribution directly affects the chemical composition of bottom sediments in the middle section of the Dniester reservoir (Boyko, 1999), since the largest amount of absorbed pollutants – up to 70% - falls on the medium silt fractions there (Denisova, 1975). Active deposition of suspended solids also leads to significant clarification (increased transparency) and a change in the color of water (Gulyaeva, 2013). In contrast to the Dubossary reservoir, an increase in the content of suspended matter in water is observed downstream of the Dniester dam during high water season and spring floods as compared to low water periods (State Cadastre, rivers).

Downstream of the reservoirs, only a partial restoration of the suspended matter content in the water takes place and the flow rate increases to 0.1 kg/s per kilometer of the channel. At a distance of 148 kilometers from the dam of the HPP-2 in the region of o/p Hruska in some years mean monthly values may reach 80-90 kg/s, while multiyear monthly and annual average flow rate of suspended solids ranges from 5 to 25 -30 kg/s (Fig. 2.3 - 2.4).

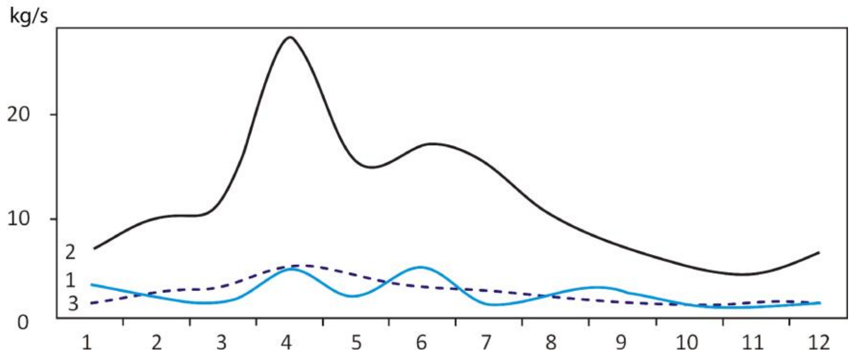

Fig. 2.3. The average monthly flow rate of suspended sediment (kg/sec) for 1994-2015, downstream of the Dniester HPP: Mogilev-Podolsky (1), Grushka (2), the downstream of the Dubossary HPP (3)

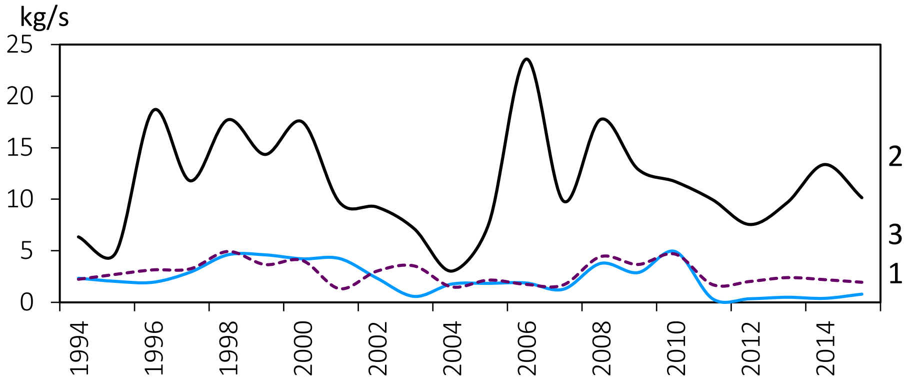

Fig. 2.4. The average annual flow rate of suspended sediment for 1994 - 2015 downstream of the Dniester HPP: Mogilev-Podolsky (1), Grushka (2), the downstream of the Dubossary HPP (3)

Thus, today, no more than 1–1.2 million tons/year of suspended solids arrive at the mouth of the Dniester (the State Cadastre, rivers), which is 3-6 times less than before the regulation of runoff[5].

2.2. Effect on physico-chemical conditions

The temperature regime of the river is largely determined by the design features of the Dniester HPP-1 dam (water is taken from a depth of 27–43 meters), as well as the thermal regime of the Dniester reservoir (Insert 2.2).

[5] The above estimates relate to the total runoff of suspended solids, including solid particles of various origins and sizes (including clay, silt, sand). In the framework of this study, the long-term variability of the runoff of individual sediment fractions was not explored, since it would require a detailed analysis of data on particle size distribution for different time periods. In general, solid runoff downstream of reservoirs is determined both by the volume and composition of sediment entering the reservoirs: light fractions are less actively precipitated. According to the data of the Zalishchyky observation post, at the beginning of the 2000s, the share of sand fractions in the solid runoff upstream of the Dniester reservoir amounted to 5–10%. One-way extraction of sand and gravel from the Dniester riverbed also affects the redistribution and volumes of solid runoff (there are no quantitative estimates).

Insert 2.2. Features of the thermal and oxygen regime of the Dniester reservoir

Water masses are present in the Dniester reservoir for 4–5 months. As a result, all water quality indicators are formed in the reservoir itself. A characteristic feature of its thermal regime is the separation of the water mass of the reservoir in the summer period into three horizontal layers, the thickness of each of which is unstable and depends on hydrometeorological conditions. The upper layer (epilimnion) with a thickness of up to 10 meters arises, in particular, due to the low velocities of runoff and wind currents, as well as weak wind-wave mixing. The largest vertical temperature drop (1-3 ° C/m) in the summer is most often observed at a depth of 10 to 20 meters (State Cadastre, lakes). The passage of floods leads to significant mixing of water throughout the entire depth and the formation of a picture atypical for the summer period lacking distinct thermal layers.

Similar to the temperature regime, the oxygen content of the river section downstream of the Dniester cascade of HPPs and the PSPPs is affected by the dissolved oxygen content in the deep water masses of the Dniester reservoir entering the upstream of the HPP. In summer and early autumn, there are no oxygen sources in the lower layer of the reservoir (hypolimnion), and due to the aerobic decomposition of suspended organic matter, it is actively consumed. Accordingly, the reserves of dissolved oxygen accumulated in the winter-spring period are gradually depleted in this zone. The largest vertical difference in oxygen concentration usually coincides with the thermocline layer.

The presence of a buffer reservoir and the PSPP upper reservoir only smoothens out the influence of the Dniester reservoir on the water temperature, but it does not make a significant contribution to its increase (Shevtsova, 2008).

The greatest influence on the thermal regime of the river section is observed directly downstream of the HPP-2 dam in June (temperature decrease by 7.5–8 degrees) and November (temperature increase by 5.5–6 degrees). Downstream, the temperature of the water gradually approaches its natural values (Fig. 2.5).

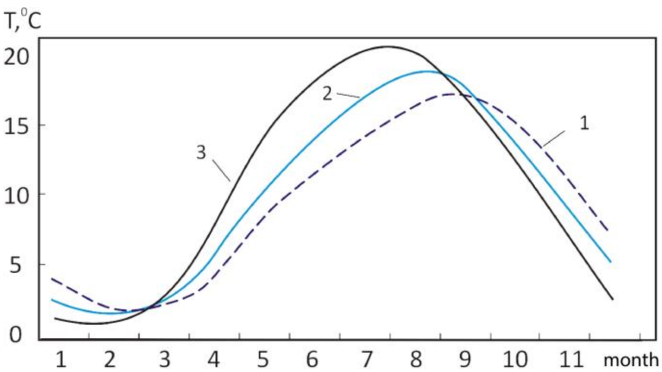

Fig. 2.5. The average long-term annual variation in the water temperature of the downstream of the Dniester HPP-1 (1), at the Mogilev-Podolsky (2) and Grushka o/p(s) (3) from 1990 to 2015 (1-12 at the y axis stand for months).

Sources: Hydrological Yearbook of Ukraine 1990–2015; State Water Cadastre of the Republic of Moldova, 1978–2015.

The heating of the water in the river bed section occurs more intensively (0.3–0.4 degrees per 10 kilometers) than cooling (0.2–0.3 degrees per 10 kilometers). In Camenca, according to many years of observations, in the summer, the deviation of the water temperature from its natural values does not exceed 2.7 degrees (Fig. 2.6). In reservoirs water heats more intensively than in river areas. As a result, in the upper portion of the Dubossary reservoir (town of Rybnitsa-Rezina), water temperature corresponds to natural values. The thermal regime of the Lower Dniester is outside the influence zone of the reservoirs of the Dniester cascade of HPPs and PSPPs (State Cadastre, rivers).

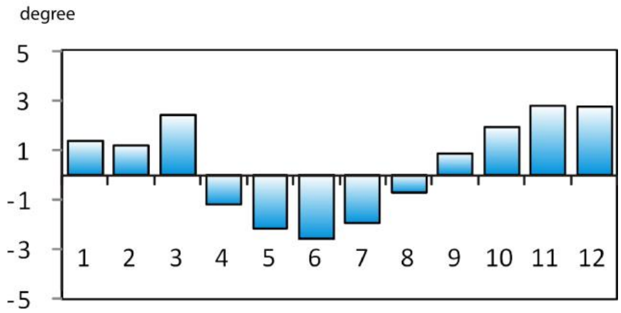

Fig. 2.6. The difference in the average monthly water temperature at the Camenca o/p in 1990–2015, compared with 1951-1980. (the x axis represents months, the y axis – degrees).

Sources: Hydrological Yearbook 1951-1977; State Water Cadastre of the Republic of Moldova, 1978–2015

The oxygen regime of the river section downstream of the Dniester cascade of HPPs and PSPPs is affected by the dissolved oxygen content in the deep-water masses of the Dniester reservoir entering the upstream of the hydropower plant (Insert 2.2). In the winter-spring period, there is no oxygen deficiency in the lower layer, however, in summer and early autumn, its concentration may decrease to zero. Nevertheless, the increased turbulence of the flow in the buffer reservoir, in the upper reservoir of the PSPP and in the upstream of the HPP-2 leads to a fairly rapid re-saturation of water with oxygen. According to monitoring data[6], the concentration of water dissolved oxygen at the transboundary site mainly varies between 7–12 mg/dm^3.

Currently, in areas of the river with intensive development of macrophytes (upstream of the Volchinets village) in the absence of wastewater sources in the daytime, there have been cases of a decrease in oxygen content to 56 - 64% saturation (Zubkov, 2007).

In addition to the parameters listed above, the joint Moldovan-Ukrainian hydro chemical expedition in 2011 (Meliyan, 2011) also noted a rather sharp decrease in the acid reaction (pH) of water in the buffer reservoir compared to the Dniester reservoir: from 8.1–8.2 to 7.6 with subsequent increase in the downstream section of the river to 8.1 at the entrance to the Dubossary reservoir. In the Dubossary reservoir, further alkalization of water was noted (probably associated with the vital processes of aquatic vegetation) - up to 8.3 in the upstream and upstreams of the dam.

The expedition, based on one-time sampling along the river, also found the absence of any noticeable effect of channel reservoirs on the content of water-soluble organic substances (value of chemical oxygen consumption) and a number of other parameters, including the salt composition (sulfates, chlorides, dry residue), biogens (mineral forms of nitrogen and phosphorus), the content of petroleum products, heavy metals, some organic pesticides and polyaromatic hydrocarbons.

[6] http://dnister.meteo.gov.ua/ua/water_quality *and Hydrochem. Yearbook. EQMD.*

2.3. Impact on aquatic organisms

Higher aquatic vegetation

In 1945-1948, the higher aquatic vegetation was very poorly developed in the Dniester, although plants were distributed throughout the river (Yaroshenko, 1957). Prior to construction of the Dubossary reservoir in the middle reaches of the Dniester in the section between the town of Soroca and the village of Cioburciu one could find only single specimens of several species of macrophytes (pondweed, watermilfoil, hornwort). In the upper and lower reaches of the Dniester, the shore vegetation of hornwort, watermilfoil, and various species of pondweed had developed relatively well (Yaroshenko, 1957).

The construction and operation of reservoirs caused a decrease in maximum flow rates and increased water transparency in the lower sections of the bed, which contributed to massive development of higher aquatic vegetation in the middle reaches and gave macrophytes the opportunity to firmly root in the ground. By 1991, the higher aquatic vegetation, represented mainly by hydatophytes (plants wholly or mostly submerged in water), appeared along the entire river from Naslavcea to Dubossary. As a result, the number of macrophyte species developing in the Naslavcea-Camenca section increased from several to 26, in the Dubossary reservoir – to 43, and the degree of overgrowing of the water area increased from 0.7-1% to 10-15% in the 1980s and up to 85% at present time (Sharapanovskaya, 1999, Smirnova-Garaeva, 1980, data from the Institute of Zoology of Moldova). The massive development of higher aquatic vegetation in the middle reaches of the river, mainly caused by the construction of the Dniester cascade, has diverse effects. On the one hand, plant communities provide new substrates and habitats for other aquatic organisms, contribute to oxygenation of water during photosynthesis and are involved in the processing of pollution, etc. On the other hand, the processes of rotting of aquatic vegetation and periphyton lead to secondary pollution of water with organic substances and a decrease in the water dissolved oxygen content (Zubkov, 2007).

The redistribution of runoff and the associated decrease in the flow velocity at the confluence of the Dniester and Glubokoy Turunchuk into the Dniester estuary contributed to a 9.5 km^2 increase in the area of the water caltrop *Trapeta natantis* and yellow pond lily *Nuphareta luteae* formations, both of which are listed in the Green Book of Ukraine. The regulation of runoff did not have a negative impact of some species of macrophytes of the Lower Dniester listed in the Red Books of Ukraine and Moldova: the floating moss *Salvinia natans* (L.) All., water chestnut *Trapa natans* L. and the floating heart Nymphoides *peltata* (S.G. Gmel.) O. Kuntze. However, the development of macrophytes worsened the living conditions of fish: the death of large masses of macrophytes in the delta flood lakes in autumn and winter accelerates the course of natural successions, leads to siltation and a decrease in the depth of water bodies, and increases the likelihood of die-offs due to a decreasing levels of water dissolved oxygen.

Macroinvertebrates

Comparison of modern features[7] of the dominant macroinvertebrate groups in the transboundary section of the river downstream of the Dniester cascade (according to data of the Institute of Zoology and the Surface Water Quality Yearbook of the Republic of Moldova on the hydrobiological elements of EQMD) with those from before the construction of the reservoirs (according to

[7] Calculation of characteristics was performed using the ASTERICS software (http://www.aqem.de/), which allows us to calculate more than 60 parameters for macrobenthos invertebrate communities.

Yaroshenko, 1957) made it possible to draw a number of conclusions regarding changes that took place (Tables 2.1 and 2.2).

Table 2.1 Comparison of the characteristics of the dominant macroinvertebrate groups in the transboundary area before and after the construction of the Dniester hydropower complex

Years	Number of ind./m^2	Biomass, g/m^2	Wealth of taxa EPT [%][a]	Saprobity	The proportion of species related to a particular substrate [%]					Jacquard Similarity Index
					silt	sand	gravel	rocks	veg.	
1945–1951[b]	2500	31	21,4	2,10	5	5	4	53	28	<10%
2016–2017[c]	12000–18000	24–150	4,8–5,6	2,11	18–21	4–14	4–5	13–19	31–34	

a – EPT-Taxa - the relative number of species (%) Ephemeroptera, Plecoptera, Trichoptera (mayflies, stoneflies, caddisflies).
b – Averaged data for the section from Galich to Soroca.
c – Averaged data for the section from Naslavcea to Soroca.

Data sources: Yaroshenko, 1957; The Yearbook of Surface Water Quality of the Republic of Moldova on the hydrobiological elements of EQMD and the data of the Institute of Zoology of the Academy of Sciences of Moldova (Mungiu, 2017)

Table 2.2 Comparison of the characteristics of the dominant macroinvertebrate groups in the area downstream of the Dubossary reservoir (Vadul-lui-Voda district) before and after its construction*

Years	Number ind./m^2	Biomass, g/m^2	Wealth of taxa EPT [%][a]	Saprobity	The proportion of species related to a particular substrate [%]					Jacquard Similarity Index
					silt	sand	gravel	rocks	veg.	
1945–1951	2300	20,3	14,3	1,98	17	10	1	45	15	≈7–17%
2016	11200	56	9,3	2,12	20	12	5	10	33	

a – EPT-Taxa - the relative number of species (%) Ephemeroptera, Plecoptera, Trichoptera (mayflies, stoneflies, caddisflies).

