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**D** – data interpretation
**E** – manuscript preparation
**F** – literature search

# Evaluation of the possibilities of using water-damming devices on the Tyśmienica River to build small hydropower plants

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## Abstract

Hydropower plants in Poland currently use only 19% of the river's energy potential. Development of hydropower is limited by environmental regulations as well as by economic grounds. From the environmental point of view, it is desirable to build small hydropower plants integrated into the local landscape. This paper presents results of the research aimed at estimating the amount of energy that could be produced in the case of small hydroelectric power plants on weirs existing on the Tyśmienica River. There is also a legal framework that should be adapted at hydropower development. It was calculated that the technical capacity of the small hydropower plants that could be built on 4 existing weirs, is 0.131 MW. These power plants could produce 786 MWh of electricity per year. The economic efficiency of this production is currently difficult to assess, because a new support system for renewable energy sources is currently being implemented, which will be a decisive factor for entrepreneurs. It should be borne in mind that potential investments will be made in protected areas within the Natura 2000 network, which may limit their constructing or impose the obligation to assess their impact on selected environmental elements. Location within the protective area does not eliminate such investments, especially when solutions with the least possible environmental impact are used.

**Key words:** *alternative energy sources, ecoenergetics, hydropower, small hydropower plants, water-damming devices*

## INTRODUCTION

For years, hydroelectric power plants have been used as a source of renewable energy in the world. In 2014, they delivered a total of around 3884 TWh of electricity, representing 16.5% of global electricity production. Power of the largest hydroelectric power plants to be built exceeds 10 GW. Countries such as Norway, Democratic Republic of Congo, Paraguay, and Brazil have more than 85% of their electricity from hydropower. In 65 countries, hydropower accounts for more than 50% of national energy production. Electricity produced in hydroelectric power plants is a pure energy, because it is to mention that as much as 1595 million tons of coal would be used to produce the same amount of energy in conventional power plants [KOCH 2002]. The increase in the use of renewable energy, recommended by the European Union, and justified due to economic and environmental reasons, encourages, among others, the use of hydropower [BEŁEJ, OSTROWSKA 2007; JAROSIEWICZ, TOCZKO 2006; KAMIŃSKI, WÓJCIK-JACKOWSKI 2011]. Although the largest hydropower development in many European countries took place many years ago, it is still an active branch of the energy industry. This is due to both the construction of new hydroelectric power plants as well as the renewal and modernization of older, small hydropower facilities (Pol. małe elektrownie wodne –MEWs) with capacities from 0.1 to 10 MW.

Poland does not have good conditions for hydropower development due to low and unevenly distributed precipitation and high soil permeability [KUŁAGOWSKI 2001]. However, a major problem limiting the development of hydroelectricity in Poland (especially large hydroelectric power plants) is the hydrographic system of the country, in which lowland rivers in small inclination areas prevail, which makes it impossible to obtain large damming. Also, the potential of water and energy resources is unevenly spread across the country. Approximately 80% of it occurs in the Vistula catchment area, and only 18% in the Odra and Warta River catchments [TOKARZ 2016]. Apart from the Vistula River, mountains and foothills, the remaining hydroelectric resources of Polish Rivers are more likely to be used locally in a form of small hydropower plants.

Despite such unfavourable conditions, theoretical hydropower resources in Poland, under conditions of medium hydrological year, are estimated at around 23 TWh (equivalent to 2700 MW), and technically feasible for about 12 TWh, while the economic resources for about 8 TWh. Theoretically, the hydropower sector would cover about 8% of the country's energy needs [GAJDA 2006; MIKULSKI 1998]. However, in 2014, hydropower was responsible for only 1.4% of electricity production (2.2 TWh) produced in 771 hydroelectric power plants, including 743 MEWs with a total capacity of 977 MW [URE 2015]. It is estimated that hydropower plants currently use only 19% of the national rivers energy potential, which puts Poland at one of the last places in Europe [MALICKA 2013].

