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The comparison of possibilities for demolition or rehabilitation of hydraulic structures

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Abstract: Study on evaluation the technical state of dams, the impact on ichthyofauna, socioeconomic benefits, and the results of cost–benefit analyses was performed in 2021–2022. A list of dams whose demolition would improve the ecological state of rivers and have the least negative impact from a socioeconomic point of view was compiled. A more detailed analysis of demolition/reconstruction possibilities was performed for the 15 dams with the highest position in the list. Analysed under two scenarios. Scenario No. 1 – the pond is drained, the existing surplus water fall spillway is demolished, and part of the sludge accumulated in the pond is removed; compensatory measure – a bridge is installed at the culvert place and a small water pond (for recreation) is formed. Scenario No. 2 – the pond is not drained, the existing dam/ surplus water fall spillway is repaired, and a new fish pass is installed. A guide screen or fish barrier is installed. Costs for implementing scenario No. 2 were obtained higher than according to scenario No. 1 in 5 out of 15 investigated objects, while in the remaining 10 it was the opposite.

The total costs mainly depend on total area of ponds (important for calculation amount of sludge removal (for implementing scenario No. 1 and 2)), costs for demolition (scenario No. 1) or repairing of existing hydraulic structures (scenario No. 2) and costs for installing compensatory measures (scenario No. 1) or fish pass (scenario No. 2).

Keywords: demolition, ecological state of rivers, hydraulic structures, rehabilitation, repairing, technical state

INTRODUCTION

The International Commission on Large Dams database contains records of 58,700 registered dams (ICOLD, 2020). According to report (Perera *et al.*, 2021), the construction of large dams experienced a significant increase during the mid-20th century and reached its highest point during the 1960s and 1970s. This trend was particularly prominent in Asia, Europe, and North America. However, in Africa, the peak in large dam construction occurred in the 1980s.

At present there are more than 1,100 dams with the reservoir area larger than 0.5 ha constructed in Lithuania. The highest numbers of middle and small dams were constructed in Lithuania during the 1970s and 1985s – illustrated in Figure 1.

Following the liquidation of over 30,000 ha of irrigation systems in Lithuania, a number of reservoirs with their dams, no longer serve their original purpose. Currently, these reservoirs are utilised for fishing, recreation, and leisure activities. However, they are not adequately maintained, leading to accelerated wear and potential risks of accidents, failures (Foster *et al.*, 2000; FEMA, 2005; Zhang, Xu and Jia, 2009; Zhang *et al.*, 2016; ASDSO, 2021; Pearce, 2021; Perera *et al.*, 2021).

The technical state of earth dams (ED) in Lithuania is analysed in study of Šadzevičius, Damulevičius and Skominas (2013). According to the technical state investigation of 260 Lithuanian earth dams performed in 2002–2009 and comparing results of the ED state assessment obtained in 1997 it was found that ED state has worsened – in 1997 in unsatisfactory condition

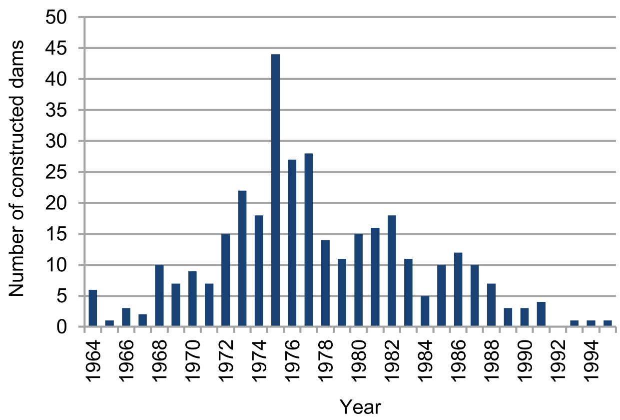

Fig. 1. The construction of middle and small dams in Lithuania; source: Damulevičius, Rimkus and Vyčius (2001)

were 16% of the total amount of investigated objects, and the 2002–2009 investigations showed that the number of objects in unsatisfactory and critical state increased up to 19% of the total amount of investigated objects.

