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PROGRAM OF HYDROPOWER POTENTIAL ASSESSMENT AS AN EFFECTIVE POSSIBILITIES IN UPPER VISTULA WATER REGION IN POLAND

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ABSTRACT

Assessment of hydropower potential is the most important part of renewable sources balances. Quantification of the feasibility of hydropower plants realization is essential for estimating production of these kind of renewable energy sources. The quantitative assessment is most often based only of theoretical, technical and economic potential, which does not compare with real potential allowed to get from the river. The main scope of the paper is to show the course of action to estimate the effective potential of hydropower.

Estimating the effective potential was done by research of actual legal procedures which allow the small hydropower plants realizations. The Upper Vistula water region in South Poland has been selected as an example area because of the highly recognized procedural conditions and many years' experiences of the author. However the presented course of the analysis seems to be universal for investments in other regions in Poland and also in the other countries. The study case showing the main course, calculations and results of theoretical, technical and proposed effective potential of hydropower was based on Szreniawa river as an example.

The resulting "effective potential of hydropower" provides the actual view on the hydropower generation capacity of the river and brings the actual values in prognosis and other computational appraisal. The comparison of results shown a very low value of actual potential with real possibilities of small hydropower plant realizations. The quantitative assessment based only of theoretical and technical potential of hydropower provides the overoptimistic results.

Keywords: effective potential of hydropower, technical potential, theoretical potential, hydropower potential, renewable energy sources, hydropower plant

INTRODUCTION

Acquiring energy from renewable sources constitutes currently one of the major challenges of mankind in the aspect of preventing unfavourable environmental changes in both local and global scale. Drafting up numerical summaries in the scope of the actual production of electricity from the functioning HPPs does not pose difficulties. On the other hand, numerical estimate of HP potential is difficult and often leads to ambiguous results, estimated unduly optimistically. Numerical analysis usually includes provision of the values of theoretical (Prajapati, 2015; Folvarcny et al., 2012; Rourke et al., 2010; Zhou et al., 2010; Larentis et al., 2010; Winkler, 2005), technical and economic potential (Kjaerland, 2007; Mondial and

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Denich, 2010; Grigoras and Scarlatache, 2015; Diaf et al., 2015; Purohit et al., 2013; Angelis-Dimalis et al., 2011; Oztirk et al., 2009).

Proposing a new term of "effective potential of hydropower" was the consequence of long-term practical experience (Operacz, 2017). Under Polish circumstances, a number of procedural regulations are effective that often prevent establishing of a HPP, even in the conditions when its execution would be possible technically and economically. The term of "effective potential of hydropower" proposed for common use in previous paper (Operacz, 2017) allow estimation of production of energy from the given river with the method closest to the real possibilities of execution of new HPP. In the present manuscript the assessment of "effective potential of hydropower" is shown more particularly as a program.

This paper presents the idea aimed at determination of the "effective potential of hydropower" based on natural conditions, available data, effective guidelines and legal regulations in the Upper Vistula water region (South Poland).

THE TERM "EFFECTIVE POTENTIAL OF HYDROPOWER"

The literature in the field of numerical estimation of HP potential uses varied terminology. During the writing process of the Fifth Assessment Report 2014, the definition of „potential" was described in the Glossary (Allwood et al., 2014) as "the possibility of something happening, or of someone doing something in the future".

Apart from the commonly approved terms, such as theoretical, technical (understood as technically feasible) and economic (ensuring satisfactory profit) potential, such terms are applied as: market potential (Allwood et al., 2014; Hoogwijk and Graus, 2008; Krewitt et al., 2008), realistic or realizable potential (Stangeland and Grini, 2007), demand potential (Krewitt et al., 2008), mid-term potential (Resch et al. 2008) and others. Most authors come up with their own definitions that are mostly not well explained (Verbruggen et al., 2010). Too many terms and definitions associated with ''potentials' provide no clarity on assessed values therefore Operacz (2017) proposed term of "effective potential of hydropower" (see: Fig. 1).

The method seems to be closest to the real possibilities of execution of new HPPs in line with respect for the environment without economical calculations (considered to be highly individualised). The "effective potential of hydropower" term includes bureaucratic, environmental impact and any additional procedural regulations. Basic analyses of potential assessment were shown by Operacz in previous paper (2017). This article provides details about the numerical determination of "effective" potential under Polish conditions in the Upper Vistula water region.

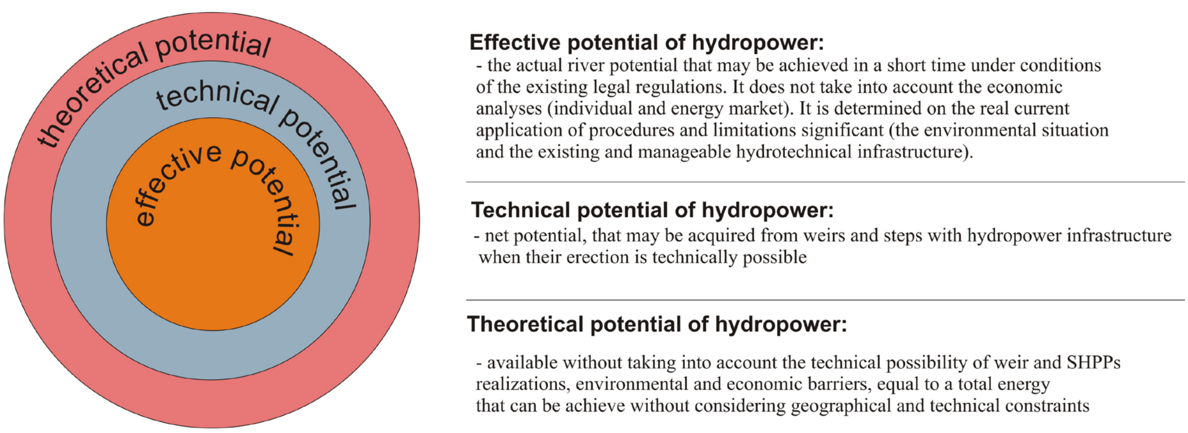

Fig. 1. Terminology and basic methodology of potentials assessment (Operacz, 2017 modified)

BASIC ANALYSES

Theoretical HP potential

The theoretical HP potential is usually understood as ones that are generally available without taking into account the technical possibility of their acquisition, environmental or economic limitations. As mentioned, theoretical potential in a specific situation is equal to a total energy that can be harvested without considering geographical and technical constraints (Izadyar et al., 2016). The theoretical potential A_{th} is most often defined as the raw potential (gross) equal to the sum of energy obtainable for a particular section of the river according to the formula:

$$A_{th} = 8760 \cdot P_a \text{ [kWh]} \qquad (1)$$

where:

8760 – the number of hours in the year,

P_a – the average river section power [kW], expressed with the formula:

$$P_a = 9.81 \cdot SSQ \cdot H \qquad (2)$$

where:

9.81 – normal acceleration of gravity [m · s^2],

SSQ – average annual mean flow [m^3 · s^{-1}],

H – the average gradient of the river section [m].