The Lublin province, the surface water resources are among the smallest in Poland (total outflow from the Lublin region is 2565.0 $hm^3$) looks very weak against the background of the country in terms of hydroelectricity [PICHLA, JAKIMIUK 2014]. The share of the province in the installed capacity of hydroelectric power plants and in the production of energy from water resources in the country is small, as are the theoretical and technical resources of Lublin province, which constitute about 0.6% of the country resources [BPP 2012]. The capacity of hydroelectric power plants is between a dozen and several hundred kilowatts. MEWs are usually located in areas of existing damming facilities that are used for retention, drainage or fish ponds. They are also often located in places, where water mills once existed. Despite the lack of cost-effective construction of new damming devices for the production of electricity on an industrial scale (5 MW minimum), the use of water resources in the Lublin province can be a significant renewable energy source on a local scale. Therefore, it is necessary to look for all possibilities of building small hydropower plants on the rivers of Lublin region using existing dams. The small degree of the Lublin province hydroelectric potential utilization is not only due to the technical conditions, but also to the increasingly widespread environmental problems posed by the construction and operation of hydroelectric power plants. From the investor's point of view, economic aspects which are not favourable in the short term, are equally important and the long-term perspective is difficult to predict due to the instability of Polish law. This paper is an analysis of the technical capacity of the energy management of existing damming constructions on the Tyśmienica River and the environmental and legal conditions for the possible construction of small hydroelectric plants in these locations.

## HYDROGRAPHIC CHARACTERISTICS

The study was carried out on the Tyśmienica River, which is the largest right-bank tributary of the Wieprz River with its mouth at 241.2 km run. The Tyśmienica River catchment covering an area of 2688.6 $km^2$, belongs to two geographic regions – Polesie Lubelskie and Nizina Mazowiecka. The river, which is 75 km long, originally came from Lake Krzczeń. In the 1960s, the water channel that formed the beginning of the Tyśmienica River was led away from the east of Lake Krzczeń. As a result of hydrotechnical work, the beginning of the river was moved to Lake Rogóźno [GRZYWNA, MAZUR 2014]. The river flows here in a poorly-landscaped valley, with a 3 km wide bottom cut by numerous drainage ditches. Below Bójki village and above Siemień village, the bottom of the valley is occupied by complexes of fish ponds. Two fish farms are producing fish here: "Tyśmienica" on the area of 239.4 ha and "Siemień" on the area of 731 ha. In the vicinity of Siemień village, the average flow of Tyśmienica River is 3.8 $m^3 \cdot s^{-1}$. Next, the river flows through the valley of about 2 km wide and between 26.8 and 20.7 km of its runway, Tyśmienica River turns a big bow, changing direction from NNW to SW. In the middle and lower sections, the river was straightened and shortened by cutting down the meanders, thus the river was regulated along its entire length. Tyśmienica River goes Wieprz River at 131.7 m a.s.l. Its mean bottom fall is 0.48‰ and average flow is 8.6 $m^3 \cdot s^{-1}$ [MICHALCZYK, WILGAT 1998; WILGAT 1998].

The Tyśmienica River valley is characterized by high natural virtues, primarily because of ornithological values. There are two bird sanctuaries that are part

**Table 1.** Technical characteristics of water constructions

| Type of construction | Kilometer of the river | Locality | Light, m | Damming, m | Barrage, m | Use |
|---|---|---|---|---|---|---|
| Weir | 37+540 | Glinny Stok | 2 × 4 | 2.00 | – | fish ponds |
| Weir | 41+560 | Siemień | 2 × 4 | 2.50 | – | fish ponds |
| Weir | 42+400 | Gródek | 1 × 4 | 2.45 | – | fish ponds |
| Weir | 52+000 | Bójki | 1 × 4 | 1.90 | – | fish ponds |
| Threshold | 53+340 | Ostrów Lubelski | 3.0 | – | 0.40 | fall reduction |
| Weir | 60+280 | Kolechowice | – | 1.16 | – | irrigation |
| Threshold | 60+670 | Kolechowice | 2.0 | – | 0.40 | fall reduction |
| Threshold | 60+820 | Kolechowice | 2.0 | – | 0.50 | fall reduction |
| Threshold | 61+220 | Kolechowice | 2.0 | – | 0.30 | fall reduction |
| Weir | 63+570 | Krasne–Rozkopaczew | 2 × 2.9 | 2.35 | – | irrigation |
| Barrage | 67+300 | Krzczeń | – | – | 0.60 | fall reduction |
| Barrage | 71+500 | Rogóźno | – | – | 0.60 | fall reduction |
| Valve | 72+000 | Rogóźno | – | 1.50 | – | irrigation |
| Valve | 74+120 | Rogóźno | – | 1.40 | – | irrigation |

Source: own study based on Voivodship Board of Land Reclamation and Water Equipment in Lublin data [WZMiUW 2008].