The assessment of technical state of spillway concrete gravity dams (SCGD) in Lithuania is presented in paper by Šadzevičius, Skominas and Radzevičius (2021). The article presents the concrete structure deteriorations, defects and technical state evaluation results of 34 Lithuanian spillway concrete gravity dams performed in 2006–2018. According to results of technical state research, it was found that only 3% (1 SCGD) dams are in good technical state, 27% (9 SCGD) – moderate, 47% (16 SCGD) – satisfactory, 12% (4 SCGD) – unsatisfactory and 12% (4 SCGD) – in critical state.

For the safety of existing dams evaluation should be performed. Improvement of damaged (deteriorated) parts must be made or the deteriorated dam should be removed (ERN, 2018; Hepler, 2013; O'Connor, Duda and Grant, 2015; Ho *et al.*, 2017; Rewilding Europe, 2019; Graber *et al.*, no date; Pearce, 2021).

The number of barriers on rivers found in the "Amber barrier atlas" (Amber Consortium, 2021) in Lithuania is 1,257. The remainings of reinforced concrete spillway in Bražuolė dam, Lithuania were demolished in 2021 (LGF, 2020; DRE, 2021). The second demolished dam in Lithuania was Salantai dam (BNS, 2021). Ministry of the Environment of the Republic of Lithuania ordered the study (LRV.LT (2022). Study on evaluation the technical state of dams (Įsakymas, 2017), the impact on ichthyofauna (Garcia and Honey-Roses, 2014; Owusu, Mul and Slinger, 2020), socioeconomic benefits (Headwaters Economics, 2016; Tullos *et al.*, 2016), and the results of cost–benefit analyses was performed in 2021–2022. The method that is used to help to evaluate and use different and usually contradicting criteria is multi-criteria decision analysis (Kasiulis, Šadzevičius and Virbickas, 2022). A list of dams whose demolition would improve the ecological state of rivers and have the least negative impact from a socioeconomic point of view was compiled (LRV.LT, 2022).

In this article, the main attention focused on 15 dams with the highest position in the list. The task – to perform a more detailed analysis of demolition/reconstruction possibilities for selected 15 dams.

MATERIALS AND METHODS

Dams with the highest position in the list (LRV.LT, 2022) were selected for detailed analysis (Fig. 2).

All data on evaluation the technical state of dams, the impact on ichthyofauna, socioeconomic benefits, and the results of cost–benefit analyses are presented in study LRV.LT (2022). The explanation of demolition/reconstruction scenario for selected 15 dams.

- **Scenario No. 1**

The pond is drained, the existing surplus water fall spillway is demolished, and part of the sludge accumulated in the pond is