* The river in the Vadul-lui-Voda area is prominently influenced by the polluted Reut tributary

Data sources: Yaroshenko, 1957; data of the Institute of Zoology of the Academy of Sciences of Moldova (Mungiu, 2017)

Between the two periods, a radical change in the species composition of the dominant group of macroinvertebrates in the transboundary area is observed (Jacquard species similarity index <10%; Insert 2.3). Today, in the dominant core of macroinvertebrate communities, the largest number of species (34%) belongs to the species of the phytophilic group (associated with aquatic plants), while before the construction of reservoirs, species of the lithophilic group (associated with a solid substrate – rocks) were predominant (52%). First of all, these changes are a effect of the massive development of macrophytes in this section of the river. There is also significant (from 5% to 21%) increase in the number of pelophilic species (associated with silts).

Insert 2.3 List of dominant macroinvertebrate species in the transboundary area before and after construction of the Dniester hydropower complex

	Before[a]	After
Alboglossiphonia heteroclite (Linnaeus, 1761)		+ [b]
Anopheles sp.		+ [b]
Baetis sp.	+	+ [c]
Bithynia tentaculata (Linnaeus, 1758)		+ [b, c]
Chaoborus sp.		+ [b]
Chironomus plumosus-Gr.		+ [a]
Chironomidae Gen. sp.		+ [b]
Cricotopus sylvestris-Gr.	+	+ [c]
Elmidae Gen. sp.		+ [b]
Erpobdella sp.		+ [b]
Esperiana esperi (Férussac , 1823)	+	
Gammarus kischineffensis (Schellenberg 1937)		+ [b]
Haliplus ruficollis (De Geer, 1774)		+ [b]
Heptagenia sp.	+	
Hydropsyche sp.	+	
Lepidostoma hirtum (Fabricius, 1775)		+ [b]
Lithoglyphus naticoides (C. Pfeiffer, 1828)	+	+ [c]
Monodiamesa bathyphila (Kieffer, 1918)	+	
Oligochaeta Gen. sp.		+ [b]
Ophidonais serpentina (Muller, 1774)	+	
Orthocladiinae Gen. sp.	+	
Physella acuta (Draparnaud, 1805)		+ [b, c]
Pisidium casertanum ssp.		+ [b, c]
Polypedilum scalaenum-Gr.	+	
Radix sp.	+	+ [b]
Rheotanytarsus sp.	+	
Stagnicola corvus (Gmelin, 1791)		+ [b]
Theodoxus danubialis ssp.	+	
Theodoxus fluviatilis ssp.		+ [b, c]
Thienemannimyia lentiginosa (Fries, 1823)	+	
Valvata piscinalis ssp.		+ [b]
Valvata pulchella Studer, 1789		+ [c]

a – According to Yaroshenko, 1957.
b – Data of EQMD of SGS of Moldova (2016).
c – Data of the Institute of Zoology of the Academy of Sciences of Moldova

In the river downstream of HPP-2 and Dubossary reservoir water area, rheophilic or typical river aquatic species are being displaced by typical limnophilic (*Cricotopus algarum* (Kieffer, 1911), *Cricotopus sylvestris* (Fabricius,1794), *Chaetogammarus warpachowskyi* (Sars, 1894), *Limnomysis benedeni* Czerniavsky, 1882, *Physella integra* (Haldeman, 1841), *Lymnaea peregra* (O.F. Müller, 1774), *Eudiaptomus gracilis* (Sars G.O., 1863) and *E. graciloides* (Lilljeborg, 1888)) (Zubkov, 2007).

Due to the reduction in the number of mayfly specimens, a decrease in % of EPT wealth is observed (from 21% to 5%). A direct comparison of the richness of macroinvertebrate species in the transboundary section of the river before and after the construction of reservoirs is not possible. At the same time, according to indirect data[8] it can be assumed that the total number of species has not changed significantly.

The total number of macroinvertebrates increased from 2.5 to 18–24 thousand ind./m^2, while their biomass changed from 31 to 24 - 150 g/m^2.

Due to the presence of a favorable oxygen regime for macroinvertebrate communities, the saprobity indices used to assess the degree of pollution of water bodies with organic substances remained at the same level as before the construction of Dniester reservoirs (about 2.1, which corresponds to the II quality class or “good condition”). The same changes, albeit less stark, are also observed in the macroinvertebrate communities of the Dniester channel downstream of the Dubossary reservoir (Table 2.2).

In the Dniester, there are identifiable risk zones for degradation of macrobenthos macroinvertebrate communities, which include the Naslavcea site (in samples from 2016, 25 taxa were recorded) and the section of the river downstream of Soroca affected by wastewater (18 taxa were recorded in 2016) (Mungiu, 2017).

Plankton

The quantitative indicators of the presence of phyto- and zooplankton in the channel downstream of the Dniester hydropower complex and the Dubossary reservoir are close to each other. Moreover, the current abundance of zooplankton in the riverbed is comparable to that before the construction of reservoirs (Tables 2.3 and 2.4).

Table 2.3 Comparison of modern characteristics of phytoplankton in the river sections downstream of the Dniester and Dubossary reservoirs

Sites	Years	Number, cells / ml	Biomass, mg / L	Saprobity	Number of species
Naslavcea, Ataky	2011–2017	330	0,82	1,91	12
Vadul lui voda	2011–2017	350	0,63	1,99	15

Data sources: Yearbook of Surface Water Quality of the Republic of Moldova on the hydrobiological elements of EQMD

[8] According to the long-term data (Yaroshenko, 1957), 123 forms are represented in the section from Galich to Soroca. The combination of EQMD of Moldova data for 2017 (Naslavcea station) and data from two stations (Naslavcea and Valcinet) for 2016 (Mungiu, 2017) indicates the presence of 76 species.

Table 2.4 Comparison of the characteristics of zooplankton in sections of the river downstream of the Dniester and Dubossary reservoirs before and after the construction of the Dniester hydropower complex

Sites	Years	Abundance, ind./m^3	Biomass, mg /L	Saprobity	Number of species
Naslavcea, Ataky	1947–1951	2300	n/a	n/a	n/a
	2011–2017	4000	22,1	1,65	6
Vadul lui voda	1947–1951	1800	n/a	n/a	n/a
	2009–2012	3500	7,3	1,72	4

* n/a. – no available data.

Data sources: Yaroshenko, 1957; Surface Water Quality Yearbook of the Republic of Moldova on hydrobiological elements of EQMD

At the same time, according to the Institute of Zoology of the Academy of Sciences of Moldova for 2015-2017, in the area from Naslavcea to Camenca the production of zooplankton during the vegetation season is virtually absent.

Ichthyofauna

Under the influence of the number of factors, which are seen as related[9] and unrelated to the construction and operation of reservoirs[10], the Dniester fish communities have undergone significant changes. The species richness of the Dniester fish before and after the creation of reservoirs according to data of various authors is presented in table 2.5.

Table 2.5 Species richness of the Dniester fish before and after the creation of reservoirs

Source	Dniester as a whole	Middle section	Dubossary Res.	Lower section
Prior to 1954				
Berg, 1948–1949	74 [a]			
Burnashev et al. , 1954	81 [a]			
Burnashev et al. , 1955		47		
Tomnatic, 1964		53		
Ecosystem, 1990				55
Yaroshenko, 1951		37 [a]		
Yaroshenko, 195 7	49 [б]			
Bulat, 2017	62 [б]			
1996–2017				
Snigirev, 2012				65
Bulat, 2017	75	57 [в]	36	64
Usatîi, 2004	59	42	40	51

a – Quoted from Tomnatic, 1964.

b - Only the channel of the Dniester.

c – At the same time, only 7 species were present in the control catches of 2017–2018 made directly downstream of the dam site of HPP-2 near Naslavcea: three-spined stickleback, dace, bleak, baleen, roach, mustard, sculpin (Bulat et al., 2018)

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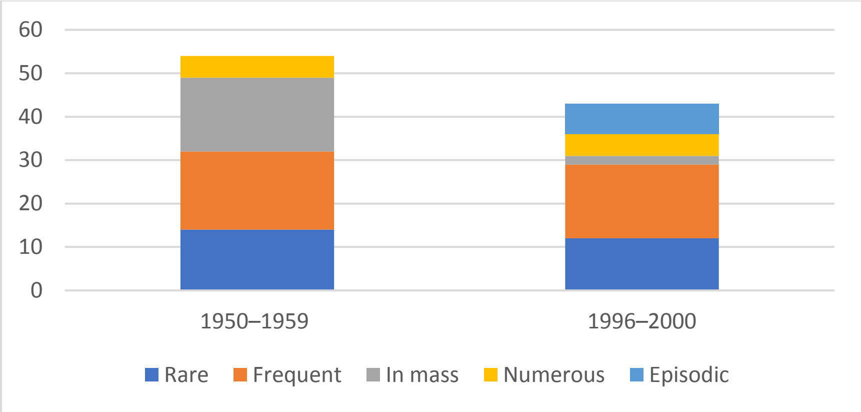
9 Blockage of migratory fish migration paths by reservoir dams; changes in bottom substrate and feed base; changes in the temperature regime and atypical daily fluctuations in the level and temperature of water (chapter 3) in transboundary section; changes, compared with natural, in timing and regime of spring floods (chapter 4).

10 Diking and cutting off of oxbows and wetland floodplains, stocking, breaches of the ichthyofauna protection regime, pollution, etc.



Data Sources: Usatîi, 2004; Tomnatic, 1957; Reports of the Institute of Zoology of the Academy of Sciences of Moldova

Fig. 2.7. The number of fish species in the Naslavcea-Camenca area in 1950-1959 and 1996–2000.

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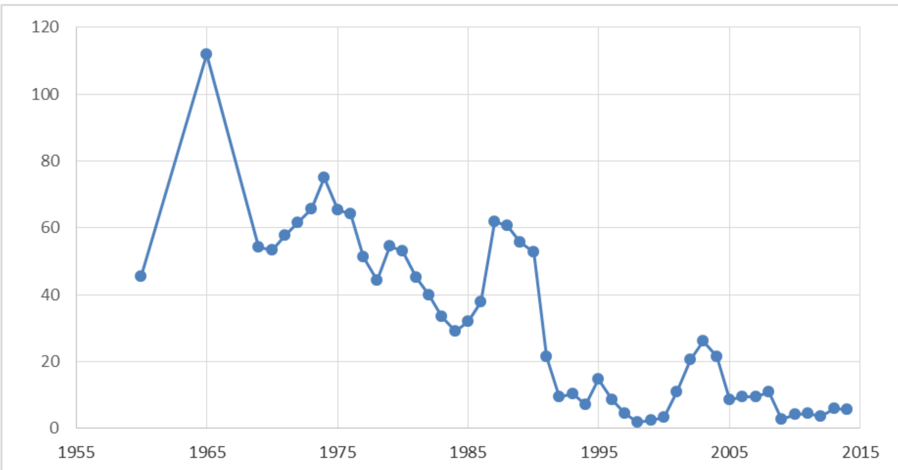
* The graph shows the total number of species found for all years of the indicated periods. With the commissioning of the Dubossary reservoir in 1955, the number of species in it decreased from 53 to 42 by 1959 (Tomnatic, 1964). Since the decrease in the number of fish species in the reservoir occurred primarily due to the loss of migratory species (Tomnatic, 1964), it can be assumed that similar changes occurred in the upper part of this section.

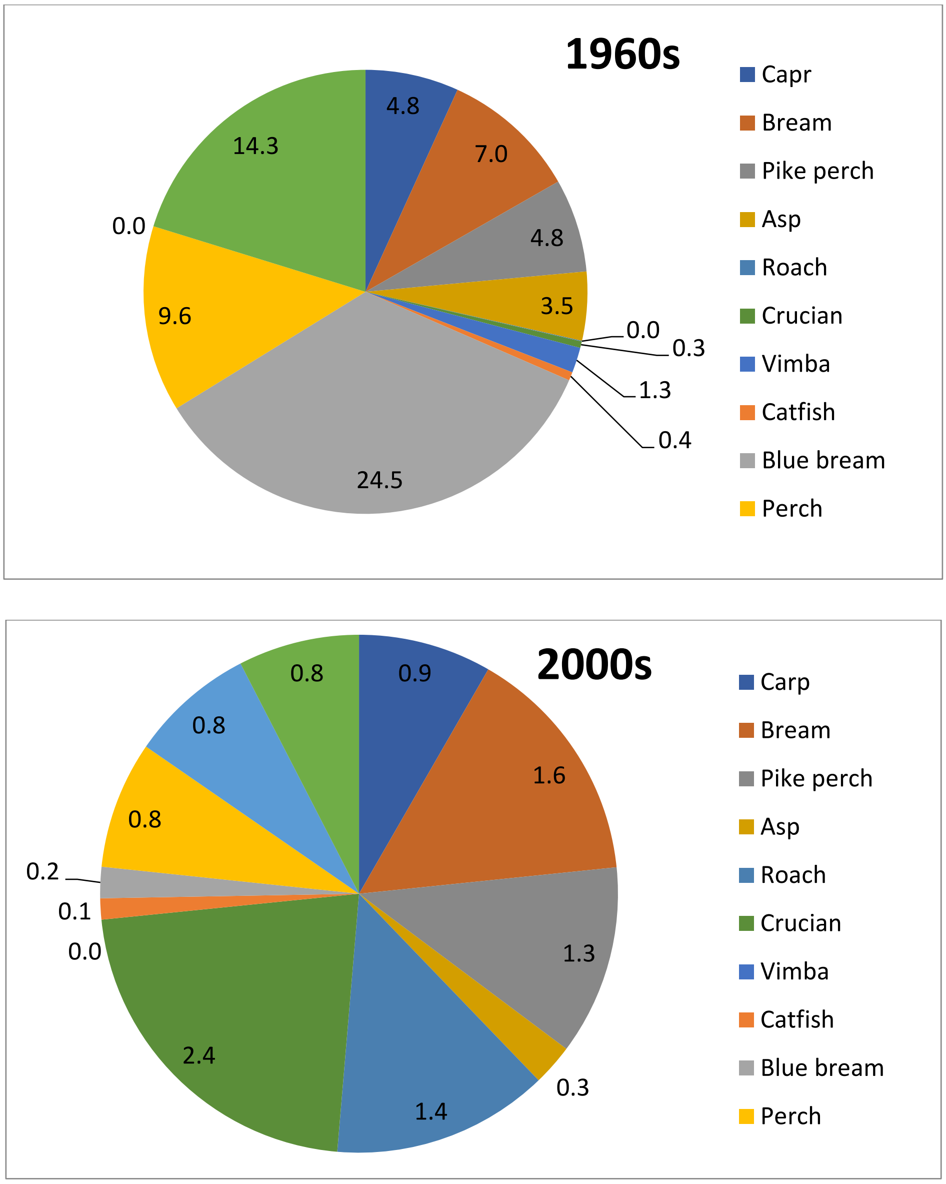
In the Naslavcea – Camenca section in 1996–2000, 42 fish species were recorded, including previously absent invasive species; among them 25 species - of the family Cyprinidae, 5 - of Percidae and Gobiidae, 2 - of Sobitidae and Gasterosteidae and 1 - of the families Acipenseridae, Esocidae and Siluridae. According to (Burnashev et al., 1955); Until 1955, 47 species were found in the Khotin - Dubossary section (Fig. 2.7).