According to the formula (2), the flow of the watercourse is the basic parameter affecting potential power output and production of electricity. Stationary river flow observations in Poland are conducted within the water level indication network of The Institute of Meteorology and Water Management–the National Research Institute. The most optimum situation is when several water-level indicators are functioning in the watercourse to provide the actual information about the flows of the river. With extrapolation and interpolation methods, the values of the flows may be easily translated from controlled into uncontrolled sections, using the river basin area function. For uncontrolled streams, according to the hydrological practice, the flows should be calculated according to the hydrological analogy method or using the empirical formulae pursuant to Annex 4 to the Resolution no 4/2014 of the RZGW Director in Krakow. The computational methods, as example Sahu-Mishra-Eldo method and mathematical analyses may be useful for estimating the flows in uncontrolled catchments (Wałęga et al., 2016; Wałęga et al., 2017).

To determine the values of theoretical potential, the input sufficient flow is the value of the mean flow from the *SSQ* period. The values of the *SSQ* flows for all water-level indicator stations functioning in the Upper Vistula water region have been published in Annex no. 5 to the Resolution no. 4/2014 and are available free of charge.

Knowing the flows and the mean declines, the watercourses should be divided into fragments of similar values. The number of fragments of the watercourse should be determined with the analysis of the character of the watercourse and variability of natural flows, so that the selected sections may be considered uniform in HP terms.

Technical HP potential

The whole energy theoretically produced from the river can't be fully used. For this reason, investigations should take into account the technical possibility of HPPs realization. The technical resources are those resources that are available for the given source, and that can be acquired with the best processing technology when limitations are considered, mostly related to space. The technical potential, also referred to as net potential, is understood as the potential that may be acquired from dams and HPPs when their erection is technically possible (Operacz, 2017). Basically, it is assumed that execution of dams and of the power plant would be technically possible even in the places where there are no hydrotechnical structures.

The technical potential is due to many limitations and losses, the most important of which are (Operacz, 2017):

- **non-uniformity of natural flows in time** (the necessity of taking flooding periods into consideration, when impoundage must be reduced, and the periods when the flow is too low to start the turbines). This results in introduction of limits on the number of hours during the year with the HPP operating to the more realistic value equal to 6720 hours on the average, i.e. 280 days during the year. For the specific location, the curve of mean flow durations is most optimum;
- **variation of head depending on river flow**. For assessment of HP potential of the river, it appears

to be sufficient to isolate the days when the head drops down to the value that does not allow the operation of the turbine as a result of increase in the flow, which is included in the number of 280 days of work of the turbine during the year. The head curve is optimum to calculate production in the specific location;

- **efficiency characteristics of the equipment used**. Introduction of 80% efficiency for the whole HP has been deemed sufficient. The performance of the turbo unit in the specific location highly depends on the temporary flow,
- **the necessity of ensuring the inviolable flow** (in the main river bed for derivative power plants or in fish-pass). The necessity to maintain the minimum acceptable flow (inviolable flow/environmental flow) as a factor of significant environmental impact is above of management or economic criteria. It means a such volume of water that should be left in the river so that the balance of the environment is not disturbed. Thus, it is the volume of water that cannot be used for energy generation purposes. In Upper Vistula water region inviolable flow is calculated according to the so-called Kostrzewa method (Grela and Stochliński, 2005; Kostrzewa, 2005, Operacz et al., 2018) as an obligatory method by the Resolution no 4/2014 of the Regional Water Management Authority. The confirmed relationship between the inviolable flow and the mean value of annual minimum runoff (*SNQ*) is expressed in the correlation between the hydrological type of the river (lowland, transitory, foothill, mountain) and the area of its river basin, and the value of *SNQ*. The inviolable flow is determined as one value during the whole year, according to the following formula (Kostrzewa, 2005):

$$Q_n = k \cdot SNQ;\ \text{assumption: } Q_n \geq NNQ \tag{3}$$

where:

k – the empirical parameter from the tables for the river type and the area of the basin [9],
NNQ – minimum of annual minimum flows [$m^3 \cdot s^{-1}$].

Finally, the technical potential of the river is calculated to the formula:

$$A_{tech} = 6720 \cdot P_t \text{ [kWh]} \tag{4}$$

where:

6720 – the number of hours in 280 days,
P_t – the average river section power [kW], expressed with the formula:

$$P = 9.81 \cdot Q_d \cdot H \cdot 0.8 \tag{5}$$

where:

9.81 – the normal acceleration of gravity [$m \cdot s^2$],
H – the average gradient of the river section [m];
Q_d – available flow taking into account the inviolable flow Q_n:

$$Q_d = SSQ - Q_n \text{ [}m^3 \cdot s^{-1}\text{]} \tag{6}$$

0.8 – the efficiency of the power plant equal to 80%.

THE CONCEPT OF „EFFECTIVE POTENTIAL OF HYDROPOWER" ASSESMENT

The term "effective potential of hydropower" proposed by Operacz (2017) is basically different from the so-called economic/market/realizable/etc. potential that is currently commonly used. The author is of the opinion that economic grounds for the execution of HPPs are highly individual.