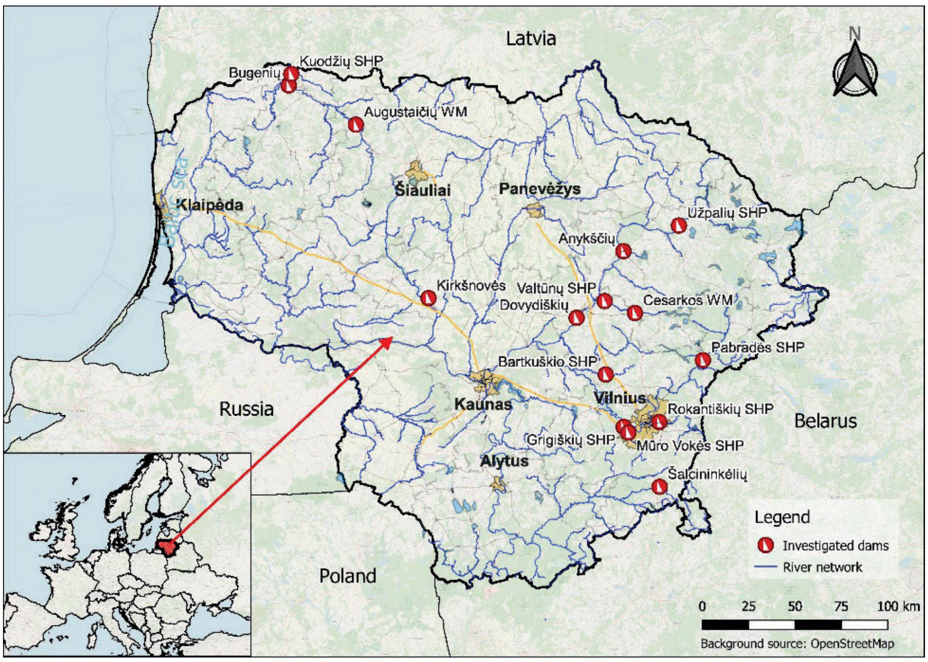

Fig. 2. The location of investigated dams in Lithuania; source: own elaboration

removed, another part will be removed during flood (MacBroom and Schiff, 2013; Rubin *et al.*, 2017). Compensatory measure – a bridge is installed at the culvert place and a small (0.4 or 0.8 ha) water pond (for recreation) is formed.

It is assumed that the sludge volume is calculated as a 0.3 m layer of sludge from half of the existing pond area (excluding the Augustaičiai and Cesarka hydroschemes).

Sludge removal costs (C_{1a}) were estimated acc. to Equation (1):

$$C_{1a} = V_{1a} \cdot c_{1a} \tag{1}$$

where: C_{1a} = costs of sludge removal (EUR), V_{1a} = volume of sludge (m^3), c_{1a} = unit cost of sludge removal, which is 10 EUR·m^{-3}.

Unit costs c_{1a} … c_{4a} and c_{1b} … c_{4b} are accepted from document (Įsakymas, 2020).

Demolition works are calculated and evaluated according to the calculated market prices of construction resources.

Demolition of reinforced structures costs (C_{2a}) were estimated acc. to Equation (2):

$$C_{2a} = V_{2a} \cdot c_{2a} \tag{2}$$

where: C_{2a} = costs of reinforced structures demolition (EUR), V_{2a} = volume of reinforced structures (m^3), c_{2a} = unit cost of demolition of reinforced concrete structures and removal of construction waste, which is 430.82 EUR·m^{-3}.

When preparing technical work projects for the reconstruction of hydroschemes (dams), it is necessary to assess the complexity of demolition works taking into account the local conditions – by assessing the complexity of the construction site (limited space, limited access, works above the river or under water, the possibility of waste storage, etc.). Some hydroschemes are in protected areas (regional park, Natura 2000 area, etc.) – various pollution restrictions could be applied, some construction time restrictions – fish spawning periods; some hydroschemes are located in the urban area or recreational area – restrictions on noise and pollution could be applied.

Compensatory measures: bridge – to ensure communication using road, which is currently built over the top of the existing earth dam, a girder-type reinforced concrete bridge is installed at the place of the former culvert. In cases where a spill-type excess water culvert is dismantled, it is accepted that 15% of the amount of construction waste will be used for the installation of new bridge on the dismantled parts of the spillway. A different construction of bridge may be selected during the preparation of the technical projects for hydroschemes reconstruction. The costs of new bridge construction (C_{3a}) are accepted 40,000 EUR (Įsakymas, 2020).

Water reservoir (for recreation) – for the installation of a small (0.4 ha; in the Pabradė hydroscheme – 0.8 ha) water reservoir, the earth works are planned – excavation and creating embankment. Earth works costs (C_{4a}) were estimated acc. to Equation (3):

$$C_{4a} = V_{4a} \cdot c_{4a} \tag{3}$$

where: C_{4a} = costs of earth works (EUR), V_{4a} = volume of earth works (m^3), c_{4a} = costs of earth works, which is 8.37 EUR·m^{-3}.

The culverts are planned to be installed in the inflow and outflow parts of the planned reservoir, and these parts must be additionally reinforced. The size, shape and location of the reservoir may change after discussion and coordination with the local community.

Total cost of demolition/reconstruction scenario No. 1 (C_a) were estimated as below formula:

$$C_a = C_{1a} + C_{2a} + C_{3a} + C_{4a} + C_{ad} \tag{4}$$

where: C_{ad} = additional costs (EUR).