Data source: data from the State Fisheries Service of the Republic of Moldova (Usatîi et al., 2016)

Fig. 2.8. Commercial fishing in Dubossary reservoir by years, tons

At present, commercial fish species have almost disappeared from the river in Moldova. Prior to hydro construction in the Naslavcea – Camenca section, the main commercial species of fish were sterlet, common carp, zanthe, catfish, sneep, barbel (Yaroshenko, 1957). Today, commercial fish species are almost completely replaced by low-value short-cycle and invasive species, while three-spined stickleback, mustard, and bleak dominate (Bulat, 2018, Bulat et al., 2017). In Dubossary reservoir, recorded fishing catches significantly decreased, and their structure changed (Fig. 2.8–2.9).



Data source: State Agency for Fish Protection of the Republic of Moldova; Usatîi et al., 2016

Fig. 2.9. Averaged fishing pattern in the Dubossary Reservoir
in the 1960s and 2000s

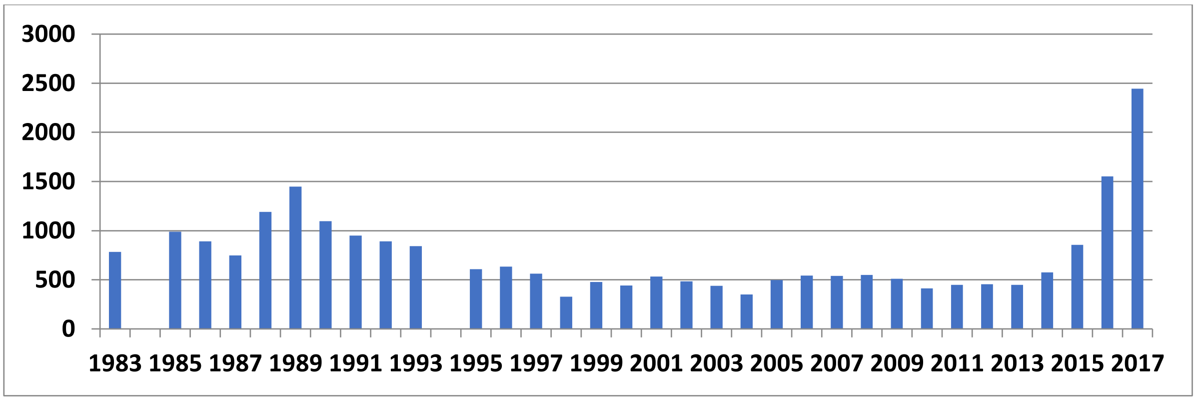
Before regulation of the Dniester runoff, the Dniester estuary, the floodplain system of the delta, and the lower section of the middle Dniester were a single ecosystem with rich ichthyofauna, spawning grounds for rheophilic, lithophilic, phytophilic, and psammophilic fish species, as well as their feeding grounds. The construction of the Dubossary HPP divided the Dniester basin into two isolated sections and led to significant changes in the structure of the ichthyocenosis of the Lower and Middle Dniester. Due to lack of fish passage structures, the dam of the Dubossary reservoir interdicts migration routes of spawning anadromous sturgeon species: beluga *Huso huso* Linnaeus, stellate sturgeon *Acipenser stellatus* Pallas, Russian sturgeon *Acipenser gueldenstaedtii* Brandt et Ratzeburg, which led to a drastic reduction in their numbers, and the thorn sturgeon *Acipenser nudiventris* Lovetskiy was classified as an extinct species. In the Dniester estuary, zanthe *Vimba vimba* Pallas almost disappeared from fishing catches, and in the late 90s, in the Dniester delta, apparently, due to the deterioration of spawning conditions, previously abundant sabre fish *Pelecus cultratus* Linnaeus completely disappeared.

The increase in water transparency in the Dniester due to sediment deposition in the Dniester and Dubossary reservoirs stimulated the growth of macrophytes in the flooded lakes and the Dniester bed, which caused a reduction in the number spawning grounds of lithophilic and psammophilic fish species. The situation is worsened by the extraction of gravel and sand in the Dniester channel, which as a whole led to a significant decrease in the number of four rare and endangered fish species: carp *Rutilus frisii* Nordmann, sterlet *Acipenser ruthenus* Linnaes, large chop *Zingel zingel* Linnaeus and small chop *Zingel streber* Linnaeus.

Impoverishment of the species composition of the fish fauna of the Lower Dniester in its delta part was also due to the disappearance in the Dniester estuary of several marine species: the Black Sea sprat *Sprattus sprattus phalericus* Nordmann, anchovy *Engraulis encrasicholus ponticus* Alex, Black Sea salmon *Salmo trutta labrax* Pallas, garfish *Belone belone euxini* Gunther, whiting *Odontogadus merlangus* Linnaeus, bluefin *Pomatomus saltatrix*, kalkan flounder Scophthalmus maeoticus Pallas, and in the 60s of the last century – of mackerel *Scomber scombrus* Linnaeus.

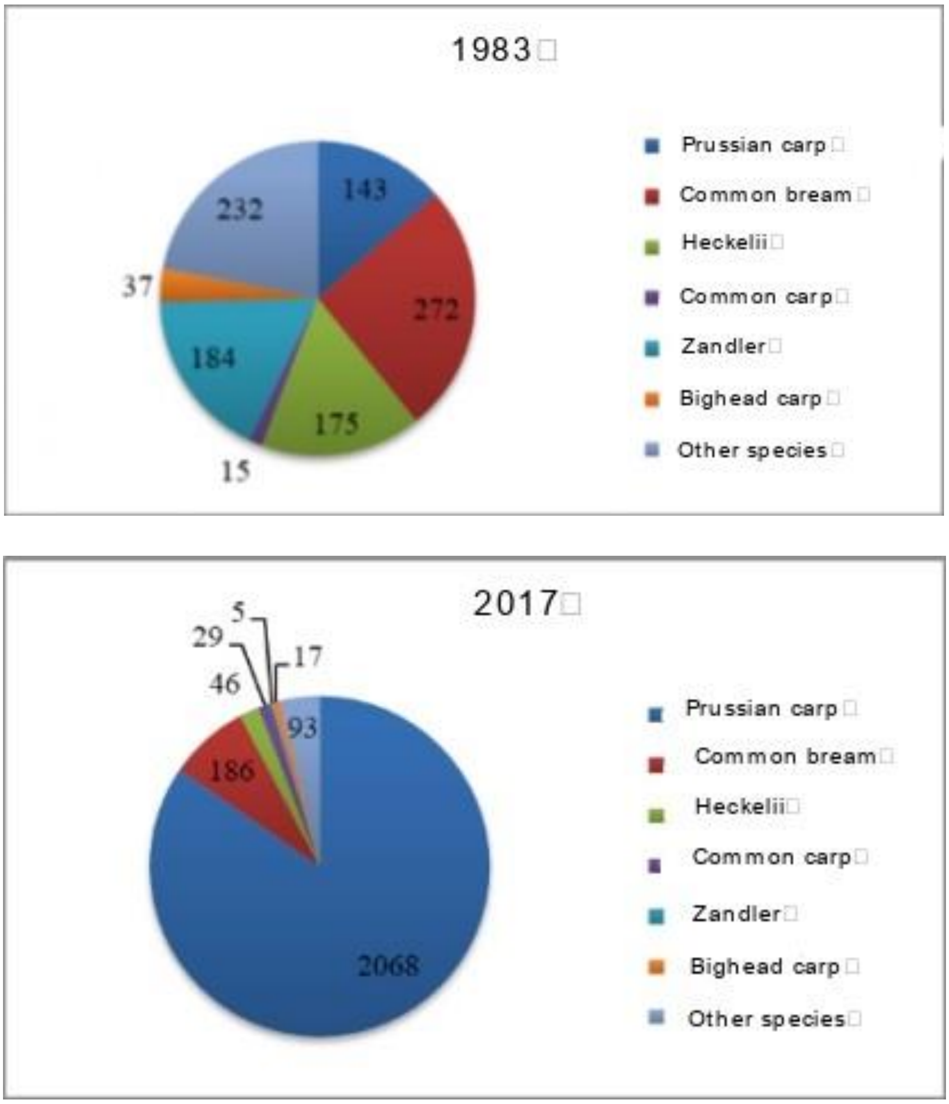
During the same period, for the unidentified reason, another previously abundant commercial species *Percarina demidofii* Nordmann practically disappeared from the Dniester estuary and was listed in the Red Book of Ukraine, while crucian carp *Carassius carassius* Linnaeus almost disappeared in the Dniester delta.

At the same time, an increase in the number of fish species in the Lower Dniester basin can be explained by the directed introduction of some commercial species: silver carp *Hypophthalmichthys molitrix* Valenciennes, bighead carp *Hypophthalmichthys nobilis* (Richardson, 1845), grass carp *Ctenopharyngodon Idella* Valenciennes, black carp *Mylopharygodon piceus* Richardson, so-iuy mullet *Lisa haematocheila* Temminck & Schlegel, 1845, channel catfish *Ictalurus punctatus*, as well as due to the penetration of the three invasive species: sunfish *Lepomis gibbosus* Linnaeus, topmouth gudgeon *Pseudorasbora parva* Temminck & Schlegel and amur sleeper *Perccottus glenii* Dybowski.



Data source: Statistics of the «Odeasrybvod» Department

Fig. 2.10. Catch of aquatic biological resources in the Dniester estuary, the lower reaches of the Dniester River and the floodplain system in the Odessa region in 1983 - 2017, tons



Data source: Statistics of the «Odeasrybvod» Department

Fig. 2.11. The structure of commercial catches in the Dniester estuary, the lower reaches of the Dniester River and the flood plain system in 1983 and 2017, tons

As a result, the structure and volumes of commercial catches, which are currently dominated by phytophilic species, have changed substantially in the Lower Dniester, with the Prussian carp *Carassius auratus gibelio* Bloch (Fig. 2.10–2.11) becoming predominant commercial fish. The significant growth in fish catches in the lower reaches of the Dniester in 2015 - 2017 is associated with an increased catch of the Prussian carp and increased fishing intensity in the Dniester estuary, as well as the prohibition of commercial fishing in the Republic of Moldova, including its Transdniestrian region.

3. DAILY RUNOFF FLUCTUATIONS AND THEIR IMPACT ON THE STATE OF THE TRANSBOUNDARY SECTION

Insert 3.1 Methodology issues of daily runoff fluctuations

To account for daily runoff fluctuations, modern hourly water discharge rates data of the Dniester HPP-1 and HPP-2 for 2017–2018 were used. Data were provided by PJSC Ukrhydroenergo and PJSC Nizhnednistrovskaya HPP.

The analysis of intraday fluctuations in water level was based on the data for the second half of 2018, retrieved from the automated posts in Naslavcea, Soroka, and Vadul-lui-Voda. These are the only hydrological data series of hourly fluctuations in water level available at three posts simultaneously, therefore, the data array for this period is represented by the most complete series of observations.

To assess the transformation of the waves of releases and physico-chemical indicators, we used data from publications of the Institute of Hydrobiology of the NAS of Ukraine.

3.1. Description of daily runoff fluctuations

During normal operation of the cascade in the absence of floods, depending on the needs, the hydraulic units of the Dniester HPP-1 are switched on one, two (less often – three, four) times a day. The total duration of operation varies from 2 to 12 hours a day. The water flow rate to the buffer reservoir can vary from 200 to 1700 m^3/s, while the highest water flow rate in the downstream of the HPP (flow rates of HPP-1) is observed in the evening.

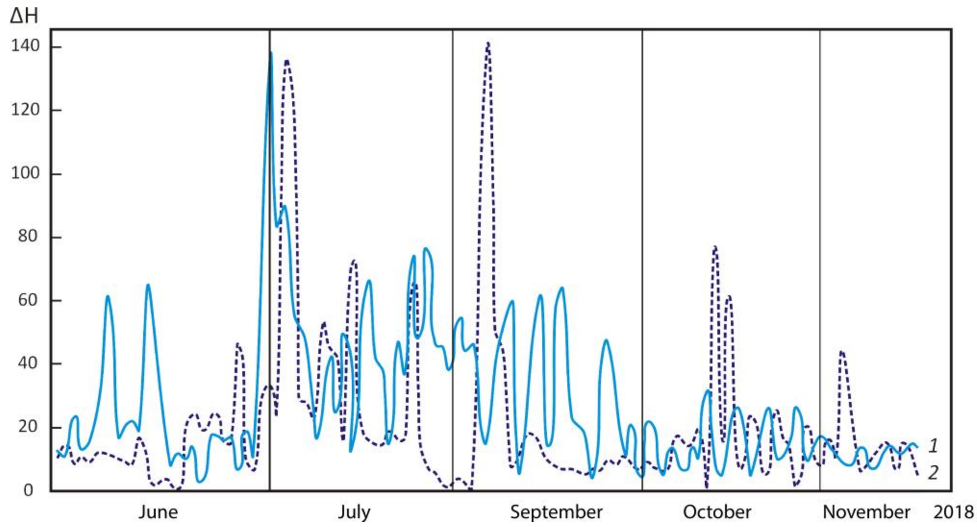
Dniester HPP-2 operates 24 hours a day. Water can pass through turbines of electric generators or discharged through spillways without generating electricity. According to hourly data for 2017-2018, the maximum amplitude (variation) values for the water flow rate during the day to the upstream of HPP-2 amounted to 380 m^3/s during high water. Reducing flow rate to the upstream of HPP-2 to less than 100 m^3/s is not allowed throughout the entire year.

During river floods and high water, the cascade of the Dniester HPPs and the PSPPs modifies its operation: HPP-1 operates anywhere from 12 to 24 hours a day, while HPP-2, working around the clock, discharges water through turbines and spillways simultaneously. In case high water flow rate exceeds 5700 m^3/s the nuclear power plant limits its operations up to a halt (Draft Rules, 2017).

For most of the year, the cascade operates in normal mode and performs releases that are uneven in comparison with natural flow rate during the day. According to the Draft Rules (2017), water level fluctuations during the day in the upstream of HPP-2 (outside the flood period) cannot exceed 20 centimeters. Based on the automated hydrological post operational data[11] in the second half of 2018, the average downstream amplitude of diurnal fluctuations in the water level near Naslavcea was about 30 centimeters, the minimum value in the normal mode was 4 centimeters, and the maximum value was 60–65 cm/day (Fig. 3.1). Maximum amplitude of diurnal fluctuations during floods reached 135 centimeters. In Soroka, due to the transformation of releases, the amplitude of fluctuations in water level is reduced by 55%.

[11] http://nistru.meteo.gov.ua/en/autoposts_operational_data/

Downstream of Dubossary HPP, according to operational data from the automated hydrological post in Vadul-lui-Voda[12], the second half of 2018 saw daily fluctuation amplitude of the water level of about 18 centimeters with its minimum value in the normal mode being 1 centimeter, and maximum being 40-60 cm/day. During floods, the maximum amplitude of water level fluctuations reached 137 centimeters (Fig. 3.1).



Source: data from automated stations http://nistru.meteo.gov.ua/en/autoposts_operational_data/

Fig. 3.1. The amplitude of diurnal fluctuations in the water level downstream of the Dniester HPP-2 (Naslavcea-1) and the Dubossary HPP (Vadul-lui-Voda - 2) in the second half of 2018

In addition to fluctuations in the water level, there is also a temporal variability of the hydrodynamic characteristics of the flow (Fig. 3.2): depending on the volume of the release, the flow velocity in Mogilev-Podolsky can vary from 0.40 to 2.75 m/s (State Cadastre, rivers).