HP as a type of RE sources is recognized, in the light of the *European Parliament and Council Directive 2009/28/EC of 23 April 2009 on the promotion of the use of energy from renewable sources* as promoted source of energy due to care for the environment. However, it does not mean that such projects never have any negative impact on the environment. The analysis of the possible impacts, both negative and positive, must constitute a mandatory element of the feasibility study of the project. Years of experience, ecological consciousness and caring about habitat conditions for migrating water organisms result in introduction of many limitations in execution of HPPs. The Polish national law includes a number of conditions specified for example for areas under protection of the environment and for watercourses which are important for migration of diadromous fish.

HYDROTECHNICAL CONDITIONS

Currently in the Upper Vistula water region the thesis is grounded that the possibility is assumed of production of energy only in the existing dams and the places where they were located in the past and at least some parts of the infrastructure are still left. According to Art. 8.1 of the Resolution no 4/2014 of the Regional Water Management Authority, planned use of waters must take into consideration requirements of morphological continuity. This does not directly mean the ban on execution of new hydrotechnical structures that cross rivers, but in practice construction of a new weir solely for energy generation purposes is highly difficult (Operacz, 2017). For this purpose, thorough recognition and inventory of the existing hydrotechnical structures. There is no comprehensive documentation in this respect for the Upper Vistula water region. The existing HPPs are presented in the RZGW map portal in Krakow. The prospective locations for construction of new power plants may be selected with the Restor-Hydro project, and the field reconnaissance appears to be necessary to confirm or update information.

For the initial criterion, the minimum head equal to 1.0 m (existing or possible) should be assumed. This limit is assumed conventionally on the basis of experience related to the actual technical possibilities of turbine set operation. The turbines available in the market, like VLH (Very Low Head), are dedicated for head within the limits of 1.4 m to 3.4 m (Institute of Energy Technologies), and the lower head limit for screw Archimedes turbines is assumed at 1 m (Good Energy portal).

PROTECTED AREAS

To select a location with high probability of HPP construction, the analysis of the location is necessary in reference to protected areas under the Polish act on protection of nature (The Act of Nature Protection from 14 April 2004) and the European Natura2000 network. Prospective locations for HPPs in Poland may be set in the areas under national protection (national parks, landscape parks, nature parks) or in the areas under protection within the Natura 2000. Execution of HPP in reserves is impossible. In other areas, such a project is related to the risk of not obtaining a positive environmental decision, depending on the main objective of the protection and bans effective in these areas. All the prospective locations selected in the previous step (e.g. based on Restor-Hydro) must be checked in terms of collision, if any, with the objectives of the protection of the nature.

ENVIRONMENTAL CONDITIONS ACCORDING TO THE WATER FRAMEWORK DIRECTIVE

For the European Union countries, the obligatory document is WFD, effective as of 22 December 2000, whose most important message is the protection of water resources for the future generations (Directive 2000/60/EC). The operating objective is to achieve high status of all SWBs, which means the condition close to the natural, that is featuring the smallest possible human interference, and allowing for water to flow in a naturally shaped bed. Good ecological and chemical conditions should be achieved for natural water bodies (rivers, lakes, transitional and coastal waters), with good ecological potential and good chemical status in case of artificial and highly modified bodies of water.

In accordance with the regulations of WFD, planning of water management is broken down into river basin areas. The Upper Vistula water region is managing basically under The Water Management Plan for the Vistula River Basin and in detail under the Resolution no 4/2014 of the Regional Water Management Authority. The Upper Vistula water region has been divided into 763 uniform SWBs, and 172 of them has been entered in the list of watercourses posing the risk of not achieving the environmental objectives. The conducted HP generation projects must be compliant with the environmental objective set for the SWB, within which they will be executed. Their execution is possible, but it is very important to determine the environmental impact and the execution of the environmental objectives with biological, morphological, physical and chemical factors taken into consideration. Due to the returnable nature of water abstraction and emissionless operation of HPPs, special emphasis is placed on morphological changes and passability of the watercourse for ichtiofauna. Thus, designing new projects is justified close to already existing dams that are fitted with facilities for migration of fish or will be provided with them during the project (Operacz, 2017).

PASSABILITY OF THE WATERCOURSE

In the Upper Vistula water region 10 rivers partly has been entered in the list of watercourses for which it is necessary to maintain the possibility of migration of diadromous fish (Resolution no 4/2014 of the RZGW Director in Krakow), along with the statement of the characteristic two species of fish: salmon and sturgeon. It means that all new projects should be obligatorily fitted with the properly designed fish-pass. From the point of view of the effective potential of hydropower, this adds the necessity of calculation of the inviolable flow (roughly equal to the flow of water in the fish-pass) and to consider this value to be idle flow without the possibility of its use for power generation (Operacz, 2017).

The necessity of leaving the idle inviolable flow run through the fish-pass results from Art. 19.1 of the Resolution of the RZGW Director in Krakow no. 4/2014: the execution of impounding building structures in the watercourse bed crucial for migration of diadromous fish requires it to be fitted with water devices that ensure migration of characteristic fish species (unless the design of the structure ensures maintenance of such migration at low mean SNQ flow). In the design practice, the entries of the said section force the execution of the properly designed effective fish-pass (Operacz, 2017).

COURSE OF ACTION FOR EFFECTIVE POTENTIAL OF HYDROPOWER ASSESSMENT

The "effective potential of hydropower" term is understood as the closest to the actual possibilities of execution of HPPs that will produce electricity. Thus, the concept of numerical estimation of this potential is based first of all on the selection of the locations that will most probably be included in energy management programmes in near future. Drawing up the inventory of the existing hydrotechnical structures or their historical remains is necessary in terms of the possibility of using them for power generation. Broadly understood environmental conditions as the factor potentially blocking the project should be recognised, and the locations, e.g., in nature reserves, should be excluded from further analyses. The presented course of the analysis (see: Fig. 2) seems to be universal for investments in other water regions in Poland and in other countries.

The resulting "effective potential of hydropower" provides the actual view on the HP generation capacity of the river and brings the actual values in prognosis and other computational appraisal.

Finally, the modified formula (4) should be used to determine the total effective potential of hydropower in the Upper Vistula water region, in the form of:

$$A_e = 6720 \cdot P_e \text{ [kWh]} \tag{7}$$

where:
P_e – the selected locations power [kW], expressed with the formula:

$$P_e = 9.81 \cdot Q_d \cdot H \cdot 0.8 \tag{8}$$

where:
H – head (existed or possible) [m].