- **Scenario No. 2**

The pond is not drained, sludge from the entire area of the pond is removed, the existing dam/ surplus water fall spillway is repaired, and a new fish pass (Įsakymas, 2007) is installed (except for Augustaičiai and Cesarka hydroschemes), a guide screen or fish barrier is installed (in Anykščiai, Bartkuškis, Grigiškės, Pabradė, Rokantiškės, Šalčininkėliai, Užpaliai hydroschemes).

Sludge removal – it is assumed that the volume of sludge is calculated as a layer of 0.3 m of sludge in the entire area of the pond (except for Augustaičiai and Cesarka hydroschemes).

Sludge removal costs (C_{1b}) were estimated acc. to Equation (5):

$$C_{1b} = V_{1b} \cdot c_{1b} \tag{5}$$

where: C_{1b} = costs of sludge removal (EUR), V_{1b} = volume of sludge (m^3), c_{1b} = unit sludge removal costs, which are accepted at 10 EUR·m^{-3}.

Repair of reinforced structures costs (C_{2b}) were estimated acc. to Equation (6):

$$C_{2b} = V_2 \cdot 2\% \cdot c_{2b} \tag{6}$$

where: C_{2b} = costs of repair reinforced structures (EUR), V_2 = volume of reinforced structures (m^3), c_{2b} = unit cost of repair reinforced structures, which is 510.0 EUR·m^{-3}.

The costs of installing a fish pass are accepted based on the costs of installing fish passes built by the Fisheries Service. The construction price c_{3b} is accepted in the case of a fish pass width of up to 1.2 m.

The costs of installing a fish pass (C_{3b}) were estimated acc. to Equation (7):

$$C_{3b} = L \cdot c_{3b} \tag{7}$$

where: C_{3b} = costs of installing a fish pass (EUR), L = length of fish pass (m), c_{3b}= unit cost of installing a fish pass, which is 4,500 EUR·m^{-1}.

Notes: in cases where a fish pass is currently installed, the costs of its reconstruction/modernisation (usually measures for downstream fish migration), including the costs of installing a guide screen or fish barrier, assumed to be equal to 10–25% of the costs of installing a new fish pass. The stone stacks are installed instead of fish passes at the Augustaičiai and Cesarka hydroschemes.

The construction costs of the new bridge over the fish pass (C_{4b}) (in those hydroschemes where it is needed) are accepted 10,000–20,000 EUR (Įsakymas, 2020).

Total cost of demolition/reconstruction scenario No. 2 were estimated as below formula:

$$C_b = C_{1b} + C_{2b} + C_{3b} + C_{4b} + C_{ad} \quad (8)$$

Additional costs (C_{ad}) in scenarios No. 1 and 2 are assessed:
– the cost of the environmental impact assessment procedure of the planned economic activity;
– percentage rates (7% from the estimated construction total cost) for the preparation of project proposals, structural design works, supervision services ofproject execution (Įsakymas, 2020).

RESULTS AND DISCUSSION

Dovydiškiai dam (hydroscheme) was selected for illustration of 15 dams demolition/reconstruction possibilities. Dovydiškiai pond with dam (hydroscheme) before demolition/reconstruction (scenario No. 0) is shown in Figure 3.

The results of scenario No. 1 are presented in Figure 4: the pond is drained, the embankment of the existing earth dam is not demolished, the structure of the culvert is changed – instead of the shaft-type excess water culvert, a bridge is installed. Compensatory measure – a bridge is installed at the culvert place and a small (0.4 ha) water pond (for recreation) is formed.

Fig. 3. The visualisation of the Armona River ecological integrity restoration scenario No. 0 at the Dovydiškiai dam; source: own study

Fig. 4. The visualisation of the Armona River ecological integrity restoration scenario No. 1 at the Dovydiškiai dam; source: own study

The results of scenario No. 2 are presented in Figure 5: the pond is not drained, the existing dam and surplus water fall spillway are repaired, the new fish pass with guide screen are installed.