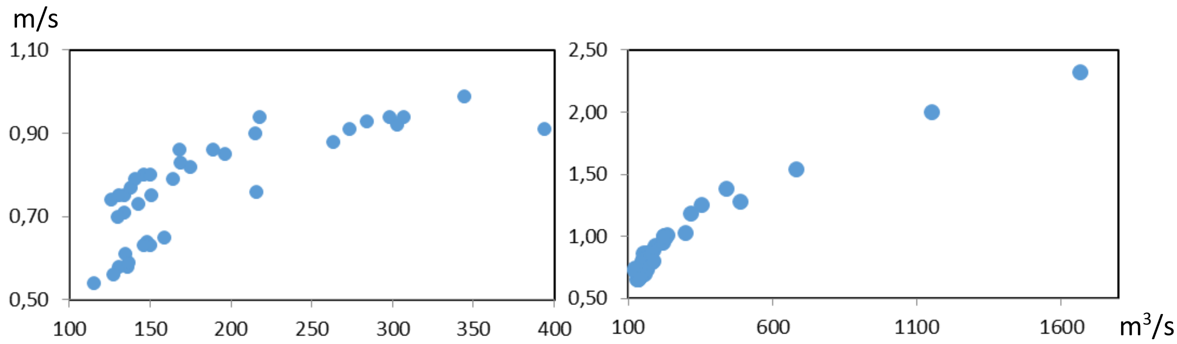


Fig. 3.2. Measured flow rate (m^3/s) and flow velocity (m/s) in Mogilev-Podolsky (2012 and 2013)

[12] Same as above.

Insert 3.2 Transformation of release at a transboundary site

Calculation of the propagation of release and flood waves is one of the most difficult problems of river hydraulics. In this regard, field measurements of the unsteady movement of water are of great importance. In October 2014 and April 2015 at the Institute of Hydrobiology of the National Academy of Sciences of Ukraine, a number of hourly field observations of the water level was carried out at four sections located at different distances from the dam of HPP-2 (2.3 km, 27 km, 57 km, 83.4 km) . The measurement results showed that:

- as the distance from the dam increases, the velocity of the wave crest decreases from 4.6 to 2.9 km/h;
- as the distance from the dam increases, the waveform (release hydrograph) changes: wave height decreases by more than 75%, the maximum intensity of level change decreases by 85% (from 30 to 4 cm/h), the duration of the level rise and fall phases increases (from 3 to 12 hours);
- depending on natural conditions, at a distance of up to 27 kilometers from HPP-2, the wave can expand by 16-50%. In the autumn low-water season, the greatest wave transformation was observed at a distance of 27–57 kilometers from HPP-2;
- the process of wave transformation is significantly affected by the water level (average depth) in the river and the amount of release through the dam: during the spring discharge, the transformation was twice as intense as in the autumn low-water season.

The results of the analysis, approximated in quantitative terms, give only a qualitative description of these phenomena.

It should be noted that the release waves carry a significant amount of “new” water and, thus, can perform a flushing function in a transboundary area that is exposed to significant anthropogenic load in the summer-autumn period.

Source: O.A. Gulyaeva

3.2. Impact on the physico-chemical characteristics of water

As already noted in paragraph 2.2, the thermal and oxygen stratifications in the Dniester reservoir during the summer-autumn period have a great influence on the physico-chemical parameters of the water downstream of the HPP-1 and HPP-2 dams. During this period, during synchronous releases of HPP -1 and HPP-2, jumps in water temperature and dissolved oxygen concentration, which are often not captured by regular observations, can be observed in the transboundary section. The data of episodic observations (Fig. 3.3) show that the temperature can fluctuate within three degrees, and the dissolved oxygen content can decrease to 2–4 mg/dm^3, after which the initial values are restored (Analysis, 2008; Gulyaeva, 2016). Daily fluctuations of other water quality indicators are possible; however, additional specialized studies are required to give a definitive answer.

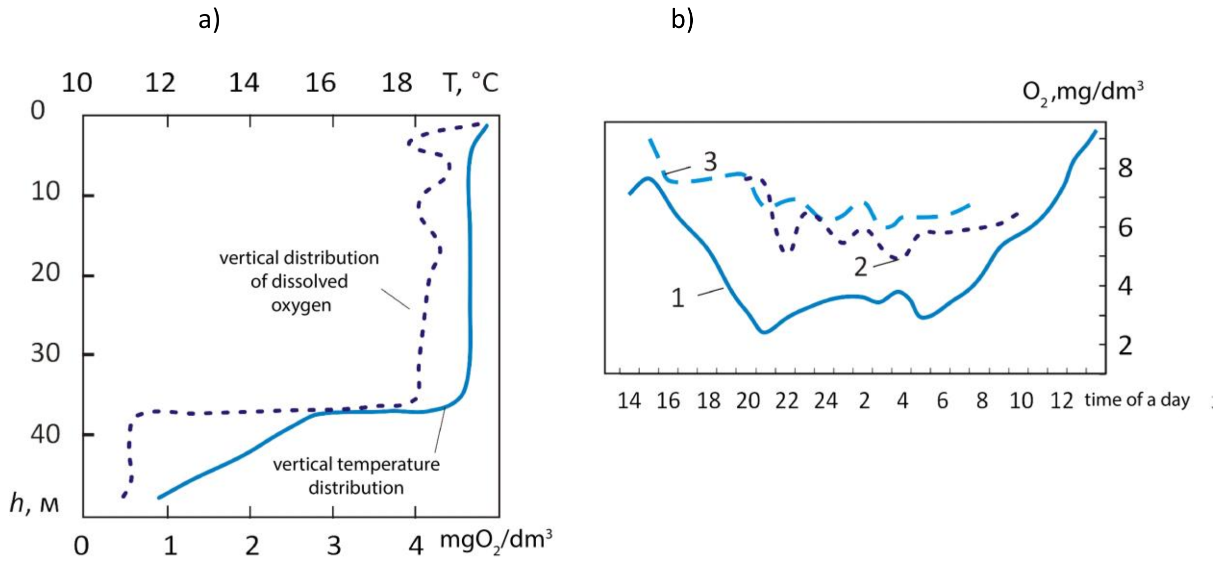


Fig. 3.3. Oxygen and temperature stratification in the dam section of the Dniester reservoir (a) and dissolved oxygen fluctuations downstream of the HPP-2 dam during the day (a special case - autumn 2014: 1 – 2 km, 2 – 57 km, 3 – 83 km from the HPP-2 dam) (b)

In the absence of thermal and oxygen stratifications in the Dniester reservoir, the releases of hydropower plants have practically no effect on intraday fluctuations in physicochemical parameters in the transboundary section of the river (Fig. 3.4).

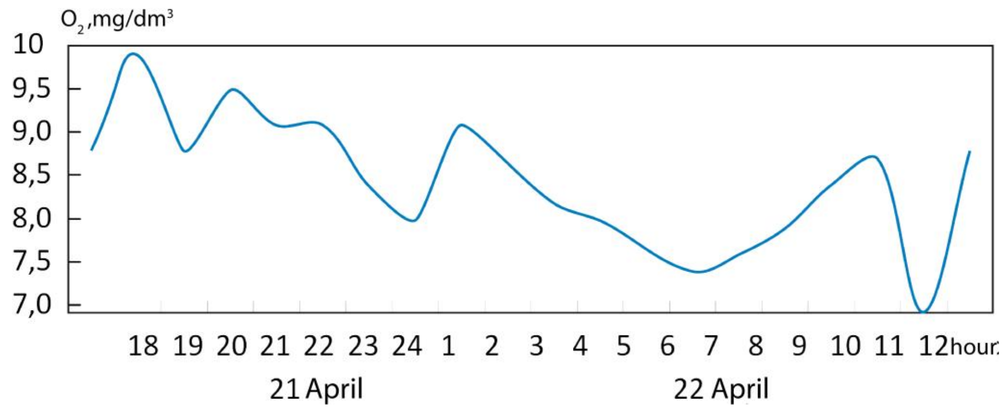


Fig. 3.4. The daily dynamics of the dissolved oxygen content in the transboundary section of the Dniester (2 km from the HPP-2 dam) in the absence of oxygen stratification in the Dniester reservoir during environmental release (spring, 2015)

3.3. Impact on aquatic organisms

Diurnal water level fluctuations in cross-border section of the river downstream of HPP-2 cause periodic draining of parts of the channel that may lead to partial demise of aquatic organisms in drained areas, and also adversely affect the environment and productivity of spawning of fish[13].

[13] Members of the expert group disagreed on the effect of diurnal fluctuations on higher aquatic vegetation and the content of dissolved oxygen. Due to the lack of field data, special field studies are needed to quantify the impact.

4. LONG-TERM CHANGES AND INTRA-ANNUAL REDISTRIBUTION OF RUNOFF

Insert 4.1 Methodology issues of the analysis of long-term runoff changes

In order to analyze the changes in the hydrological regime, a fundamental agreement was reached on the following points:

- as in the analysis of the impact of structural changes (chapter 2), two periods are considered: the period before the construction of the HPP-1 dam (1951-1980) and the period of operation (1990-2015);
- to assess the hydrological regime features in 1990–2015, shorter time periods are considered: the period after the launch of HPP-1 and the operation of the HPP-2 reservoir in the buffer mode before HPP-2 was put into operation; the period after the launch of HPP-2 (1999-2002) before the launch of the PSPP (1st unit - end of 2009); and the period of 2012–2018 after the commissioning of the PSPP upper reservoir;
- to assess the impact of reservoirs on runoff, daily data of the State Hydrometeorological Center of Ukraine from two main hydrological sites - Zaleshchyky and Mogilev Podolsky are used. To get a comprehensive picture, daily data from the Bendery River Post in Moldova are used as well.

The calculations were carried out using the Indicators of Hydrological Alteration recommended by Guidelines No. 31 “Accounting for Environmental Runoff Requirements” on the implementation of the Directive of the European Parliament and the European Council on framework conditions for water policy activities.

To analyze the characteristics of spring floods as well as ecological and reproductive release, we used long-term data on the regime and resources of surface waters (Water Cadastre of Ukraine) as well as daily water flow data at the Dniester HPP-1 site.

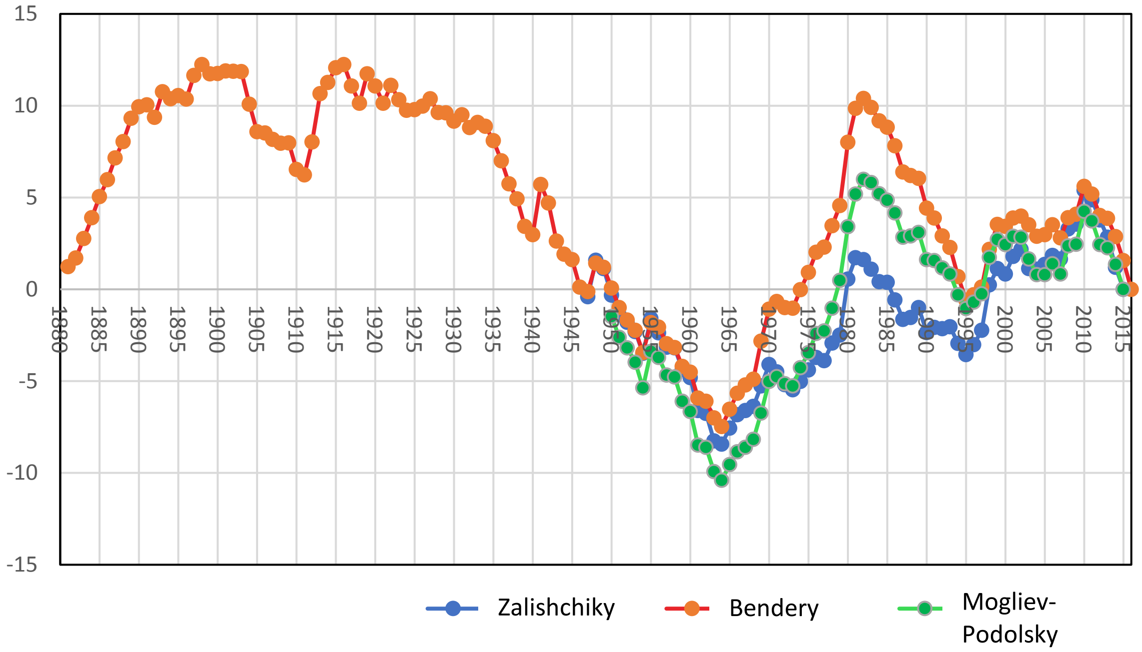
Analysis of the Dniester reservoir water balance is based on the calculations of the Novodnistrovsk lake station.

As a part of the of water use analysis, its condition was assessed in the Moldavian part of the Dniester River basin (including the left bank) and in the Odessa кegion in 1951–1980 and during the period of operation of the reservoirs (1990–2015). We analyzed the existing water supply and sanitation systems, the dynamics and prospects of irrigation development. We also summarized annual reports form 2-TP “Vodkhoz”, as well as strategic and policy documents in the field of water supply, treatment and management in Moldova and Odessa region of Ukraine.

For the analysis of hydrobiological changes, available information on the species composition, abundance, biomass of aquatic organisms, aquatic and semi-aquatic birds was used. The information was derived from monographs and scientific articles summarizing the results of field hydrobiological studies before and after the creation of the reservoirs, as well as hydrobiological monitoring data of the State Hydrometeorological Service of the Republic of Moldova, State Fish Protection Service of the Republic of Moldova and the statistical data of the “Odessarybvod”.

4.1. Long-term changes in the natural runoff

The long-term course of the Dniester runoff is characterized by the alternation of high water and low water years. For existing historical series of observations, from 1880 to 2015, the average yearly below normal water runoffs[14] were repeatedly observed in series of 3–6 years, above normal – up to 9 consecutive years. In the long-term course of runoff prior to 1946, short low water periods were observed[15], to be replaced by more high-water ones. Long low water phase in 1916 – 1964 was balanced out by a high-water period in 1965 – 1981. Long-term annual runoff fluctuations comprise a full cycle from 1982 to 2010. From 2011 to present, a low-water phase of the Dniester runoff is observed (Fig. 4.1).



Data Sources: Hydrological Yearbook 1951 - 1977; State Cadastre rivers 1978 - 2015.

Fig. 4.1. Difference integral curves of the Dniester average annual water flow in sections of individual hydrological posts

On average, the seasonal distribution of runoff in the Dniester HPP-1 site is as follows (*Draft Rules, 2017*):

- 38% - in the spring (March – May), when the main part of the runoff is formed due to melting of snow in the Carpathian part of the basin;
- 27% - in the summer (June – August), which accounts for the bulk of rain floods;
- 19% – in the fall (September – November);

[14] The runoff norm is understood as the *average runoff value* over a multi-year period of such a duration, which, if increased, will have practically no effect on the obtained value, meaning it will remain within the margin of error. If the average value is determined over a short series of observations or there is a suspicion that the series is not representative, such a value is called the long-term average value, but not the norm.

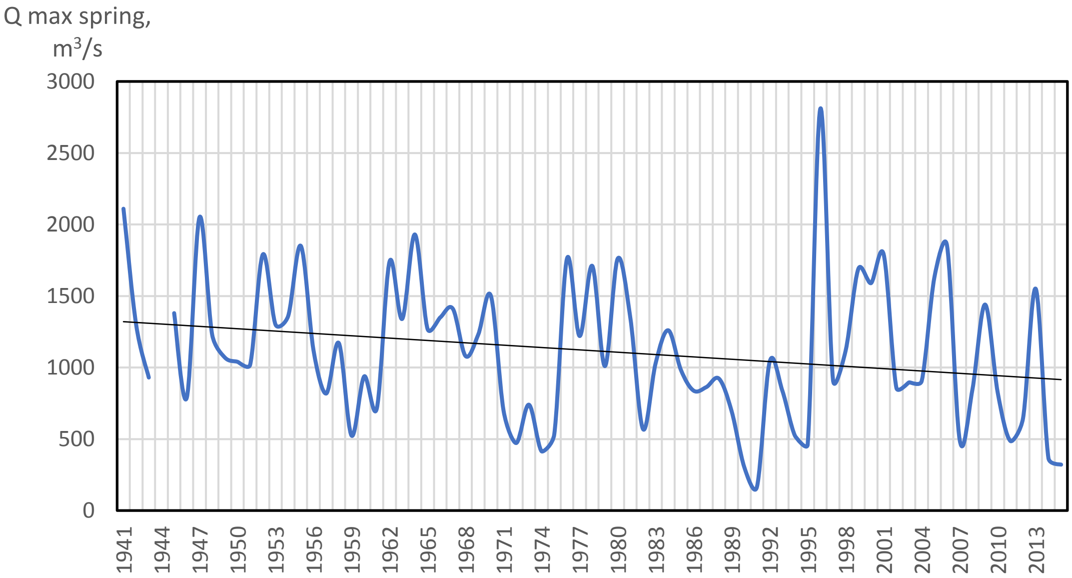
[15] The graph shows not the absolute values of the runoff, but the result of a usual conversion into "integral-difference curves" used in hydrology. A section of such a curve with an upward slope corresponds to a high-water phase of cyclical flow fluctuations (or generally a phase of increased values), and a section with a downward slope corresponds to a low-water phase (or a phase of reduced values). Fracture points of the curve indicate the beginning or end of the cycle.