Photo 1. View of the multi-chamber weir in Glinny Stok village (phot. A. Mazur)

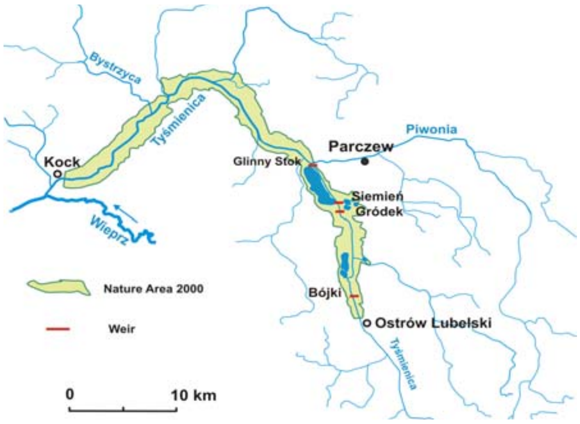


Fig. 1. Location of the damming structures on Tyśmienica River, where construction of small hydroelectric power plants is possible; source: own elaboration

of the Natura 2000 network. They covered a part of the Tyśmienica River valley between Ostrów Lubelski and Kock. There were 25 bird species listed in Annex I of the Birds Directive [Council Directive 2009/147/EC], including 11 from the Polish Red Book [GŁOWACIŃSKI (ed.) 2001]. In addition, there is an exceptionally varied landscape, rich vegetation and numerous spots of protected and rare plant species [Instytut… undated]. Agricultural use dominates in the catchment area: mainly grassland; the area is not urbanized (no towns). The town of Kock (about 3,500 inhabitants) is located about 5 km from the mouth of the river.

Based on the planning data of the Voivodship Board of Land Reclamation and Water Equipment in Lublin (Pol. Wojewódzki Zarząd Melioracji i Urządzeń Wodnych) [WZMiUW 2008], Table 1 presents basic technical parameters of water structures located on the Tyśmienica River. They include: 6 multi-chamber weirs (Photo 1), 6 concrete barrages and thresholds and 2 swords. Due to the hydrological conditions, i.e. flow of water above 1 $m^3 \cdot s^{-1}$, only structures situated in the middle section of the river can be used for the location of small hydropower plants (Fig. 1).

## ENERGY SPECIFICATION

For calculating the power potential of hydroelectric power plants that could be built on the damming facilities, following formula was used [KAROLEWSKI, LIGOCKI 2004]:

$$P = \gamma \cdot g \cdot Q \cdot h \qquad (1)$$

where: $P$ = energy potential, W; $\gamma$ = specific gravity of water, $\gamma$ = 1000 $kg \cdot m^{-3}$; $g$ = acceleration of the Earth; $g$ = 9.81 $m \cdot s^{-2}$; $Q$ = flow rate, $m^3 \cdot s^{-1}$; $h$ = water fall, m.

The theoretical power of each power plant was calculated on the basis of average flow across the river and the dam height (based on data obtained from the Voivodship Board of Land Reclamation and Water Equipment in Lublin), assuming construction work throughout the year. The technical capacity of the power plant was calculated on the basis of the reliable flow, taking into account the system efficiency factor. Measured flow was assumed to be 90% of average flow. The efficiency factor of small hydropower plants, for technically more advanced, is in the range of 0.86–0.90 [LEWANDOWSKI 2007]. The average value of 0.88 was accepted for computations. To calculate the potential amount of energy that can be obtained at a given hydroelectric facility, the actual operating time of the power plant should be taken into account. It depends on the location of the building, its use for other purposes, and the conditions of the water flow taking into account the inviolable flow [BUKOWSKI 2013; MIODUSZEWSKI 2012; 2014; WITOWSKI *et al*. 2001]. The working time of the power plant has been adopted for 250 days due to: the need to fill fish ponds, the location of damming structures in the vicinity of meadow complexes, the need for maintenance, the possibility of ice phenomena.

Table 2 shows the characteristics of parameters for small hydropower plants that can be implemented on the studied river.

**Table 2.** Hydropower characteristics of the structures

| Kilometer of the river | Flow rate $m^3 \cdot s^{-1}$ | | Potential of power kW | | Operating time of the power plant $days \cdot year^{-1}$ | Technical potential of energy $MWh \cdot year^{-1}$ |
|---|---|---|---|---|---|---|
| | average | reliable | theoretical | technical | | |
| 37+540 | 2.00 | 1.80 | 39.2 | 34.5 | 250 | 207.2 |
| 41+560 | 1.80 | 1.62 | 44.1 | 38.8 | 250 | 233.1 |
| 42+400 | 1.75 | 1.58 | 42.1 | 37.0 | 250 | 222.1 |
| 52+000 | 1.25 | 1.10 | 23.3 | 20.5 | 250 | 123.0 |

Source: own study.