The cost of demolition/reconstruction possibilities for selected 15 dams are presented in Table 1.

According to results presented in Table 1 river ecological integrity restoration scenario No. 1 requires compensatory

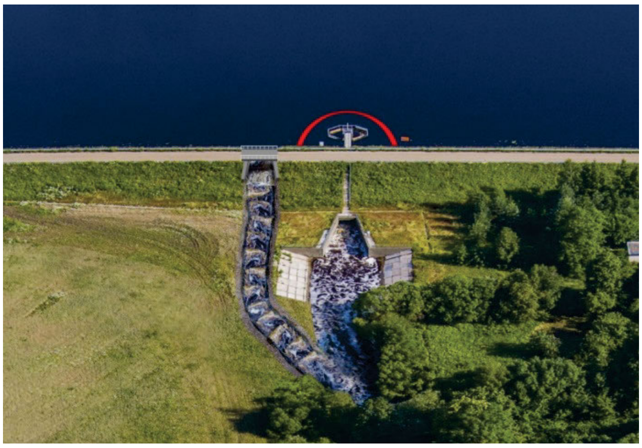

Fig. 5. The visualisation of the Armona River ecological integrity restoration scenario No. 2 at the Dovydiškiai dam; source: own study

Table 1. The cost of demolition/reconstruction possibilities (all costs are presented in EUR)

Dam (hydro-scheme)	River ecological integrity restoration scenario No. 1				River ecological integrity restoration scenario No. 2			
	demolition of the existing surplus water fall spillway C_{I1}	compensatory measures: Bridge (B), Water reservoir (WR) C_{I2}	removing part of the sludge accumulated in the pond C_{I3}	total costs (including additional costs) C_{T1}	installation/ modernis ation (M) of the fish pass C_{II1}	repairing of existing dam/surplus water fall spillway C_{II2}	removing sludge from the entire area of the pond C_{II3}	total costs (including additional costs) C_{TII}
Anykščiai	590,900	91,700 (B)	351,000	**1,088,200**	46,500	68,400	702,000	**826,100**
Augustaičiai WM	3,700	–	0	**4,000**	–	3,300	0	**3,600**
Bartkuškis SHP	446,100	60,000 (B) + 125,600 (WR)	789,000	**1,471,200**	498,200	150,000	1,578,000	**2,278,100**
Bugeniai WM	123,700	60,000 (B) + 125,600 (WR)	49,500	**383,500**	243,000	25,200	0	**289,700**

cont. Tab. 1

Dam (hydro-scheme)	River ecological integrity restoration scenario No. 1				River ecological integrity restoration scenario No. 2			
	demolition of the existing surplus water fall spillway C_{I1}	compensatory measures: Bridge (B), Water reservoir (WR) C_{I2}	removing part of the sludge accumulated in the pond C_{I3}	total costs (including additional costs) C_{T1}	installation/ modernis ation (M) of the fish pass C_{II1}	repairing of existing dam/surplus water fall spillway C_{II2}	removing sludge from the entire area of the pond C_{II3}	total costs (including additional costs) C_{TII}
Cesarka WM	7,500	60,000 (B)	0	**72,900**	–	75,000	0	**81,000**
Dovydiškiai SHP	191,300	60,000 (B) + 125,600 (WR)	399,000	**806,100**	461,700	1,400	0	**500,100**
Grigiškės SHP	247,500	43,700 (B) + 125,600 (WR)	135,000	**585,100**	364,500	79,600	270,000	**749,600**
Kirkšnovė	82,200	60,000 (B)+ 125,600 (WR)	54,000	**343,200**	243,000	50,500	0	**317,000**
Kuodžiai SHP	1,294,400	–	465,000	**1,863,000**	48,000 (M)	27,400	0	**81,400**
Mūro Vokė SHP	428,100	75,500 (B) + 125,600 (WR)	159,000	**838,500**	243,000	15,300	0	**279,000**
Pabradė SHP	857,400	15,000 (B) + 165,550 (WR)	466,500	**1,679,900**	364,500	27,500	933,000	**1,356,400**
Rokantiškės SHP	327,900	57,900 (B) + 125,600 (WR)	108,000	**660,300**	24,300 (M)	23,000	216,000	**267,100**
Šalčininkėliai	41,600	150,000 (B) + 125,600 (WR)	265,500	**608,100**	364,500	44,400	531,000	**972,600**
Užpaliai SHP	376,700	–	385,500	**792,300**	48,600 (M)	27,400	771,000	**853,100**
Valtūnai SHP	872,400	125,600 (WR)	48,000	**1,125,800**	24,300 (M)	48,900	0	**105,300**