- 16% - in winter (December – February).

Climate change affects the cyclicity of the runoff. In recent decades, they manifest themselves in increased (compared to the 1950-1980) cold season runoff, which is most likely due to the restructuring of the synoptic processes and an increase in rainfall in the autumn, as well as milder winters with thaws. The unstable nature of the snow cover, shallow soil freezing depth all contribute to infiltration of melt water and the transfer of surface runoff to underground. This leads to an increase in winter low water runoff. Over the past decades, the minimum average daily water flow rate has increased by 73% (the minimum average monthly water flow rate has increased to a lesser extent - less than 20%) (State Cadastre, rivers).

Significantly smaller changes are characteristic of the maximum water flow rate, which in 80% of cases is not due to melting of snow, but rather rain floods: the maximum average daily water flow rate increased by only 4%, the maximum monthly average – by less than 2% (State Cadastre, rivers)

Climate changes contribute to a decrease in the maximum flow rates during spring floods for both the Dniester and its tributaries; the last significant spring flood of the rivers of the basin was observed in 1996 (State Cadastre, rivers, Ovcharuk, 2013). Despite a slight decrease in the last decades of maximum spring flood water flow rates of the Dniester (Fig. 4.2), the flood runoff volume during for this period remained virtually unchanged.



Data sources: Hydrological Yearbook 1941 - 1977; State Cadastre, rivers 1978 – 2015

Fig. 4.2. Multi-year changes in the maximum water flow rate during spring floods at Zalishchyky site (m^3/s)

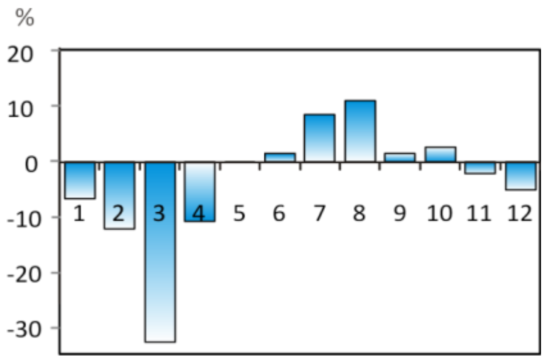
The average long-term runoff volume during the flood period amounts to about 1.9 km^3, the average flow rate is 380 m^3/s, the maximum values vary significantly – from 167 m^3/s to 2810 m^3/s. River floods can begin as early as February and end in late May for an average duration of about two months. Often the flood comes in several waves, which is especially pronounced during the early ice break-up and subsequent return of the cold weather. The course of the flood can be complicated, and runoff volume can increase due to rainfall; in such cases, the second peak of the flood often exceeds the first.

4.2. Intra-annual redistribution of runoff by reservoirs

Comparative analysis of the annual runoff variation of the Dniester done by the year of commissioning of hydropower plants and reservoirs (1990-1998 – HPP-1 operation; 1999-2008 – operation of HPP-1 and HPP-2, 2009-2015 – operation of HPP-1, HPP-2 and PSPP) showed that the annual runoff in the downstream of the cascade almost always coincides with the value of the total inflow of water into the reservoirs.

The decrease in the annual runoff of the Dniester River downstream of the cascade of HPPs and PSPPs (Mogilev-Podolsky) amounts to 3.2–6.6%, and is due to additional evaporation from the surface of reservoirs, the presence of intakes in this section of the river (Insert 4.2), and also, possibly, the insufficient accuracy of regular runoff observations due to diurnal fluctuations. According to the authors of a detailed study of karst processes taking place in the region of the Middle Dniester (Axiom, 2002), possible karst influences on the runoff characteristics of the Dniester and its tributaries in the vicinity of the HPP-1 and HPP-2 cascade can only result in runoff increase due to leakage of underground water through a system of tectonic disturbances from the Prut River basin side.

Reservoirs of the Dniester complex ensure intra-annual redistribution of runoff. When accumulating or discharging water, their influence is manifested primarily in a decrease in the maximum flow rate during floods and high water, as well as in a decrease in spring flow rate in general (except in May, when ecological and reproductive release is carried out – see below) and in an increase in the summer-autumn low water flow rates (Fig. 4.3).



Data source: State Cadastre, rivers 1978–2015.

Fig. 4.3. Change in average monthly water flow rates (%) in 1990–2015 in relation to natural runoff due to regulation

A similar picture is observed when considering changes with respect to the time of commissioning of reservoirs and hydropower plants (Fig. 4.4): 1990– 1998 – operation of HPP-1; 1999-2008 – operation of HPP-1 and HPP-2; 2009-2015 – operation of HPP-1, HPP-2 and PSPP.

The main regulator of the Dniester runoff is the Dniester reservoir of HPP-1. It receives the discharge of the upper Dniester and its tributaries: Zbruch, Zhvanchik, Smotrytch, Studenitsa, Ushitsa and Kalyus (lateral inflow accounts for 19 - 23% of the total inflow). In most cases, the buffer reservoir and the upper reservoir of the PSPP are only involved in daily flow rate regulation.

Insert 4.2 Water balance of the Dniester reservoir

The water balance equation can be represented in the following general form:

$$W_{пр} + W_{б} + W_{бр} + W_{ос} + W_{п} - W_{гэс} - W_{фгэс} - W_{фложе} - W_{ис} - W_{сп} = \Delta W_{ак},$$

where

$W_{пр}$ – Dniester tributary (h/p Zalishchyky);

$W_{б}$ – measured lateral inflow;

$W_{бр}$ – estimated lateral inflow from the area where water flow rate is not measured;

$W_{ос}$ – precipitation in the reservoir water table; it is determined from precipitation observations the data by stations and posts (the water table area of the reservoir, which varies with changing water level, is taken into account)

$W_{п}$ – discharges of enterprises;

$W_{гэс}$ – runoff through hydropower facilities of HPP-1;

$W_{фгэс}$ – filtration through the dam body;

$W_{фложе}$ – filtration in the reservoir bed;

$W_{ис}$ – evaporation of the reservoir water surface; calculated using hydrometeorological observations on the banks and water area of the reservoir, accounting for changes in the area size of the reservoir water surface;

$W_{сп}$ –withdrawal of water for economy needs;

$W_{ак}$ – accumulation of water in reservoir basin.

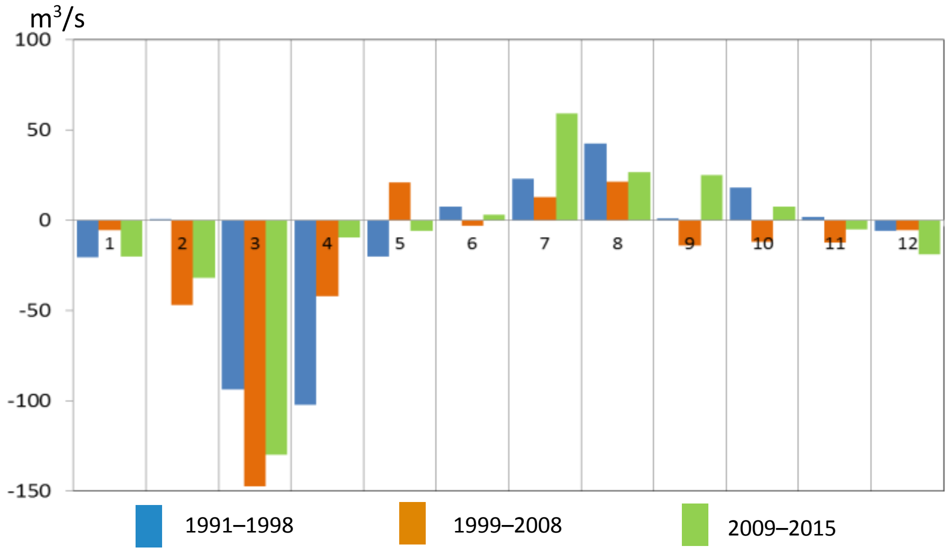
The upper Dniester runoff is main contributor to the inflow of the water balance. According to observations of the Hydrometeorological Center of Ukraine, an average of 6–8 km^3 of river water flows into the reservoir each year. In some years, the inflow can reach 12 km^3/year. In some dry years, the runoff of the upper Dniester does not exceed 4–5 km^3/year. The second largest component of the water balance is the lateral inflow. The volume of discharges of enterprises, including household wastewater, is given according to the data provided by water using enterprises and departments of the water supply network of the cities of Kamenetz-Podolsky and Khotin. It is rather small and averages at 15-17 million m^3/ year. The annual rainfall affecting the reservoir water table averages at 500–600 millimeters (70–80 million m^3).

Essentially, the outflow component of the water balance is formed due to discharge into the buffer reservoir, which makes up 80–97% of the total inflow to reservoirs. Evaporation from the water table of the Dniester reservoir amounts to 700-800 millimeters per year, which causes an annual loss of up to 95-105 million m^3 (1-2% of water inflow). The flow rate of the filtration through the body of the HPP-1 dam averages at 7 m^3/ s (220–225 million m^3/ year). Filtration in the reservoir bed does not exceed 3%. The abstraction of water for household needs from the Dniester reservoir ranges within 35–45 million m^3 / year.

Data source: Lake station Novodnistrovsk GMC Ukraine

Comparison of data from hydrological posts in Zalishchyky and Mogilev-Podolsky (including lateral inflow) for 1951-1980 and 1990-2015 shows that after the creation of reservoirs, minimum average runoff increased by 102-118%, the minimum average – by 35-42%. At the same time, a decrease of

20–25% of the maximum daily average and 15% of the maximum average monthly water flow rate is observed[16] (Fig. 4.5).



Data Source: State Cadastre, rivers 1978–2015.

Fig. 4.4. Change in average monthly water flow rate in relation to natural runoff for different periods reservoirs and HPPs operation

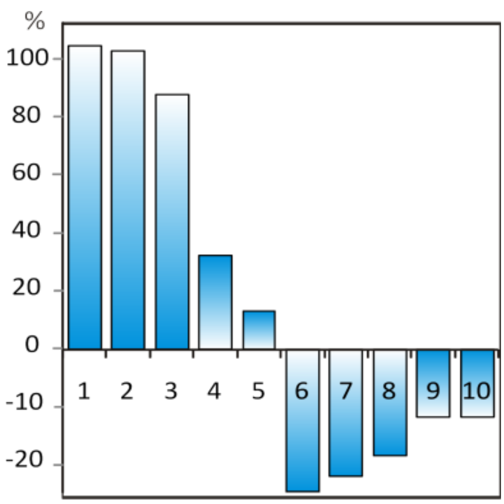


Fig. 4.5. Change in the minimum and maximum runoff (%) in Mogilev-Podolsky in 1990–2015 compared with 1951-1980.

1 - average daily minimum runoff,
2 - minimum runoff (average for 3 days),
3 - minimum runoff (average for 7 days),
4 - average monthly minimum runoff,
5 - minimum runoff (average for 90 days),
6 - average daily maximum runoff,
7 - maximum runoff (average for 3 days),
8 - maximum runoff (average for 7 days),
9 - average monthly maximum runoff,
10 - maximum runoff (average for 90 days)

As these calculations show, the general trend is towards the decrease in the absolute value of the changes with an increase in the averaging period. When comparing the data form posts in Mogilev-Podolsky and Bendery between 1990 and 2015, the same patterns are observed – an increase in the minimum and a decrease in the maximum runoff. The forms of runoff hydrograph at these posts are also quite similar (Fig. 4.6).

[16] These changes are also partly due to the transformation of unregulated runoff parameters over the indicated period – compare to information in the previous section.

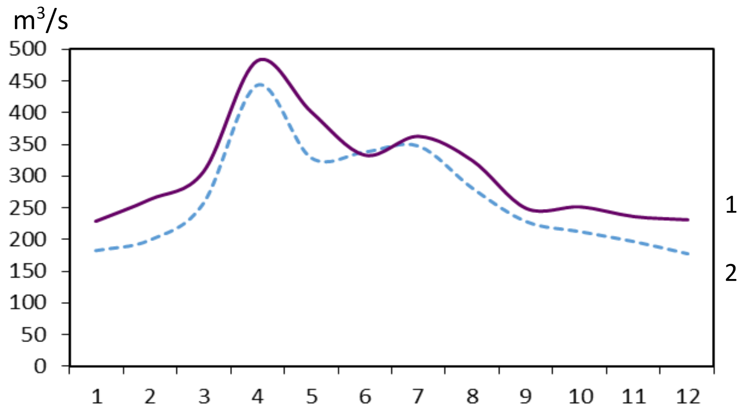


Fig. 4.6. Intra-annual distribution of average monthly water flow rates for 1990–2015
at Bendery (1) and Mogilev-Podolsky (2) o/p

In spring (usually in April – May) an ecological and reproductive release from the Dniester reservoir is carried out (Insert 4.3). The release begins based on the water temperature in the Dniester delta reaching 10–12 °C. In most cases, such values are observed in the second decade of April. Release lasts for an average of 30 days. When determining the course of release, the Interdepartmental Commission of Ukraine for coordinating the operation of Dnieper and Dniester reservoirs generally adheres to the following schedule: an increase in the short term (up to 6–8 days) flow rates up to average daily values of 450–500 m^3/s; maintaining this level for 10-12 days; subsequent gradual decrease. The volume of release averages at 0.9–1.2 km^3; the minimum required volume, according to studies of the Institute of Hydrobiology of the NAS of Ukraine (Shevtsova, 2003), is 0.8 km^3.

Insert 4.3 Environmental and reproductive release

Ecological and reproductive release is designed to maintain the environmental sustainability of the natural river system. Its parameters are set annually by the Interdepartmental Commission of Ukraine to coordinate the operation of the Dnieper and Dniester reservoirs. Compliance with the release schedule is ensured by NEC Ukrenergo and PJSC Ukrhydroenergo. Analysis and control of the hydrological situation in the Dniester basin during the release period is carried out by the State Water Resources Agency of Ukraine.

It should be noted that at the state level in Ukraine there is no mechanism for monitoring the effectiveness of environmental and reproductive releases and, accordingly, no key environmental indicators have been identified, the assessment of which could indicate its effectiveness. As part of its own monitoring programs, the Dniester Delta ecosystem is monitored by the Lower Dniester National Nature Park. The value of ecological reproductive release does not include the volume of water to ensure economic and other activities.

The main difficulty in agreeing on the regulations for environmental releases is the lack of synchronization of water inflow into the Dniester reservoir during the spring flood with the established dates for the ecological and reproductive releases (Fig. 4.7). This often leads to significant spring triggering of the Dniester reservoir and a decrease in the water level in it, which is detrimental to the fish of the reservoir itself, especially in its upper section. If there are contradictions between the water requirements of the Dniester delta and the Dniester reservoir, especially in dry years, the delta, which is more important for the conservation and reproduction of valuable hydrobiocenoses, takes precedence (Shevtsova, 2003)[17].