This analysis allows to assess production of energy from the given rivers with the method closest to the real possibilities of execution of new HPPs based on the actual legal procedure containing barriers. Effective potential of hydropower is closely related to water managing in Poland, especially in using of waters for energy generation purposes. Proposed definition of "effective potential of hydropower" concerns a short time of HPP realization when legal conditions are constant.

CASE STUDY FOR RIVER SZRENIAWA

The workflow presented in this paper, aimed at determining the value Q_n is shown with the example of the selected river Szreniawa, as a main river without confluents. Szreniawa is the left-bank tributary of Vistula (see: Fig. 3) with the lengths of 79.8 km and 713.4 km^2 of the river basin. The gradient of the river is not uniform; it is 4.5‰ on the average.

Stationary observations of water level and flows are conducted by the Institute of Meteorology and Water Management – National Research Institute. The national water level gauge system in the Szreniawa river is represented by one post (see: Table 1; Fig. 3).

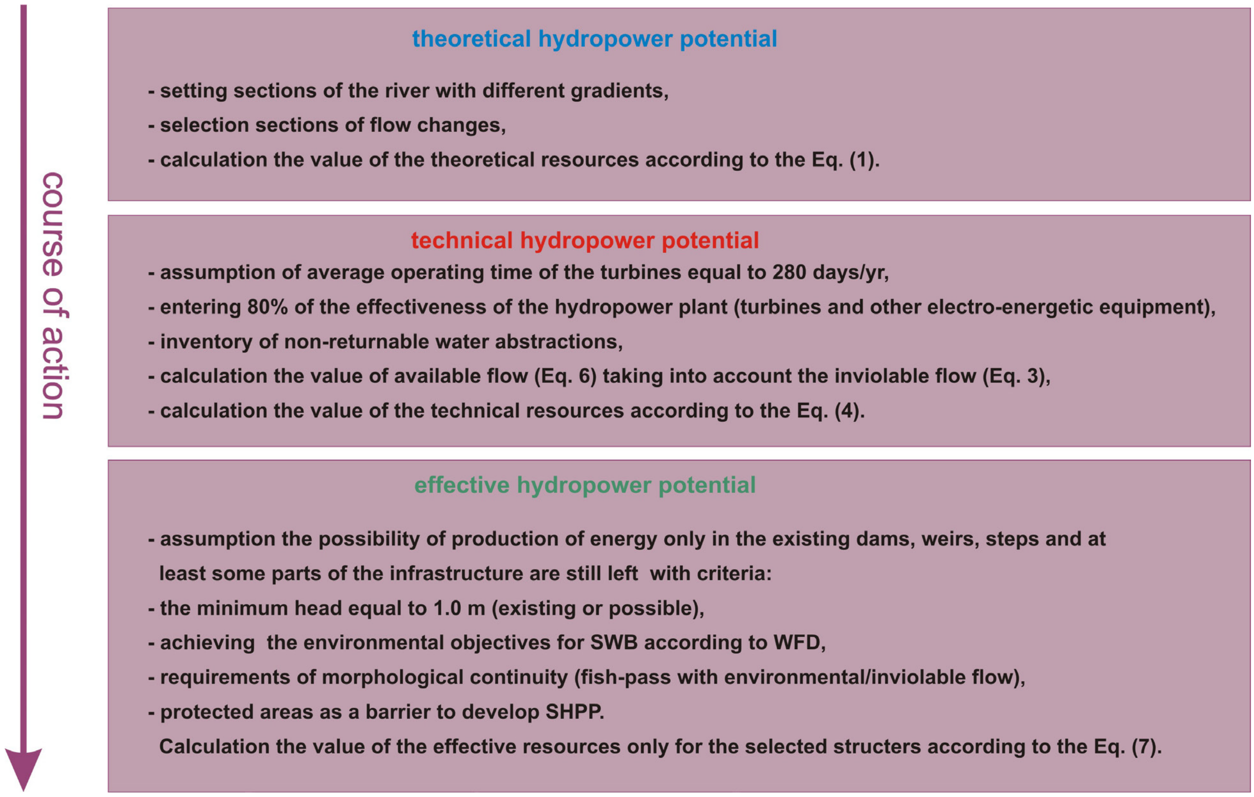

Fig. 2. Course of action for effective potential of hydropower assessment in Upper Vistula water region (Operacz, 2017 modified)

Table 1. Stationary observation station of surface waters (water-gauge) on the Szreniawa river

name of water gauge	Szreniawa [km]	drainage basin area [km^2]	hydrological characteristics (1981–2010)				
			SSQ [m^3 · s^{-1}]	*SNQ* [m^3 · s^{-1}]	*NNQ* [m^3 · s^{-1}]	$Q_{gw90\%}$* [m^3 · s^{-1}]	W90 [–]
Biskupice	9+130	689.17	2.671	1.279	0.62	1.13	0.8835

Note. * – the flow with 90% certainty of occurrence calculated according to the formula $Q_{gw90\%} = SNQ \times W90$

Szreniawa's regime is uniform with spring and summer freshets and features soil-rain-snow feeding (Baścik and Partyka, 2011). The average unit outflow is low (5–6 l/s · km^2), with major contribution (60%) from the underground outflow. With continuous supply of groundwater through the drainage of the river, or from efficient springs, lack of low water is typical of this region. The dynamics of freshets from summer rainfall spreading is low. Heavy rains, with short spatial range, highly contribute to relief creation (erosion), and modify hydrological parameters in the whole basin to a small degree only. The characteristic feature of Szreniawa is that even at the time of freshets flood circumstances do not occur; the whole water is usually contained within the river bed.

