ENVIRONMENTAL PROBLEMS

Vol. 3, No. 3, 2018

THE EFFECTIVE HYDROPOWER POTENTIAL OF THE MSZANKA RIVER IN SOUTH POLAND – THE COURSE OF ESTIMATION

Agnieszka Operacz, Tomasz Kotowski, Piotr Bugajski

University of Agriculture in Krakow, Faculty of Environmental Engineering and Land Surveying, Department of Sanitary Engineering and Water Management. Al. Mickiewicza 21, 31-120 Kraków, Poland a.operacz@urk.edu.pl

Received: 04.10.2018

Abstract. The aim of the paper was to calculate the actual (called "effective") hydropower potential based on the identification of real possibilities of small hydro power plants realization. As an example river Mszanka in South Poland was chosen. The course of estimation was shown in Polish conditions of law, procedures and environmental barriers. The comparison of estimated values of effective potential was done with theoretical and technical potential.

Key words: hydropower potential, RES, sustainable management, small HPP

Abbreviations:
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 [$m^3 \cdot s^{-1}$]
RE – RE
RES – RES
HPP – HPP

1. Introduction

The resources of power engineering raw materials are limited. The energy generating in conventional power plants is connected with emission of many pollutants to the environment. For these reasons, the technologies based on renewable sources are currently strongly promoted. Producing energy from these kind of sources brings no pollutants so is usually called "clean or green energy". Energy of water, or to be more precise energy of rivers, is one of the types of renewable sources that are being developed from many centuries in many countries on the Earth.

The pure definition of „potential" was described in the Glossary [1] as "the possibility of something happening, or of someone doing something in the future". Usually in published literature the notion of RE potentials is an unsettled concept. Many authors noticed the lack of terms and come up with their own definitions. The existed terms, as e.g. realistic potential [2], geographical potential [3], deployment or demand potential [4], mid-term potential [5], are not well explained. The course of calculations of their values are not shown, so the ideas of these potentials are difficult to understand and to generalize. The RE literature provides several names and definitions of RE potentials, not tuned to one another and open to criticism [6]. Not so often an actual potential of hydropower investments is presented from wide point of view based on real possibilities in a quite short time. The studies of RES are mainly focused only on calculations of theoretical potential [7–12]. The most of them presents also technical potential and costs or benefits named as economic potential [13–16].

The term "effective potential" was proposed in previous articles with explanation of the sense and course of action. The quantitative assessment of the hydropower potential is most often restricted to present value of theoretical, technical and economic potential. In practice there is a lot of procedural regulations that could block erection of a HPP, even in the conditions when its execution would be possible technically and economically. Execution only of these installations is especially important within sustainable development idea. The "effective potential" allows estimation of production of energy from the given river with the method closest to the real possibilities of execution of new HPPs. Authors believe that the term could be in common use.

The author thus proposes the term of "effective potential" to allow estimation of production of energy from the given river with the method closest to the real possibilities of execution of new HPPs in line with the sustainable development idea without the economically calculations (actual energy market, price, cost and individual financial conditions of investor).

The "effective potential" term includes bureaucratic, environmental impact and any additional procedural regulations.

As an example river Mszanka in South Poland was chosen. The paper shows basic information on the Mszanka River in accordance to hydropower possibility and characteristic of the flows. Although the Mszanka river has been selected as the example, the course of the analysis seems to be universal for investments in other countries where procedures may be differ significantly. The resulting "effective potential" provides the actual view on the hydropower generation capacity of the analysed river.

The paper consists of a computational part containing calculations of theoretical potential, technical potential and "effective" potential. The location of potential new small HPPs was proposed in places of possible energy use and was checked for possible limitations in Poland conditions. Finally, the results of calculations were compared. The results of the analysis shows that only about few percent of the theoretical potential could be realize in the real conditions of existing law and environmental limitations.

2. Experimental

2.1. Effective potential – term and course of action

The term "effective potential" is the value that shows the actual/real river potential that may be achieved in a relatively short time [17]. The estimated value is strong individually based on the legal regulations, the environmental situation and the existing and manageable hydrotechnical infrastructure of the chosen river. This value is significantly lower than the theoretical or technical potential and brings the real value of potential small hydropower realization. The value of the theoretical or technical potential of the given river section is always exaggerated resulting in too optimistic perspectives.

Proposed previous new term of "effective potential of hydropower" was the consequence of long-term practical experience [17]. 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 or economically. The term of "effective potential of hydropower" proposed for common use in previous paper [17] allow estimation of production of energy from the given river with the method closest to the real possibilities of execution of new HPPs.