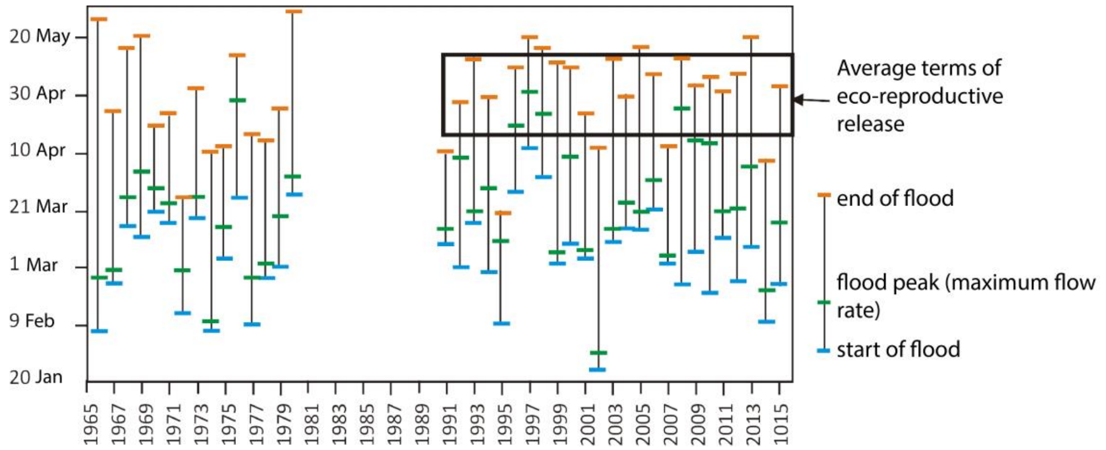


Fig. 4.7. Long-term characteristics of spring flood periods at Zalishchyky o/p and ecological and reproduction release at the Dniester HPP-1 site

It should be noted that the total (including ecological-reproductive release) volume of water passing during spring floods through the HPP-1, on average, coincides with the volume of spring flood runoff at Zalishchyky o/p. (Fig. 4. 8). The maximum flow rate at HPP-1 is observed in the second decade of March and can reach 1000 - 1500 m^3/s (State Cadastre, rivers 1978 - 2015).

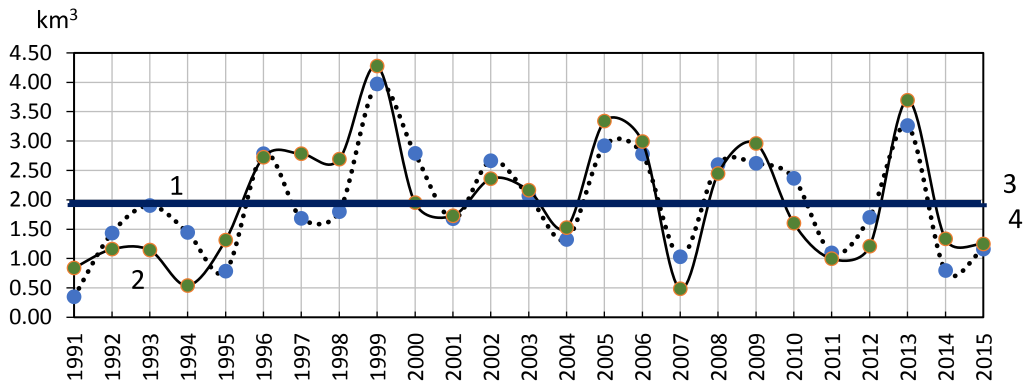


Fig. 4.8. Long-term changes in the volume of water runoff during spring flood at Zalishchyky o/p (1) and the total runoff volume during spring flood (including environmental releases) in the upstream of HPP-1 (2).

* Lines 3 and 4 – are mean annual values .

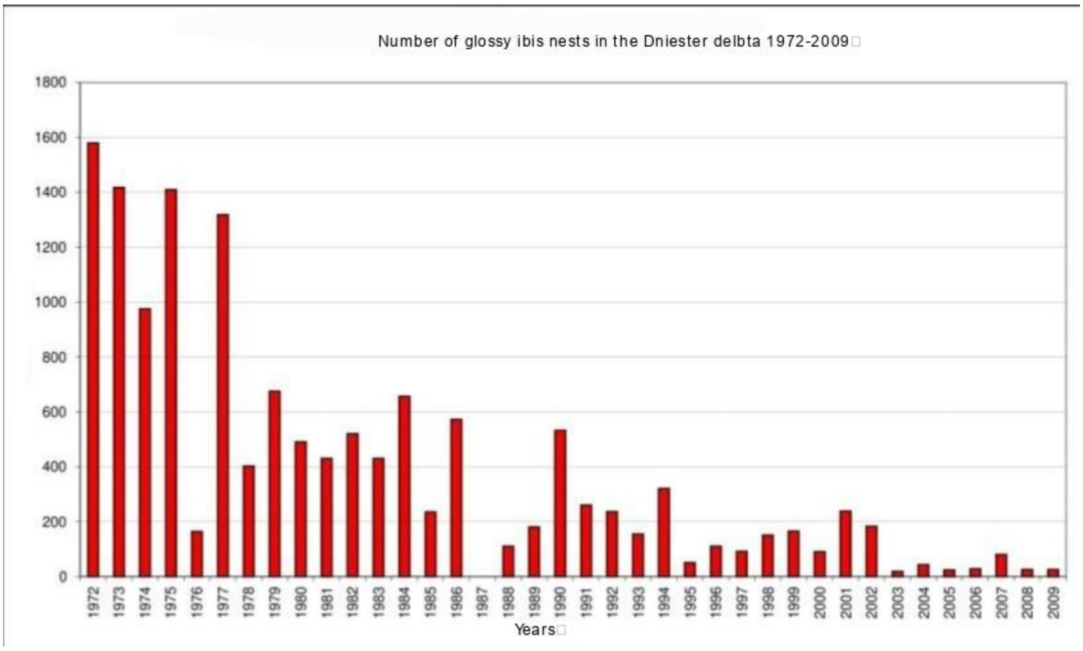
[17] At the same time, the possibility and necessity of optimizing the timeframe, duration and maximum, flow rates of ecological-reproductive release remain. In the interests of the fisheries of the Middle Dniester and Dniester floodplains, the optimal maximum flow rates, according to a number of different estimates, should be in the range of 400–500 to 700–750 m^3/s (Restoration, 2016).

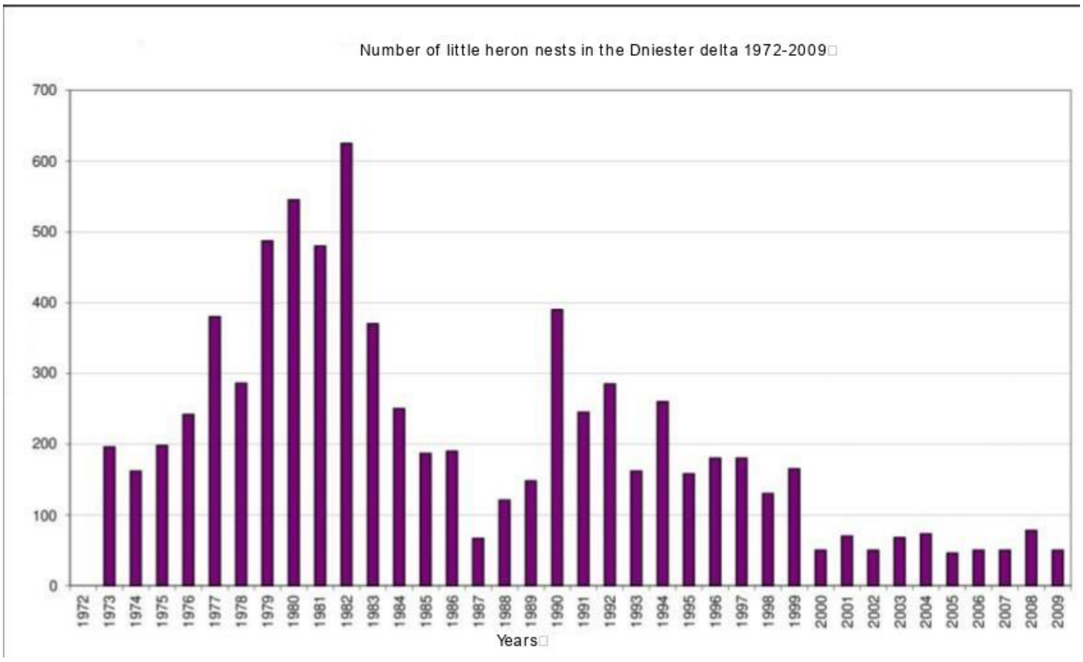
4.3. The impact of hydrological changes on the state of biotic communities in the lower Dniester

The commissioning of the Dniester complex affected the seasonal distribution of the Dniester runoff, thereby changing the spawning conditions of almost all ecological groups of fish. Because of the degradation of flood lakes due to a decrease in water exchange, the mudminnow *Umbra krameri* Walbaum – the indigenous species of the Dniester delta listed in the Red Books of Moldova, Ukraine and Europe saw a sharp decrease.

The regulation of the Dniester runoff significantly affects the condition of aquatic and semi-aquatic birds. The species composition and abundance of birds in the Dniester delta during nesting and migration periods largely depend on the hydrological conditions of the year, flooding of floodplain meadows in the spring, and the flooding of the plains. Significant fluctuations in the number of semi-aquatic birds are characteristic of the Dniester delta.

In the wake of runoff regulation, the abundance and nesting conditions in the Dniester delta for colonial semi-aquatic birds (little cormorant, night heron, great white, little, pond and purple heron, glossy ibis and spoonbill), as well as the presence of forage biotopes for a number of migratory species, are primarily defined by ecological releases from the Dniester reservoir. In dry years, when the maximum flow rates of ecological releases amount to 400–450 m^3/s, a decrease in the number of gray goose and mallard is observed. Under such conditions, the numbers of spoonbill and previously abundant glossy ibis are also reduced (Fig. 4 .9). The flooding of the plains also largely affects the placement of the gray goose and the mute swan nests in the Dniester delta. At the same time, runoff regulation does not affect the abundance of some species of fish-eating birds - the great cormorant and the white pelican, whose numbers in the Dniester delta have grown in recent years to approximately 10,000 and 2,000 individuals, respectively.





Data Source: Schegolev, 2016

Fig. 4.9. Number of nests of glossy ibis and little heron in the Dniester delta from 1972 to 2009

4.4. Provision of basic water supply functions

The Dniester reservoirs play an important role in providing water resources to the regions of Ukraine (Chernivtsi, Khmelnitsky, Ternopol, Vinnitsa, Odessa regions) and the Republic of Moldova (including the Transdniestrian region).

In the area of the Dniester reservoir, the main consumers are the utility enterprises of Novodnistrovsk, Kamenets-Podolsky, Khotin and smaller settlements of Ukraine. In most cases, before reaching a drawdown level of 114 meters[18] the reservoir ensures uninterrupted operation of water intakes.

As indicated in subsection 4.2, due to the accumulation of water resources in the reservoir of Dniester cascade of HPPs (and to a lesser extent, in the Dubossary reservoir)[19] the minimum runoff increases, providing a guaranteed flow rate of 100 m^3/s, sufficient for intakes of the Middle and Lower Dniester (designed around the flow rate of 80 m^3/s).

In Moldova, the Dniester provides 63% of drinking water in the amount of 73 to 78 million m^3 of water per year. The largest volume of water per capita (43.7 m^3/per./year) is consumed in Chisinau. In recent years, there have been issues related to lower water levels at a number of water intakes (in Chisinau and the Transnistrian region). However, upon closer examination, such issues, as a rule, turned out to be unrelated to the hydrological regime (Insert 4.4).

[18] According to the draft Rules for the Operation of Reservoirs of the Dniester cascade of HPPs and PSPPs, the minimum elevations of water intakes at Kamenetz-Podolsky (108.65 m) and Khotin (111.0 m) must be taken into account when the Dniester reservoir falls below 114.7 meters.

[19] According to the Operation Rules of the Dubossary Reservoir, the sanitary and navigation release to the upstream should collectively amount to 60 m^3/s.

Insert 4.4. Analysis of the situation at the Chisinau water intake and proposed remedial measures

Since the 1980s, according to the SA Apă-Canal Chişinău Operational Service, the water intake at the Dniester main pumping station (MPS), which supplies water to the city of Chisinau, occasionally operated with water levels in the river being well below design parameters, which jeopardized guaranteed water supply in Chisinau as well as other settlements receiving water from this group water supply system. To determine the causes of falling water level and design remedial measures, the Aquaproject Institute used its own data, as well as the archival data of the institutes and organizations of Moldgiprostroy, Chisinaugorproject, Moldgiprovodkhoz, Bendery River Port OJSC, SA Apă-Canal Chişinău, Agenţia Apele Moldovei, ÎS Direcţia Bazinieră de Gospodărire a Apelor, State Design Institute "Soyuzvodkanalproekt" Minsk, SRL GEOVANMAX. In addition, in September- December 2016, there were undertaken depth measurements at 8 sections of the Dniester, a one-hour connection of the water edge, and vertical and planned referencing to state geodetic network in the water intake area. Measurements were carried out at the same sites where SC GEOVANMAX SRL had conducted measurements in 2002, 2008, and 2009. To analyze the dynamics of changes in the river channel at the water intake, the 2016 measurements data were overlaid on the previously obtained data. In sections No. 2 and No. 8 more detailed hydraulic and hydro-technical calculations were performed.

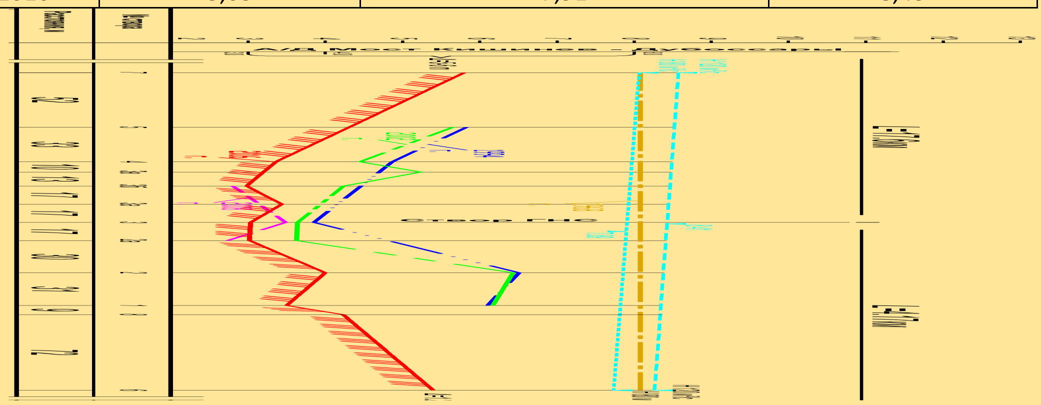
As a result of the calculations, it was established that with a modern channel profile at the water intake, the existing minimum flow rates do not meet design parameters necessary for the operation of the pumping station: 8.5 meters (hereinafter using the Baltic elevation system) with minimal sanitary and environmental releases of Dubossary HPP of 80 m^3/s and 9.0 meters – with guaranteed releases during the vegetative season of 120 m^3/s. The decrease in the estimated water level at the water intake site is caused by the following factors:

- the embankment of the Dniester channel in order to protect settlements and floodplain agricultural lands from flooding;
- the construction by the Bendery River Shipping Company (starting in 1958) of underwater directional dams (transverse dikes, jetties) on the left bank in order to ensure navigation, which led to the erosion of the bed and the right bank of Dniester;
- long-term extraction of sand and gravel from the riverbed, including in the area of the water intake,
- violation of the natural river base level in the downstream of Dubossary reservoir due to construction of the Dubossary HPP.

These changes led to the drop of the riverbed level at the MPS water intake by 3-5 meters.

Changes in riverbed and water levels at the Chisinau MPS water intake

Year	Riverbed level, м	Water level at different flow rates, m	
		80 m^3/s	120 m^3/s
1968	8,08	9,83	10,24
1994	3,85	8,01	8,55
2002	3,64	7,45	8,20
2008	3,49	7,30	7,97
2016	3,03	7,91	8,43



Longitudinal profile and changes in minimum riverbed levels in the area of water intake

Since 1994 alone, the cross-section of the Dniester riverbed at the pumping station (site 3) has increased by 91.0 m^2, which, given minimal flow rates in the river, inevitably leads to a local decrease in water levels at the water intake site. In section No. 2a, 30 meters downstream of the MPS axis, a lowering of the floor by 0.5–2.0 meters was observed in the center of the river and on the right bank.