According to planning documents, the technical capacity of Tyśmienica River is 0.13 MW, while technical annual energy potential is 1.14 GWh [BPP 2012]. The own calculations point to a smaller (by about 31%) potential for power production with approximately the same technical power potential (0.131 MW). This difference is due to the fact that in our analysis it was assumed that the overriding function of weirs is their use for fish farming and agriculture, and therefore the operating time of the power plant will be limited by the environment. Construction of small hydroelectric power plants on four selected weirs on Tyśmienica River could allow to produce about 0.785 GWh of electricity per year. This amount does not seem big, but given the fact that in Lublin province the total electricity production in hydropower plants is 5.3 $GWh \cdot year^{-1}$, Tyśmienica River could supply about 15% of the hydropower produced in the whole region.

## ECONOMIC AND LEGAL CONDITIONS

In a paper prepared by the Provincial Spatial Planning Office in Lublin (Pol. Biuro Planowania Przestrzennego) [BPP 2012], it was estimated that documented technical resources are equal to economically justified resources for Tyśmienica River. It should be noted, however, that this assessment was made several years ago. At that time, production of renewable energy was backed by "green certificates", i.e. certificates of origin of energy from renewable sources. These are transferable securities, the price of which has drastically declined in recent years. This has caused financial problems for many renewable energy producers and has contributed to speeding up the work on changing the support system. In 2016, a new support system for renewable energy production was introduced in Poland, which could significantly affect the economic performance of hydroelectric power plants. The existing "green certificates" system will be supplemented by an auction system of energy sales [PRZYBYLSKA-CZĄSTKIEWICZ 2016].

Energy producers who win at auction will be able to sell energy at a guaranteed price for a period of 15 years. These prices for hydroelectricity depend on the size of the installation. The most favourable guaranteed prices are provided for supporting micro-installations. For hydropower up to 3 kW, the price is 0.75 PLN per 1 kWh and for hydropower over 3 kW to 10 kW – 0.65 $PLN \cdot kWh^{-1}$. The first auction for small hydropower plants took place on the 30th December 2016. Unfortunately, technical problems caused the auction did not run properly [MALICKA 2017]. The failure of the first auction resulted not only from the poor functioning of the auction platform. Many users of small hydropower plants have decided not to enter the auction due to the strict rules of power supply by the manufacturers under the new system. The biggest concern is the obligation to return all public aid obtained in the auction by the manufacturer, who has not obtained a certain degree of power utilization, i.e. he did not produce the assumed volume of energy in the given period. More than two thirds of existing hydroelectric facilities in dry years do not meet the required criterion due to low water levels in rivers. These are natural factors, independent of energy producers, but for which they will bear the consequences. It would be risky for them to enter the auction because of extremely strict sanction for not using the power. Penalties include the return of public aid received plus interest. The power utilization rate is verified every year, thus the producer can be punished at various stages of operation of the plant for an independent event. The new support system has not yet been fully implemented, so it is difficult to assess its impact on the economic efficiency of hydroelectricity.

When assessing the rationality of building a small hydropower plant, consideration should be given not only to economic but also to legal aspects. Provisions of some laws and regulations may make the construction of a hydroelectric plant in some locations difficult to perform for formal reasons, or even impossible. Construction of each hydroelectric plant, regardless of its size, causes changes in the environment and their nature, scope and permanence depend primarily on the size of the hydroelectric facility and technological solutions. The environmental impact of the plant is the basis of many provisions of the Water Law Act [Ustawa… 2001a], Environmental Protection Law [Ustawa… 2001b], Act on the provision of information on the environment and its protection, public participation in environmental protection and on environmental impact assessments [Ustawa… 2008], and many others.

As part of the investment in hydroelectricity, it is mandatory to obtain a water environment permit because, according to the Environmental Protection Act of 27 April 2001 [Ustawa... 2016], such a decision takes place before obtaining a water permit. Article 81 of the Act explicitly states that the detailed rules for water protection are laid down in the Water Law Act, and the authorities are planning and implementing measures to protect water quality. Environmental impact assessment (EIA) is carried out in the environmental decision-making procedure. The EIA procedure is regulated by the Act of 3 October 2008 on the provision of information on the environment and its protection, public participation in environmental protection and on environmental impact assessments. In the decree of the Council of Ministers of 9 November 2004 on the definition of types of undertakings that may have significant effects on the environment and detailed conditions related to the eligibility of a project to prepare an environmental impact report [Rozporządzenie RM… 2004], the categories of investments covered by these requirements are specified. For hydropower plants with a capacity of not less than 2.5 MW, the EIA procedure will be mandatory. On the other hand, in the case of MEW with a capacity of less than 2.5 MW, the competent authority, i.e. the mayor, the mayor, in agreement with Regional Directorate for Environmental Protection (Pol. Regionalna Dyrekcja Ochrony Środowiska – RDOŚ), shall issue a decision on lack of obligation or obligation to carry out the EIA.