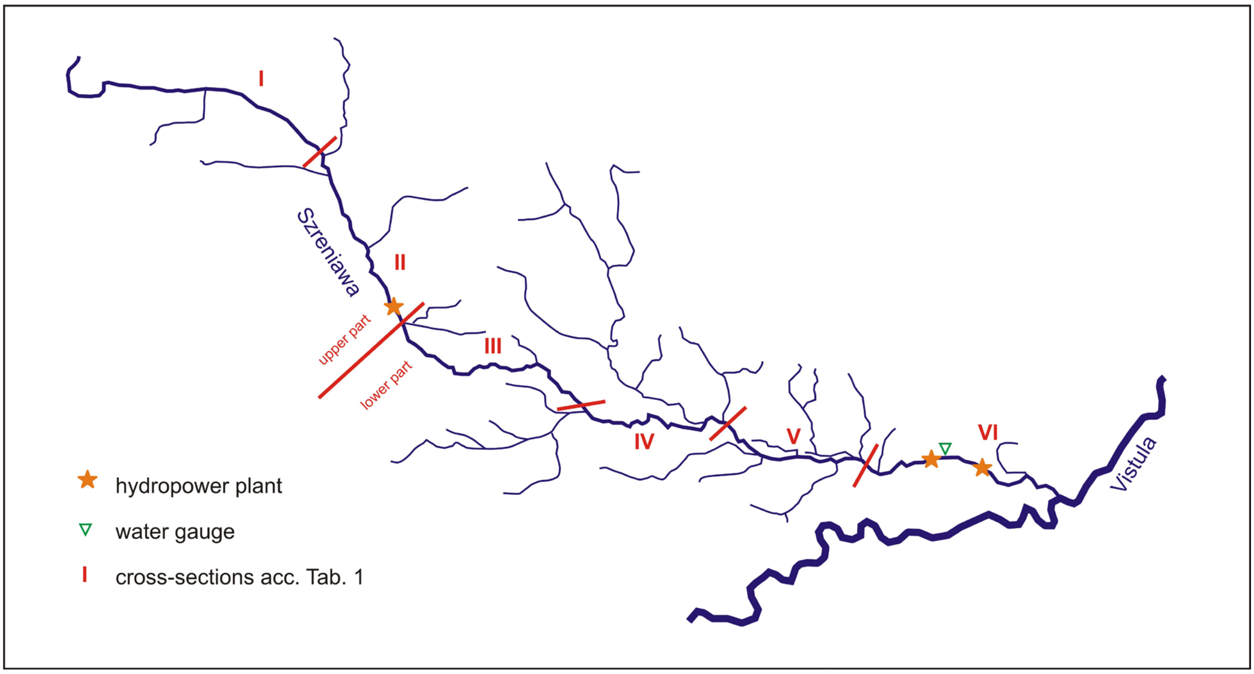

Fig. 3. Szreniawa river

USING ENERGY RESOURCES OF THE RABA RIVER

The first mills in the Szreniawa Valley based on water energy date back to the Middle Ages, established by the Order of the Holy Sepulchre of Jerusalem of Miechow. In the following centuries, manor owners used to build them Jews trading in crops, and occasionally rich farmers (Soja, 2003). Energy of water was used mostly for grinding corn, and sometimes for woodworking. Nowadays some water wheels are used for production of electricity. SHPPs do not disturb the balance of the natural environment, or even help it with improving oxygenation of water (Baścik and Partyka, 2011). Some mills have survived, but many are no longer there. The "Szreniawa Valley Mills" tourist trail was marked out in 2003 (Szreniawa valey's mills 2003). The trail runs along Szreniawa, where there are also other active water mills. Dozens of mills used to be operated on Szreniawa and its tributaries, helping farmers cultivating crops in fertile soils (loess black earth) of the Miechowska Upland. The river featured numerous weirs, watermills, water wheels and other hydrotechnical facilities. About 20 mills were still operable in the early 21st century; just a few of them survived until now. Some mills have been recently converted into SHPPs (Baścik and Partyka, 2011).

The Szreniawa course consists of 2 basic parts with different hydrographic and morphological indicators (see: Fig. 3):

- the upper course with the average gradient of 5.5‰;
- the lower course with the average gradient of 3.5‰.

The Szreniawa river is now used for production of renewable energy in three water power plants (see: Fig. 3) (RZGW map portal in Krakow, Restor-hydro project).

THEORETICAL HYDROPOWER POTENTIAL OF SZRENIAWA RIVER ASSESMENT

The theoretical potential A_{th} has been calculated according to the formula (1). Two sections of the Szreniawa river were set out with different gradients, in accordance with the characteristics of the watercourse presented in chapter *Using energy resources of the Raba river*. Each one of the selected sections was additionally broken down (by interpolation) into fragments with changes in flow equal to 0.5 $m^3 \cdot s^{-1}$ as recorded by water-level indication observations. It appears that 0.5 $m^3 \cdot s^{-1}$ steps set for the Szreniawa river offer sufficient accuracy to assess the value of the theoretical resources. As a result of the above operations, the Szreniawa river has been divided into 6 sections, the location of which is presented in Figure 3. For each of the sections, the value of the mean flow was assumed as a fixed value, whereas the value of the head of the river section H was assumed in accordance with the description in chapter *Using energy resources of the Raba river*. The input data for the calculations and the results of the calculations of the theoretical potential are presented in Table 2.

The theoretical power installable on the Szreniawa river is thus almost 4 MW, and the annual production of energy from this renewable source would theoretically amount to 27.400 MWh.

TECHNICAL HYDROPOWER POTENTIAL OF SZRENIAWA RIVER ASSESMENT

The technical potential of the Szreniawa river was calculated according to the procedure presented in section 3.2. To calculate the minimum acceptable flow Q_n, "k" coefficient of 0.77 (as for transient and mountain rivers with catchments in the scope 500–1.500 km^2) was adopted. The input values for the formula (4) and the results of the calculations are summarised in Table 3.

The technical power installable on the Szreniawa river is 700 kW according to the calculations, and the annual production of energy from this renewable source would amount to 5.000 MWh.