The analysis also showed a deepening of the river floor at the highway bridge in Dubossary from 1962 to 1990 by 4-6 meters, at the highway bridge near the city of Vadul-lui-Voda from 1978 to 2008 – by 1.4 meters. Thus, in the studied area at the Dubossary HPP dam and near the city of Vadul-lui-Voda, there is an ongoing trend towards the deformation of the channel, lowering the riverbed and, as a result, the water level during minimal releases.

The “Aquaproject” Institute proposed to carry out hydrotechnical measures to increase water level at the water intake site. These include creation of an underwater foundation sill made of cylindrical stone gabions – factory-made double torsion mesh bags filled with rubble stone in the riverbed, in section No. 8 downstream of the MPS water intake. The suggested foundation sill will not affect wintering pits and spawning grounds, thereby preserving the existing conditions for the development of the Dniester hydrobionts. Hydromorphometric and hydraulic calculations show that a foundation sill with a crest mark of 6.6 meters will ensure a water level of 8.5 meters at the water intake site with flow rate of Dubossary HPP of 80 m^3/s and 9.0 meters with the flow rate of 120 m^3/s. That will ensure uninterrupted operation of the MPS water intake and guarantee water supply to the city of Chisinau.

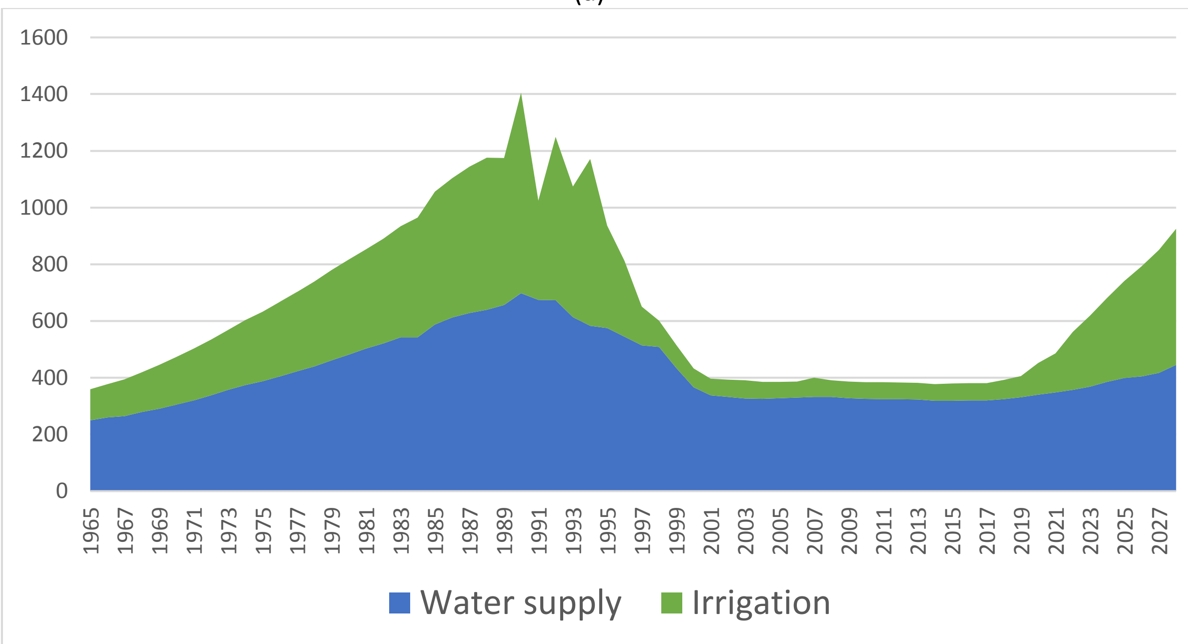
Source: Acvaproiect SRL

The Dniester water is essential to the operation of industrial enterprises, in particular, the Moldavian State District Power Plant. Its return consumption for cooling of electric generators (after use, the water is returned to the Turunchuk sleeve through the Cuciurgan estuary) amounts to an average of 555 million m^3 of water per year (State Water Cadastre of the Republic of Moldova) and can be brought up to 835 million m^3 per year when six power units are operating.

In the Odessa region of Ukraine, the cities of Odessa, Yuzhny, Chernomorsk, Belyaevka, Teplodar and settlements of Belyaevsky, Ovidiopolsky and Limansky districts with a population of 1.26 million people located in a radius of 100 kilometers from the Odessa water intake get their drinking water from the Dniester. Except for emergencies at water pipelines, no interruptions in water supply in Odessa in the last decade have been recorded. According to LLC "Infox", the branch of "Infoxvodokanal" the reduction in release volumes in the Dniester reservoir during offshore winds reducing Dniester water levels at the intake area, increases water treatment costs[20]. An analysis of the potential threat to Odessa water intake as a result of a prolonged runoff decline during periods of strong surge winds requires additional research.

In Moldova, as well as in Odessa and Vinnitsa regions of Ukraine, the Dniester water is used for irrigation. Since the 1990s, the area of irrigated lands has decreased significantly (in Moldova - from 100–240 to less than 20–35 thousand hectares), however, in recent years, interest in irrigated agriculture has increased again, which has led to an increase in size of irrigated areas. In the next decade, total water consumption in the Republic of Moldova and the Odessa region of Ukraine is expected to increase from 392 million m^3 in 2018 to 925 million m^3 by 2028 (Fig. 4.10).

(a)



(b)

[20] The results of observations made at the neares hydrological observation post in Mayaky, which is under the influence of surge phenomena, show that commissioning of the Dniester cascade of HPPs and PSPPs had almost no effect on the average annual water level values.

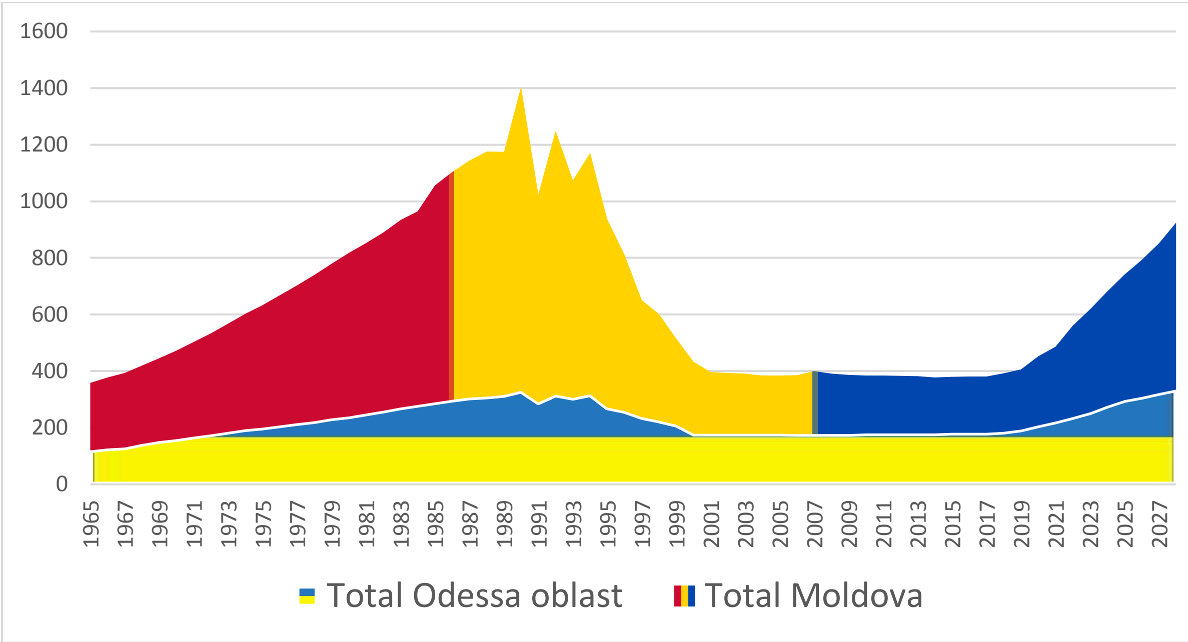


Fig. 4.10. Water consumption in the Dniester basin downstream of HPP-2 for 1965–2017 and a forecast until 2028, by (a) type of water usage, and (b) basin countries, million m^3 per year

* Without taking into account water consumption downstream of the HPP-2 in Vinnytsia and Cherkasy regions of Ukraine and the return consumption of Moldovan PSPP.

Data Sources: Water Use Report ...; Government of the Republic of Moldova, 2011; archives of the Ministry of Land Reclamation and Water Resources of the MSSR; Agency "Apele Moldovei"; Lower Dniester National Natural Park; Department of Water Resources of Odessa region; expert forecast (M.S. Penkov, A.N. Kalashnik)

Nevertheless, the estimated total irrigated area of 550 thousand hectares used as a basis for existing Rules of operation of Dniester hydropower complex reservoirs will not be attained in the next 20-30 years. In the long term, however, such an area will need to be provided with water for the expanded production of highly profitable fruits and vegetables and other crops, necessary for the economic and social development of rural communities. At the same time, the irrigation norm of 4420 m^3/ha included in the calculations is unjustifiably high and can be significantly reduced, thus releasing the necessary volume of water for the spring ecological-reproductive release not included in the initial calculation.

Existing experience shows that the regulation of minimal runoff, especially in extremely dry years, will continue to be extremely important in the years to come[21]. At the same time, it is necessary to retain the capability to regulate river floods in the summer period in order to protect from flooding agricultural lands, which in many villages are the only source of people's livelihood.

[21] Thus, an analysis of the situation in the extremely dry year of 2007 emphasizes the need for reservoirs to ensure guaranteed water consumption, which exceeded the natural inflow in July - August with irrigation of only 35 thousand hectares - much less than can be expected in the future.

5. CONCLUSION

Analysis of vast body of data conducted by an expert group enabled us to identify significant changes of hydrological, hydro-chemical, and hydro-biological indicators, described in detail in the report and summarized below.

Some indicators and processes for which, according to the available data, no significant changes were found, remained outside the summary table and recommendations. These include:

- oxygen regime downstream of reservoirs;
- total number of species and indices of saprobity of macroinvertebrate communities;
- zooplankton abundance;
- total number of fish species within the basin and its large sections;
- average annual runoff;
- the volume of spring runoff downstream of the cascade in comparison with natural floods.

However, the available data was found to be insufficient for reliable analysis of a number of processes and trends. For such cases, the group suggests conducting additional studies to fill in specific information gaps - also summarized below. Alongside the studies mentioned below, additional more detailed research may be needed for the issues not covered by this study, such as the impact of existing and planned facilities of Dniester PSPP on the state of aquatic communities downstream of the hydrocomplex, and the impact of water intake conditions and water level fluctuations in the Dniester reservoir on the condition of the fish stock, and rare and endangered species..

Finally, based on the results of the analysis, a number of specific recommendations for addressing specific problems has been given. These recommendations are preliminary and may be taken into consideration and further developed during the preparation and implementation of the Strategic Action Plan within the framework of the GEF project "Enabling Transboundary Cooperation and Integrated Water Resources Management in the Dniester River Basin ", as well as the Dniester River basin Management Plans as a part of Moldova and Ukraine commitment to the requirements of the Directive 2000/60/EU on the framework conditions for activities in the field of water policy[22].

In the same context, the distribution of responsibilities for financial support and the implementation of compensation measures to restore and improve the condition of the Dniester basin requires further analysis.

During the discussion among experts to this analysis, a proposal was made to abandon the use of the Dniester for hydropowerin principle and to begin gradual liquidation of the existing reservoirs. The expert group was not able to reach consensus on this issue, which ultimately requires strategic and political decisions at the intersection of the interests of energy, water use, and environmental protection. However, expert group members are ready to contribute to the further research of these problems and their solutions.

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[22] The study of the necessity and feasibility of building fish passage facilities through dams of Dniester HPPs was excluded from the final recommendations. Members of the expert group unanimously agreed that the current state of fish communities of the Black Sea does not allow for the recovery of anadromous fish in the Dniester. In addition, the real effectiveness of existing facilities for commercial species is small.

Table 5.1 Effects of the construction and operation of reservoirs and recommendations for further actions

The main effects of the construction and operation of reservoirs	Recommendations for conducting additional research	Recommendations for exploring opportunities or taking corrective measures
The impact of structural changes resulting from the construction of reservoirs on the aquatic environment and biotic communities		
Decreased suspended solid runoff downstream of reservoirs up to the Dniester delta	Study of long-term changes in runoff and balance of heavy particle-size fractions of river sediments (sand and gravel)	Development of a strategy for regulating solid runoff (sediment) in the Dniester basin
Change in the thermal regime of the transboundary section downstream of HPP-2		Studying the possibility of water discharge from various depths of the Dniester reservoir
The development of macrophytes, the overgrowing of the channel and flood lakes	Quantitative assessment of the extent of channel bedding and its implications (oxygen regime, secondary pollution)	An increase in the stocking of the Lower Dniester by an obligate phytophage – grass carp *Ctenopharyngodon idella*
Change in the species composition of invertebrates (replacement of rheophilic species with limnophilic species), increasing the total number and biomass of macroinvertebrates, worsening the living conditions of sensitive taxa (decreasing EPT index)	Standardized sampling of macroinvertebrates from various substrates and banks at different distances from the HPP-2 dam and downstream of the Dubossary reservoir (in the Reut River influence zone). Study of the size and age structure of populations of dominant mollusk species depending on temperature changes	
Decreased cross-border zooplankton production	Spatial and quantitative assessment of the state of zooplankton at different distances from dams	
Change in the species composition of ichthyofauna, reduction in stocks of commercial species, reduction in the number of rare and endangered species	Analysis of the prevalence of invasive and invading species in the Dniester basin	Preventing the spread of invasive species

Influence of diurnal runoff fluctuations on the state of the transboundary site		
Uneven intraday runoff fluctuations downstream of HPP-2	Study of the intraday runoff fluctuations over a longer (representative) period of time. Study of intraday variations in water quality in the downstream of HPP-2	Setting up bilateral automated monitoring of the level and flow rate of water downstream of HPP-2. Inclusion of restrictions on the minimum value of instant release at HPP-2 in the Operating Rules of Dniester Reservoirs
Uneven intraday fluctuations in temperature, water level, and drainage of channel parts in the transboundary section	Study of the dependence of aquatic communities and aquatic organisms downstream of HPP-2 on daily fluctuations in water level	
Long-term changes and intra-annual redistribution of runoff		
Reduction of maximum flow rate in reservoirs' downstreams (flood control)		Development of modeling for an accurate forecast of the hydrological situation
Increase in the minimal runoff in reservoirs' downstreams and ensuring guaranteed flow rates at water intakes and the needs of irrigated lands	Regular updates of medium- and long-term forecasts of water consumption in the Dniester basin. Study of the water intake related problems on the left bank of the Dniester (including degradation of the stream channel) and the city of Odessa (possible impact of surge phenomena at low flow rates)	Strict enforcement of the Operating Rules for guaranteed water supply and irrigated agriculture in dry years. Implementation of the "Aquaproject" Institute project proposal to ensure the water level at the Chisinau water intake
Cutting off the peak flow rates and transformation of the spring flood regime during environmental and reproductive releases. Deterioration of fish spawning conditions, bird habitats, ecosystem conditions in the Dniester delta due to a decrease in flooding of the plains	Quantitative analysis (modeling) of the processes of flooding of floodplains at different runoff volumes and surge and offshore phenomena. Studies to update data on species diversity and ichthyofauna production, occurrence of rare and endangered fish species,	Steps to enable the water level rise of the Dniester reservoir to the top mark (dam repair, removal of existing dams and prevention of the construction of new facilities between FRL and SRL). Further optimization of regular flushing of the riverbed and floodplains and of the spring ecological and reproductive release.

	assessment of fish stocks and the status of spawning grounds of lower Dniester	Development of measures for the protection of rare and endangered fish species of the Lower Dniester, restoration of spawning grounds, and regulation of commercial and recreational fishing. Incentivization of fish-breeding enterprises for stocking of natural reservoirs with zanthe, sabrefish, and other commercial and rare species. Creation of artificial meadow spawning grounds in the Dniester basin to ensure spawning of phytophilic species.