Explanations: WM = watermill, SHP = small hydropower plant, M = modernisation of fish pass. Total costs (scenario I) $C_{T1} = C_{I1} + C_{I2} + C_{I3}$, total costs (scenario II) $C_{TI1} = C_{II1} + C_{II2} + C_{II3}$.
Source: own study.

measures – bridge or water reservoir in 12 of investigated 15 dams. The highest costs for compensatory measures are in Šalčininkėliai dam – 275,600 EUR. Removing part of the sludge accumulated in the Bartkuškis pond has highest costs of investigated objects – 789,000 EUR. The cheapest demolition of the existing surplus water fall spillway is in Augustaičiai watermill – to remove remainings of dam costs 3,700 EUR. Total costs of implementing scenario No. 1 are highest in Kuodžiai SHP (1,863,000 EUR), next in Pabradė SHP (1,679,900 Eur), Bartkuškis SHP (1,471,200 EUR), Valtūnai HPP (1,125,800 EUR), and in Anykščiai (1,088,200 EUR). The cheapest costs – Augustaičiai WM (4,000 EUR) and Cesarka WM (72,900 EUR).

According to results presented in Table 1 river ecological integrity restoration scenario No. 2 the modernisation of existing fish passes should be done in Kuodžiai SHP (48,000 EUR), Užpaliai HPP (48,600 EUR), Rokantiškės SHP (24,300 EUR) and Valtūnai HPP (24,300 EUR). The stone stacks are installed instead of fish passes at the Augustaičiai and Cesarka hydro-schemes. The cheapest repairing of existing dam / surplus water fall spillway are in Dovydiškiai HPP (1,400 EUR), a bit higher in Augustaičiai WM (3,300 EUR), the most expensive reconstruction is in Bartkuškis SHP (150,000 EUR). Removing sludge from the entire area of the pond should be done in 7 from 15 of investigated 15 ponds. Total costs of implementing scenario No. 2 are highest in Bartkuškis SHP (2,278,100 EUR), next in Pabradė SHP (1,356,400 Eur), Šalčininkėliai (972,600 EUR), and Užpaliai SHP (853,100 EUR). The cheapest costs is in Augustaičiai WM (3,600 EUR), next in Cesarka WM (81,000 EUR) and Kuodžiai SHP (81,400 EUR).

CONCLUSIONS

Total costs of implementing river ecological integrity restoration scenario No. 1 (the pond is drained, the existing surplus water fall spillway is demolished, and part of the sludge accumulated in the pond is removed, another part will be removed during flood. Compensatory measure – a bridge is installed at the culvert place and a small (0.4 or 0.8 ha) water pond (for recreation) is formed are highest (>1,000,000 EUR) in these hydroschemes: Kuodžiai, Anykščiai, Pabradė, Bartkuškis, Valtūnai. The cheapest costs in these watermills – Augustaičiai and Cesarka.

Total costs of implementing river ecological integrity restoration scenario No. 2 (the pond is not drained, sludge from the entire area of the pond is removed, the existing dam / surplus water fall spillway is repaired, and a new fish pass is installed or modernised – a guide screen or fish barrier is installed) are highest in Bartkuškis, Pabradė, Šalčininkėliai and Užpaliai hydroschemes. The cheapest costs are in Augustaičiai, Cesarka and Kuodžiai hydroschemes.

The total costs mainly depend on total area of ponds (important for calculation amount of sludge removal), costs for demolition or repairing of existing hydraulic structures and costs for installing compensatory measures.

CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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