Table 2. The theoretical potential of the Szreniawa river

no. of section on Szreniawa	*SSQ* $[m^3 \cdot s^{-1}]$	gradient [‰]	longht [km]	H [m]	P_a [kW] acc. (1)	A_{th} [kWh] acc. (1)
I	0.5	5.5	20	55	270	2 365 200
II	1		15	55	540	4 730 400
III	1.5	3.5	15	35	515	4 511 400
IV	2		9	35	687	6 018 120
V	2.5		9	35	858	7 516 080
VI	3		12	35	1 030	9 022 800
totally:					**3900**	**27 393 528**

Table 3. The technical potential for the Szreniawa river

no. of section on Szreniawa	*SSQ* $[m^3 \cdot s^{-1}]$	Q_n acc. (3) $[m^3 \cdot s^{-1}]$	Q_d acc. (6) $[m^3 \cdot s^{-1}]$	H [m]	P_t acc. (5) [kW]	A_{tech} acc. (4) [kWh]
I	0.5	0.385	0.115	55	49	329 280
II	1	0.77	0.23		99	665 280
III	1.5	1.155	0.345	35	95	638 400
IV	2	1.54	0.46		126	846 720
V	2.5	1.925	0.575		158	1 061 760
VI	3	2.31	0.69		190	1 276 800
totally:					**717**	**4 817 240**

EFFECTIVE HYDROPOWER POTENTIAL OF SZRENIAWA RIVER ASSESMENT

To determine the real effective potential of hydropower, the possibility has been assumed of production of energy only in the existing impoundage and the places where they were located in the past and at least some parts of the infrastructure are still left. For this purpose, the documentation of the impoundage locations executed within the Restor-Hydro project was used, topography maps and published materials (Baścik and Partyka, 2011; Szreniawa valey's mills 2003). For the initial criterion, the minimum head equal to 1.0 m (existing or achievable) was assumed. The average annual flow was assumed in accordance with the segmentation used (see: Fig. 3). The locations of the selected facilities for prospective SHPP projects are shown in Fig. 4, and their parameters are given in Table 5.

ENVIRONMENTAL CONDITIONS ACCORDING TO THE WATER FRAMEWORK DIRECTIVE

The Szreniawa river has been divided into two uniform parts of JCWP surface waters, whose characteristics is given in Table 4.

Table 4. The surface water bodies (SWB) on Szreniawa river

European JCWP code	JCWP name	Status	Environmental objective
PLRW20007213924	Szreniawa to Piotrówka	highly modified part of the waters	good water potential
PLRW2000921392999	Szreniawa from Piotrówka to estuary	highly modified part of the waters	good water potential

None of the above units has been entered in the list of the watercourses posing the risk of not achieving the environmental objectives (Resolution no 4/2014 of the RZGW Director in Krakow). The conducted water power generation projects must be compliant with the environmental objective set for the JCWP unit, within which they will be executed.

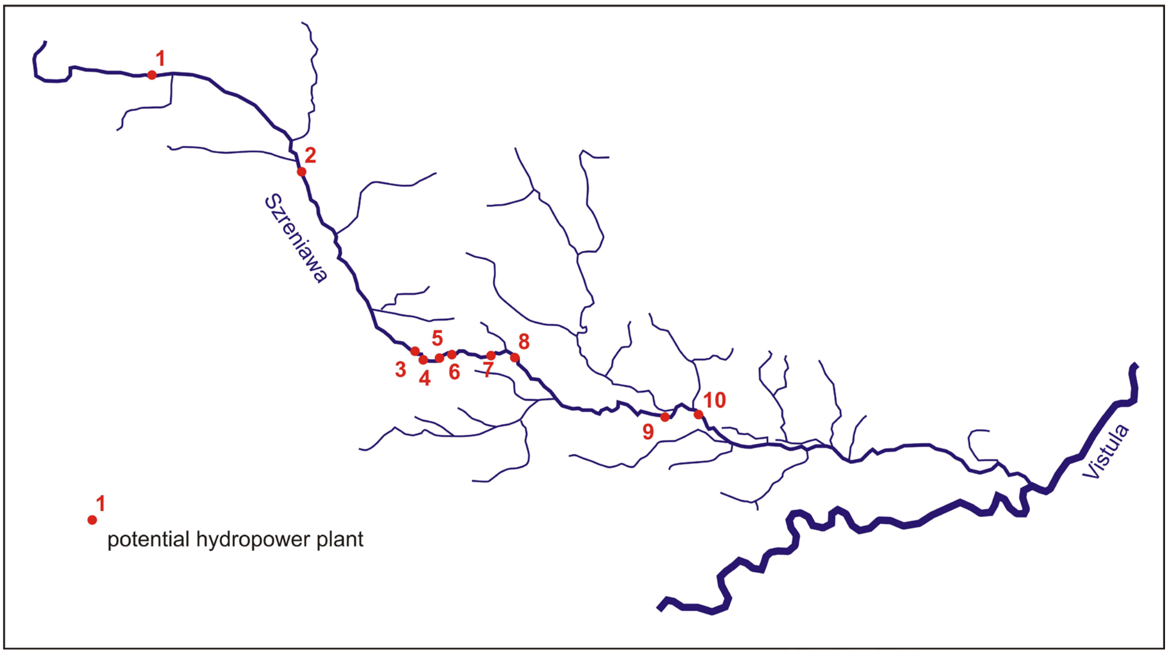

Fig. 4. Locations of the selected facilities for prospective SHPP

PASSABILITY OF THE WATERCOURSE

The Szreniawa river has not been entered in the list of the streams for which it is necessary to maintain the possibility of migration of diadromous fish (Resolution no 4/2014 of the RZGW Director in Krakow). In the design practice it means that each new investment should (although it is not obligatory) be fitted with a properly designed fish pass. From the point of view of the actual potential, the necessity of leaving the minimum acceptable flow (roughly equal to the flow of water in the fish pass) is highly unfavourable from the economical point of view. Table 5 summarises the values of the minimum acceptable flow for each of the selected prospective SHPPs facilities, calculated from the formula (3).

The necessity of considering Q_n in the minimum acceptable flow practically excludes the possibility of executing SHPPs in the Szreniawa river. In the design practice, the smallest executed projects have installed powers in excess of 20 kW. Thus, all the stated potential locations do not meet this criterion. The condition necessary for execution in these cases would be their exemption from the obligation of leaving the minimum acceptable flow. However, due to the fact that the so-called mill streams are common, that is derivations of the main river, the necessity of leaving the minimum acceptable flow in the main streamway goes without saying.

PROTECTED AREAS

The SHPP locations selected in chapter *The concept of „effective potential of hydropower" assesment* are partly in the area of the Miechowska Upland Protected Landscape, however, the execution is possible and does not collide with the objectives of the protection of the above area.