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ANNEX I. The taxonomic composition of the fish fauna of the Dniester basin before and after the regulation of runoff

Species	Before regulation, Dniester as a whole[a]	After regulation	
		Middle Dniester[b]	Lowlands and the estuary[c]
Ord. Petromyzontiformes Fam. Petromyzontidae			
Ukrainian brook lamprey *Eudontomyzon mariae* (Berg, 1931)	+		
Ord. Acipenseriformes Fam. Acipenseridae			
Starry sturgeon *Acipenser stellatus* (Pallas, 1771)	+	+	
Sturgeon *Huso huso* (Linnaeus, 1758)	+		+
Russian sturgeon *Acipenser gueldenstaedtii* (Brandt et Ratzeburg, 1833)	+		
Thorn sturgeon *Acipenser nudiventris* (Lovetsky, 1828)	+		
Sterlet *Acipenser ruthenus* (Linnaeus, 1758)	+	+	+
Ord. Anguilliformes Fam. Anguillidae			
European eel *Anguilla anguilla* (Linnaeus, 1758)	+		
Ord. Clupeiformes Fam. Clupeidae			
Black Sea shad *Alosa tanaica* (Grimm, 1901)	+	+	
Pontic shad *Alosa immaculata* (Bennett, 1835)	+	+	+
Azov shad *Alosa maeotica* (Grimm, 1901)	+		
Black Sea sprat *Clupeonella cultriventris* (Nordmann, 1840)	+	+	
Ord. Salmoniformes Fam. Salmonidae			
Brown trout *Salmo trutta fario* (Linnaeus, 1758)	+		
Fam. Thymallidae			
European grayling *Thymallus thymallus* (Linnaeus, 1758)	+		
Ord. Esociformes Fam. Esocidae			
Northern pike *Esox lucius* (Linnaeus, 1758)	+	+	+
Fam. Umbridae			
Mudminnow *Umbra krameri* (Walbaum, 1792)	+	+	+
Ord. Cypriniformes Fam. Cyprinidae			
European carp *Cyprinus carpio* (Linnaeus, 1758 Crap)	+	+	+
Crucian carp, *Carassius carassius* (Linnaeus, 1758)	+		
Goldfish *Carassius auratus* (Linnaeus, 1758)		+	+
Common barbel *Barbus barbus* (Linnaeus, 1758)	+	+	
Romanian barbel *Barbus petenyi* (Heckel, 1852)	+	+	
Tench *Tinca tinca* (Linnaeus, 1758)	+	+	+
Common nase *Chondrostoma nasus* (Linnaeus, 1758)	+	+	
Gudgeon *Gobio gobio* (Linnaeus, 1758)		+	
Ukrainian gudgeon *Gobio sarmaticus* (Berg, 1949)	+	+	
Carpathian gudgeon *Gobio carpathicus* (Vladykov, 1925)		+	
Northern whitefin gudgeon *Romanogobio belingi* (Slastenenko, 1934)		+	
Kessler's gudgeon *Romanogobio kessleri* (Dybowski, 1862)	+	+	
Stone moroko *Pseudorasbora parva* (Temminck &Schlegel, 1846)		+	+
Common bream *Abramis brama* (Linnaeus, 1758)	+	+	+
White-eye bream *Ballerus sapa* (Pallas, 1814)	+	+	+
Blue bream *Ballerus ballerus* (Linnaeus, 1758)	+	+	+
White bream *Blicca bjoerkna* (Linnaeus, 1758)	+	+	+
Zanthe *Vimba vimba* (Linnaeus, 1758)	+	+	+
Common roach *Rutilus rutilus* (Linnaeus, 1758)	+	+	+
Azov roach *Rutilus heckelii* (Nordmann, 1840)	+	+	+
Black Sea roach *Rutilus frisii* (Nordmann, 1840)	+	+	
European bitterling, common bitterling *Rhodeus amarus* (Bloch, 1782)	+	+	+
Asp *Aspius aspius* (Linnaeus, 1758)	+	+	+

Species	Before regulation, Dniester as a whole[a]	After regulation	
		Middle Dniester[b]	Lowlands and the estuary[c]
Sabrefish *Pelecus cultratus* (Linnaeus, 1758)	+		
Common chub *Squalius cephalus* (Linnaeus, 1758)	+	+	+
Ide *Leuciscus idus* (Linnaeus, 1758)	+		+
Common minnow *Phoxinus phoxinus* (Linnaeus, 1758)	+	+	+
Common dace *Leuciscus leuciscus* (Linnaeus, 1758)	+	+	+
Dnieper chub *Petroleuciscus borysthenicus* (Kessler, 1859)	+	+	+
Common rudd *Scardinius erythrophthalmus* (Linnaeus, 1758)	+	+	+
Silver carp *Hypophthalmichthys molitrix* (Valenciennes, 1844)		+	+
Bighead carp *Hypophthalmichthys nobilis* (Richardson, 1844)		+	+
Grass carp *Ctenopharyngodon idella* (Valenciennes, 1844)		+	+
Black carp *Mylopharyngodon piceus* (Richardson, 1846)		+	+
Sunbleak *Leucaspius delineatus* (Heckel, 1843)	+	+	+
Common bleak *Alburnus alburnus* (Linnaeus, 1758)	+	+	+
Pontian shemaya *Alburnus sarmaticus* (Freyhof et Kottelat, 2007)		+	+
Riffle minnow *Alburnoides bipunctatus* (Bloch, 1782)	+	+	+
Fam. Balitoridae			
Stone loach *Barbatula barbatula* (Linnaeus, 1758)	+	+	+
Fam. Cobitidae			
Siberian loach *Cobitis melanoleuca* (Nichols, 1925)		+	+
Azov loach *Cobitis tanaitica* (Bacescu et Mayer, 1969)		+	+
Spined loach *Cobitis taenia* (Linnaeus, 1758)	+	+	
Danube loach *Cobitis elongatoides* (Bacescu et Maier, 1969)		+	
Northern golden loach *Sabanejewia baltica* (Witkowski, 1994)		+	
Balkan golden loach *Sabanejewia balcanica (*Karaman, 1922)		+	
European weather loach *Misgurnus fossilis* (Linnaeus, 1758)	+	+	+
Ord. Siluriformes Fam. Siluridae			
Wels catfish *Silurus glanis* (Linnaeus, 1758 Somn)	+	+	+
Ord. Gadiformes Fam. Lotidae			
Burbot *Lota lota* (Linnaeus, 1758)	+	+	
Ord. Gasterosteiformes Fam. Gasterosteidae			
Ukrainian stickleback *Pungitius platygaster* (Kessler, 1859)	+	+	+
Three-spined stickleback *Gasterosteus aculeatus* (Linnaeus, 1758)	+	+	+
Ord. Sygnathiformes Fam. Sygnathidae			
Black-striped pipefish *Syngnathus abaster* (Risso, 1827)	+	+	+
Straightnose pipefish *Nerophis ophidion* (Linnaeus, 1758)	+		+
Broadnosed pipefish *Syngnathus typhle* (Linnaeus, 1758)	+		+
Ord. Atheriniformes Fam. Atherinidae			
Big-scale sand smelt *Atherina boyeri* (Risso, 1810)	+	+	+
Ord. Perciformes Fam. Percidae			
European perch *Perca fluviatilis* (Linnaeus, 1758 Biban)	+	+	+
Zander *Sander lucioperca* (Linnaeus, 1758)	+	+	+
Volga pikeperch *Sander volgensis* (Gmelin, 1789)	+		
Ruffe *Gymnocephalus cernuus* (Linnaeus, 1758)	+	+	
Donets ruffe *Gymnocephalus acerina* (Gmelin, 1789)	+	+	
Streber *Zingel streber* (Siebold, 1863)		+	+
Common zingel *Zingel zingel* (Linnaeus, 1766)	+	+	+
Common percarina *Percarina demidoffii* (Nordmann, 1840)	+		+
Fam. Gobiidae			
Kessler's goby *Neogobius kessleri* (Guenther, 1861)	+	+	+
Mushroom goby *Ponticola eurycephalus* (Kessler, 1874)		+	
Racer goby *Babka gymnotrachelus* (Kessler, 1857)	+	+	

Species	Before regulation, Dniester as a whole[a]	After regulation	
		Middle Dniester[b]	Lowlands and the estuary[c]
Round goby *Neogobius melanostomus* (Pallas, 1814)	+	+	+
Tubenose goby *Proterorhinus marmoratus* (Pallas, 1814)	+	+	+
Monkey goby *Neogobius fluviatilis* (Pallas, 1814)	+	+	+
Toad goby *Mesogobius batrachocephalus* (Pallas, 1814)	+	+	+
Grass goby *Zosterisessor ophiocephalus* (Pallas, 1814)	+		
Black goby *Gobius niger* (Linnaeus, 1758)			
Longtail dwarf goby *Knipowitschia longecaudata* (Kessler, 1877)			+
Brauner's tadpole-goby *Benthophiloides brauneri* (Beling & Iljin, 1927)		+	
Black Sea tadpole-goby *Benthophilus nudus* (Berg, 1898)		+	+
Stellate tadpole-goby *Benthophilus stellatus* (Sauvage, 1874)	+		+
Fam. Centrarchidae			
Pumpkinseed *Lepomis gibbosus* (Linnaeus, 1758)		+	+
Fam. Odontobutidae			
Chinese sleeper *Perccottus glenii* (Dybowski, 1877)		+	
Ord. Scorpaeniformes Fam. Cottidae			
European bullhead *Cottus gobio* (Linnaeus, 1758)	+	+	
Alpine bullhead *Cottus poecilopus* (Heckel, 1837)	+	+	
Ord. Mugiliformes Fam. Mugilidae			
Flathead grey mullet *Mugil cephalus* (Linnaeus, 1758)	+		
Leaping mullet *Liza saliens* (Risso, 1810)	+		
Golden grey mullet *Liza aurata* (Risso, 1810)			+
Redlip mullet *Lisa haematocheila* (Temminck & Schlegel, 1845)			+
Ord. Pleuronectiformes Fam. Pleuronectidae			
European flounder *Platichthys flesus* (Linnaeus, 1758)	+		+

a - According to Berg, 1949.
b - According to Bulat, 2017.
c - According to Snigirev, 2012.

ANNEX II. Water consumption in the Basin downstream of HPP-2 (mln m^3 per year)

Year	Water supply			Irrigation			Total water consumption		
	Total	Including		Total	Including		Total	Including	
		MOL[a]	UKR[b]		MOL[a]	UKR[b]		MOL[a]	UKR[b]
1965	**250**	150	100	**109**	89	20	**359**	239	120
1966	**260**	155	105	**118**	96	22	**378**	251	127
1967	**265**	160	105	**129**	104	25	**394**	264	130
1968	**279**	165	114	**140**	112	28	**419**	277	142
1969	**290**	172	118	**155**	120	35	**445**	292	153
1970	**305**	185	120	**168**	129	39	**473**	314	159
1971	**320**	195	125	**183**	139	44	**503**	334	169
1972	**338**	208	130	**196**	149	47	**534**	357	177
1973	**357**	222	135	**211**	160	51	**568**	382	186
1974	**374**	234	140	**229**	174	55	**603**	408	195
1975	**388**	246	142	**245**	187	58	**633**	433	200
1976	**405**	260	145	**263**	200	63	**668**	460	208
1977	**423**	275	148	**280**	212	68	**703**	487	216
1978	**440**	290	150	**299**	226	73	**739**	516	223
1979	**461**	306	155	**318**	240	78	**779**	546	233
1980	**481**	322	159	**336**	255	81	**817**	577	240
1981	**503**	338	165	**350**	265	85	**853**	603	250
1982	**521**	350	171	**369**	280	89	**890**	630	260
1983	**542**	365	177	**392**	298	94	**934**	663	271
1984	**562**	380	182	**423**	325	98	**985**	705	280
1985	**588**	400	188	**468**	367	101	**1056**	767	289
1986	**612**	418	194	**492**	387	105	**1104**	805	299
1987	**628**	430	198	**516**	408	108	**1144**	838	306
1988	**640**	440	200	**536**	426	110	**1176**	866	310
1989	**656**	451	205	**519**	409	110	**1175**	860	315
1990	**698**	488	210	**707**	587	120	**1405**	1075	330
1991	**675**	466	209	**349**	269	80	**1024**	735	289
1992	**673**	466	207	**576**	466	110	**1249**	932	317
1993	**613**	408	205	**461**	361	100	**1074**	769	305
1994	**583**	380	203	**588**	473	115	**1171**	853	318
1995	**575**	374	201	**362**	292	70	**937**	666	271
1996	**545**	346	199	**267**	207	60	**812**	553	259
1997	**514**	317	197	**137**	97	40	**651**	414	237
1998	**508**	313	195	**93**	63	30	**601**	376	225
1999	**434**	244	190	**81**	61	20	**515**	305	210
2000	**366**	206	160	**67**	48	19	**433**	254	179
2001	**338**	178	160	**59**	40	19	**397**	218	179
2002	**332**	172	160	**61**	42	19	**393**	214	179
2003	**327**	167	160	**64**	45	19	**391**	212	179
2004	**325**	165	160	**60**	41	19	**385**	206	179

Year	Water supply			Irrigation			Total water consumption		
	Total	Including		Total	Including		Total	Including	
		MOL[a]	UKR[b]		MOL[a]	UKR[b]		MOL[a]	UKR[b]
2005	**328**	168	160	**57**	38	19	**385**	206	179
2006	**330**	170	160	**56**	38	18	**386**	208	178
2007	**332**	172	160	**68**	50	18	**400**	222	178
2008	**332**	172	160	**59**	41	18	**391**	213	178
2009	**328**	168	160	**59**	41	18	**387**	209	178
2010	**325**	165	160	**59**	39	20	**384**	204	180
2011	**324**	164	160	**60**	40	20	**384**	204	180
2012	**324**	164	160	**59**	39	20	**383**	203	180
2013	**323**	163	160	**59**	39	20	**382**	202	180
2014	**319**	159	160	**59**	39	20	**378**	198	180
2015	**319**	159	160	**61**	39	22	**380**	198	182
2016	**320**	160	160	**61**	39	22	**381**	199	182
2017	**320**	160	160	**61**	39	22	**381**	199	182
2018[c]	**324**	164	160	**68**	43	25	**392**	207	185
2019[c]	**331**	168	163	**75**	45	30	**406**	213	193
2020[c]	**340**	172	168	**112**	72	40	**452**	244	208
2021[c]	**348**	176	172	**138**	88	50	**486**	264	222
2022[c]	**357**	180	177	**204**	144	60	**561**	324	237
2023[c]	**369**	184	185	**250**	180	70	**619**	364	255
2024[c]	**385**	188	197	**296**	216	80	**681**	404	277
2025[c]	**399**	192	207	**342**	252	90	**741**	444	297
2026[c]	**405**	196	209	**388**	288	100	**793**	484	309
2027[c]	**417**	205	212	**434**	324	110	**851**	529	322
2028[c]	**445**	230	215	**480**	360	120	**925**	590	335

a - Excluding return water consumption of CJSC “Moldavskaya GRES”.
b - Odessa region, excluding water consumption in the Vinnitsa and Cherkasy regions of Ukraine.
c - Expert assessment.

Data Sources: Water Use Report ...; Government of the Republic of Moldova, 2011; archives of the Ministry of Land Reclamation and Water Resources of the MSSR; Agency "Apele Moldovei"; Lower Dniester National Natural Park; Department of Water Resources of Odessa region; expert estimates and forecast (M.S. Penkov, A.N. Kalashnik).