The potential location of small hydropower plants on Tyśmienica River is within the Natura 2000 network. A site assessment is required for the construction of hydroelectric power plants in protected areas, which is the assessment of the impact of the investment on the Natura 2000 ecosystem. Habitat assessment, also known as project Natura 2000 impact assessment is carried out as an integral part of the environmental impact assessment or as a separate document. Decision to conduct an assessment of the impact on the Natura 2000 site is issued by the Regional Directorate for Environmental Protection when it considers that the project can have a significant impact on the Natura 2000 area. If RDOŚ finds that the investment will not significantly affect the site, there is no need for an environmental impact assessment.

Even in the absence of a significant impact of small hydropower plants on the environment, it is rational to use technologies that are less environmentally-dama-ging. A modern, inexpensive solution in the form of an Archimedes turbine – a water turbine, deserves special mention. This installation was implemented on the tributary of Tyśmienica – Bystrzyca Północna River (Photo 2) [MAZUR *et al*. 2016; WHEATON-GREEN 2016].

Photo 2. View of a hydroelectric plant built in 2016 in Tchórzew on Bystrzyca Północna River (phot. A. Mazur)

## CONCLUSIONS

The technical capacity of small hydropower plants that could be built on the 4 weirs existing on Tyśmie-nica River is 0.131 MW. These power plants could produce 786 MWh of electricity per year. It is difficult to assess the economic effectiveness of this production at present, as currently a new support system for renewable energy is being implemented in Poland, in the form of an auction system. The economic result will be the most important factor for investment decision making by entrepreneurs. Formal and legal requirements of the investment are also important. The tested weirs are located in protected areas within the Natura 2000 network, which may limit their construction. The obligation to carry out an environmental impact or Natura 2000 network impact assessment is subject to certain costs, more stringent requirements and a complex procedure. However, location of a small hydropower plant in the area covered by some forms of protection is possible, especially in the case of solutions with the least possible environmental impact.

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## Ocena możliwości wykorzystania urządzeń piętrzących wodę na rzece Tyśmienicy do budowy małych elektrowni wodnych

STRESZCZENIE

Elektrownie wodne w Polsce wykorzystują obecnie zaledwie 19% potencjału energetycznego rzek. Rozwój hydroenergetyki ograniczany jest przez przepisy związane z ochroną środowiska, a także przez uwarunkowania ekonomiczne. Ze środowiskowego punktu widzenia najbardziej pożądana jest budowa małych elektrowni wodnych, wkomponowanych w lokalny krajobraz. Niniejsza praca prezentuje wyniki badań, których celem było oszacowanie ilości energii, możliwej do wyprodukowania w przypadku budowy małych elektrowni wodnych na jazach, istniejących na rzece Tyśmienicy. Wskazano też ramy prawne, do których należy się dostosować w razie hydroenergetycznego zagospodarowania budowli. Obliczono, że potencjał techniczny mocy małych elektrowni wodnych, które mogłyby powstać na 4 istniejących jazach, wynosi 0,131 MW. Elektrownie te mogłyby produkować 786 MWh energii elektrycznej rocznie. Efektywność ekonomiczną tej produkcji trudno obecnie ocenić, ponieważ aktualnie wdrażany jest nowy system wsparcia odnawialnych źródeł energii, który będzie decydującym czynnikiem dla przedsiębiorców. Należy mieć na uwadze, że potencjalne inwestycje znajdą się na terenie objętym ochroną w ramach sieci Natura 2000, co może ograniczać ich wznoszenie lub nakładać obowiązek przeprowadzania oceny oddziaływania na wybrane elementy środowiska. Położenie w obszarze ochronnym nie eliminuje takich lokalizacji, zwłaszcza w przypadku zastosowania rozwiązań o możliwie małym wpływie na środowisko.

**Słowa kluczowe:** *alternatywne źródła energii, ekoenergetyka, hydroenergetyka, małe elektrownie wodne, urządzenia piętrzące wodę*