COMPARISON OF RESULTS FOR SZRENIAWA RIVER

The estimated theoretical potential of the Szreniawa river (along the entire length of the watercourse without tributary potential) is 3.900 kW of installable power and 27.393.528 kWh of produced energy. The technical potential (taking into consideration non-uniformity of flows, efficiency characteristics of a SHPP and the necessity of leaving the minimum acceptable flow run through fish passes) was 717 kW of installable power and 4,817,240 kWh of the produced energy, respectively. The effective potential of hydropower of the Szreniawa river, i.e. the one whose achievement is probable, amounts to 62.3 kW, with the electricity produced at the level of 418.656 kWh. The graphical comparison of the results is provided in Figure 5 and Figure 6.

Table 5. The parameters of hydrotechnical structures suitable for power generation purposes with Q_n left in the fish-pass

no. acc. fig. 4	estimated parameters		*SSQ* [$m^3 \cdot s^{-1}$]	Q_n acc. eq. 3 [$m^3 \cdot s^{-1}$]	Q_d acc. eq. 6 [$m^3 \cdot s^{-1}$]	P acc. eq. 8 [kW]	A acc. eq. 7 [kWh]
	name of weir	head [m]					
1	Przybysławice	2.0	0.5	0.385	0.115	1.8	12096
2	Przesławice	3.5	1.0	0.77	0.23	6.3	42336
3	Kacice	1.5	1.5	1.155	0.345	4.1	27552
4	Miłocice	2.5	1.5	1.155	0.345	6.8	45696
5	Ratajów	2.5	1.5	1.155	0.345	6.8	45696
6	Niedźwiedź	2.5	1.5	1.155	0.345	6.8	45696
7	Waganowice	3	1.5	1.155	0.345	8.1	54432
8	Piotrkowice Wielkie	2	1.5	1.155	0.345	5.4	36288
9	Jazdowiczki	2	2	1.54	0.46	7.2	48384
10	Klimontów	2.5	2.5	1.925	0.575	9	60480
totally						**62.3**	**418 656**

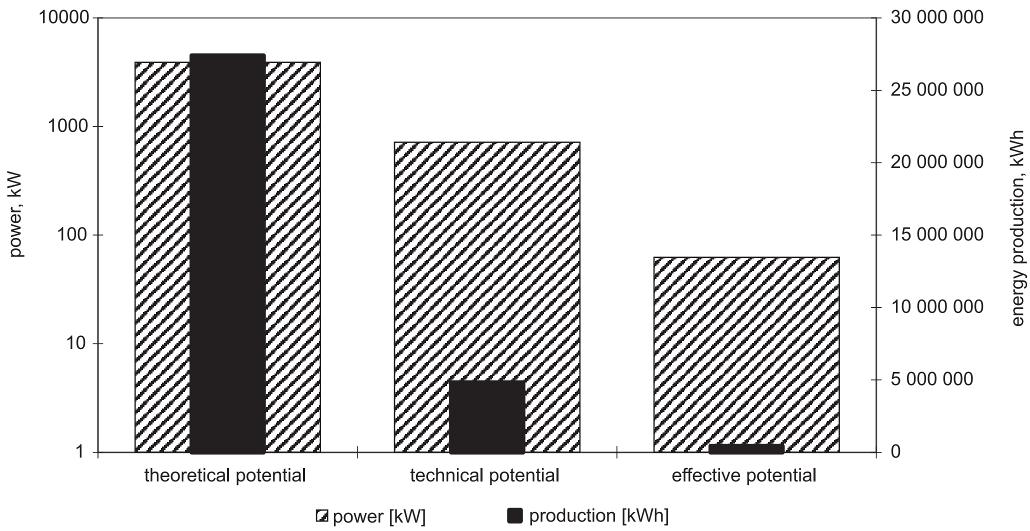

Fig. 5. Comparison of power and energy production estimated by theoretical, technical and effective potential of hydropower

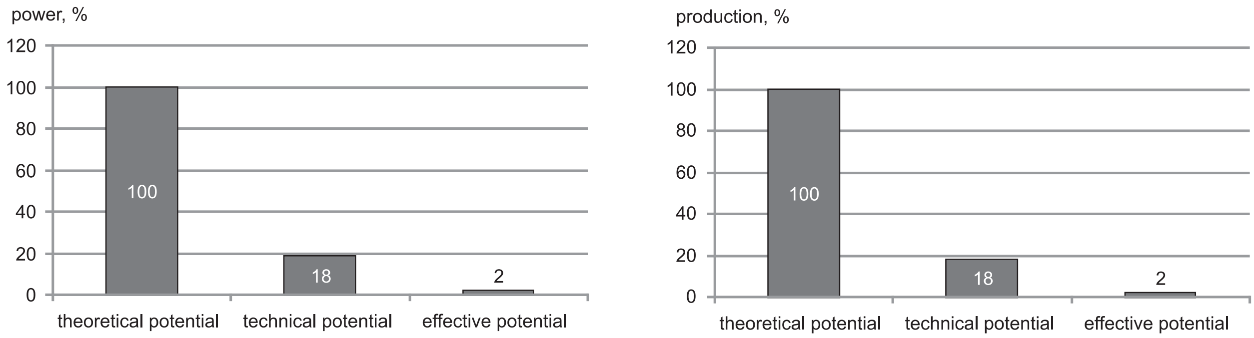

Fig. 6. Comparison of theoretical, technical and effective potential of hydropower of Szreniawa river

The strongest controversies in execution of SHPPs come from the necessity of building a hydrotechnical structure crossing the watercourse bed in order to achieve the head necessary for operation of commonly used turbines (Karolewski and Ligocki, 2004). Therefore, the projects that included the existing infrastructure feature the best chances of success. The result is extremely low value of the estimated actual potential, about 1% against the theoretical potential (see: Fig. 6).

The value of the effective potential of hydropower shows the actual possibilities of water power management of the Szreniawa river under conditions of the existing legal regulations. The "effective potential of hydropower" term (Operacz, 2017) proposed is the value that depicts the actual river potential that may be achieved in a relatively short time. The estimated value is subject to strong individuation based on the legal regulations effective for the watercourse, the environmental situation, experience and the existing and manageable hydrotechnical infrastructure. This value is significantly lower than the theoretical or technical potential. It does not include economic analysis, as it has been regarded to be excessively dependent on expectations and capacity of a prospective investor. The value of the potential of the given river section is often exaggerated in literature in the field of renewable power engineering, resulting in too optimistic perspectives. In short-term considerations of a few years' time, the "effective potential of hydropower" term should be used because it realistically reflects the possibilities of using the watercourse for the purposes of water power development and production of electricity from the renewable source of this type.

CONCLUSIONS

Assessment of hydropower potential is the most important part of renewable sources balances. The quantitative assessment based only of theoretical, technical and economic potential is not sufficient. Also generally provides the overoptimistic results. The most papers presents the way to assess only the theoretical or technical potential.

Some authors (Kusre et al., 2010; Moiz et al., 2018) claims that traditional water resources assessment made by using historically observed discharged data at outlet of the watershed would generally ignore some other potential sites within the watershed resulting poor motivation of water resources project. The power output of run-of-river SHP developments is very site sensitive and poses several complex challenges, such as inaccessible terrain and numerous possible hydropower scheme alternatives. They proposed using modeling tools to overcome the disadvantages or the systematic GIS-based hydropower site selection. The developed tool made the preliminary hydropower site selection process less time consuming, more robust, and more systematic, consequently making it less susceptible to the possible subjectiveness or bias introduced by the decision maker, both of which are due to the complexity of the problem when using a conventional approach. The new approach also reduced the number of suitable hydropower sites to a finite set that can be investigated in detail during feasibility studies. The sites identified in the investigation are only theoretically potential sites identified based on model outputs (Kusre et al., 2010). These value seems to be close to the theoretical and technical ones, not to the proposed in the article “effective potential of hydropower”.

In the global scale the theoretical hydropower potential is estimated at 150 EJ and technical potential about 50 EJ (Resch et al., 2008) which suggest that the quota of them is about 33%. In the regional scale the values of technical potential achieve from several to several dozen percents, for examples:

- in Kopili river basin in India: 50% of theoretical potential (Kusre et al., 2010);
- in Pakistan: 12% of theoretical potential (Farooq and Kumar, 2013);
- in Cameroon: 39% of theoretical potential (Kalitsi, 2003);
- in Nigeria: 23% of theoretical potential (Ohunakin, 2011).

The investigations for Nepal has brought 83000 MW of exploitable hydropower resources, but less than 650 MW has been tapped yet (Sovacool et al., 2011). Some barriers to hydro in Nepal are social, consisting of values, attitudes, regulations, and price signals. Other barriers are technical, involving challenges related to hydrology, dam design, and maintenance. The limitations seems to be similar to Polish procedures.

Kucukali and Baris (2009) presented evaluation the development of small hydro power Turkey and discusses the current situation of SHPPs in terms of government policy, economical aspects and environmental impacts taking EU policy into account. The main course is similar to presented in this paper named “effective potential of hydropower”. Kucukali and Baris (2009) haven’t proposed the new term, they used only “hydropower potential” term. The proposed course of action shown in the paper allow to estimate the real effective potential of hydropower. Presented analysis seems to be universal for investments in other regions in Poland and also in the other countries. The resulting “effective potential of hydropower” provides the actual view on the HP generation capacity of the river and brings the actual values in prognosis and other computational appraisal. The authors believe that this term will be accepted for common use.

ABBREVIATIONS:

RE – Renewable Energy; RES – Renewable Energy Sources, HP – Hydropower, HPP – Hydropower Plant, SHPP – Small Hydropower Plant; GIS – Geographical Information System, RZGW – Regional Water Management Authority, WFD – Water Framework Directive, SWB – Surface Water Bodies.

NOMENCLATURE:

A_{th} – theoretical potential [kWh]
A_{tech} – technical potential [kWh]

A_e – effective potential of hydropower [kWh]
P – power [kW]
SSQ – average annual mean flow [$m^3 \cdot s^{-1}$]
SNQ – average annual minimum flow [$m^3 \cdot s^{-1}$]
NNQ – minimum of annual minimum flows [$m^3 \cdot s^{-1}$]
H – head [m]
Q_n – inviolable flow [$m^3 \cdot s^{-1}$]
Q_d – available flow [$m^3 \cdot s^{-1}$]

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PROGRAM OCENY RZECZYWISTEGO POTENCJAŁU HYDROENERGETYCZNEGO W REGIONIE WODNYM GÓRNEJ WISŁY (POLSKA)

ABSTRAKT

Pozyskiwanie energii ze źródeł odnawialnych stanowi obecnie jedno z największych wyzwań ludzkości w aspekcie przeciwdziałania niekorzystnym zmianom środowiskowym zarówno w skali lokalnej, jak i globalnej. Sporządzenie zestawień liczbowych w zakresie rzeczywistej produkcji energii elektrycznej z funkcjonujących elektrowni wodnych nie stanowi większej trudności. Natomiast liczbowe oszacowanie potencjału hydroenergetycznego jest trudne i często prowadzi do niejednoznacznych wyników, zbyt optymistycznie przeszacowywanych. Powszechnie analiza liczbowa obejmuje podanie wartości potencjału teoretycznego, technicznego i ekonomicznego.

W warunkach polskich obowiązuje szereg uregulowań proceduralnych, które często skutecznie uniemożliwiają powstanie elektrowni wodnej, nawet w warunkach, gdy technicznie i ekonomicznie jej realizacja byłaby możliwa. Niniejsza praca przedstawia program zmierzający do określenia „effective potential" w oparciu o warunki naturalne, dostępne dane, obowiązujące wytyczne oraz uregulowania prawne w regionie wodnym Górnej Wisły (Polska południowa).

Konsekwencją wieloletnich doświadczeń praktycznych było zaproponowanie nowego terminu „effective potential", który pozwoliłby na oszacowanie produkcji energii elektrycznej najbardziej zbliżonej do realnych możliwości realizacji nowych elektrowni wodnych.

Słowa kluczowe: odnawialne źródła energii, elektrownia wodna, potencjał rzeczywisty, potencjał techniczny, potencjał teoretyczny