The main course of action presented in the paper include :

- theoretical potential estimation of Mszanka river acc. to:

– setting sections of the river with different gradients,

– selection sections of flow changes,

– calculation the value of the theoretical resources according to the Eq. (1).

- technical potential estimation of Mszanka river acc. to:

– assumption of average operating time of the turbines equal to 280 days/yr,

– entering 80 % of the effectiveness of the HPP (turbines and other electro-energetic equipment),

– inventory of non-returnable water abstractions,

– calculation the value of available flow (Eq. 6) taking into account the inviolable flow (Eq. 3),

– calculation the value of the technical resources according to the Eq. (4).

- effective potential estimation of Mszanka river according to:

– assumption the possibility of production of energy only in the existing dams, weirs, steps and at least some parts of the infrastructure are still left with criteria:

– the minimum head equal to 1.0 m (existing or possible),

– achieving the environmental objectives for SWB according to WFD,

– requirements of morphological continuity (fish-pass with environmental/inviolable flow),

–- protected areas as a barrier to develop SHPP.

Calculation the value of the effective resources only for the selected structures according to the Eq. (7).

- comparison of results.

2.2. Characteristics of Mszanka river in South Poland

The Mszanka River flows in southern Poland in the area of Beskid Wyspowy. The river has its source within the Gorce mountain range at an altitude of 1220 asl. It is 19 km long and the area of its basin is 174 km^2. The average multiannual atmospheric precipitation for the river basin is 979 mm. Over a major part of its course, the river is hydrotechnically regulated, with numerous concrete water steps.

The Mszanka river is located in the Upper Vistula Water Region. Stationary observations of water level and flows on the Mszanka river are conducted by the Institute of Meteorology and Water Management – National

Research Institute. There is an one measurement gauge post operating within the national surface observation network along the Mszanka river (Tab. 1).

Table 1

Data for water gauge on Mszanka [18]

water gauge	km of the flow river Mszanka	catchment area [km²]	hydrology characteristic (1981-2010)		
			SSQ [$m^3 \cdot s^{-1}$]	SNQ [$m^3 \cdot s^{-1}$]	NNQ [$m^3 \cdot s^{-1}$]
Mszana Dolna	3+020	166.43	3.353	0.486	0.070

At present, the Mszanka river is not used for RE production in hydroelectric power plants, but its tributary (Porębianka) features one small HPP.

2.3. Theoretical potential assessment

Theoretical resources are understood as resources of a given source generally available without considering the possibility of their technical acquisition, environmental and economic constraints. Theoretical potential A_{tch} is most often referred to as the raw (gross) potential equal to the sum of the energy obtainable for a given section of the river, according to the formula:

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

where: 8760 – the number of hours during the year; P – the average power capacity of a river section [kW], expressed with a formula:

$$P = 9.81 \cdot SSQ \cdot H \text{ [kW]} \quad (2)$$

where: 9.81 – the value of normal acceleration [$m \cdot s^{-2}$]; SSQ – multiannual mean flow [$m^3 \cdot s^{-1}$]; H – head of a river section [m]

To estimate the theoretical potential of the Mszanka River, the division of the watercourse and its left-bank Porębianka tributary into sections with a flow rate of 0.5 $m^3 \cdot s^{-1}$ was assumed. The other tributaries, due to small flows, were omitted in the analysis.

To determine the annual average flow (SSQ) for uncontrolled cross-sections (without a functioning water level indicator), an empirical formula was used (3).

The division of the Mszanka River along with its Porębianka tributary in a step of 0.5 $m^3 \cdot s^{-1}$ was deemed sufficient in terms of accuracy to estimate the value of theoretical resources. The calculations were carried out for the assumed SSQ, respective for Porębianka: 0.5 $m^3 \cdot s^{-1}$; 1.0 $m^3 \cdot s^{-1}$; 1.44 $m^3 \cdot s^{-1}$ and for Mszanka: 0.5 $m^3 \cdot s^{-1}$; 1.0 $m^3 \cdot s^{-1}$; 1.5 $m^3 \cdot s^{-1}$; 3.46 $m^3 \cdot s^{-1}$, where the highest flow value means the outflow section. For rivers with different flows, individual step selection is recommended. The larger the number of sections, the more accurate the allocation of resources. The optimal situation would be with the possibility of introducing a continuous change in the flow corresponding to the actual changes to the calculation formulas, but this requires the use of a mathematical model. In this work, the decision was made on the simplest way to determine the renewable resources of the Mszanka River, widely available in practice without the need to purchase specialized programs.

As a result of the above activities, the Mszanka River and its left-bank tributary Porębianka were divided into 7 sections, 3 of which are located on the Porębianka tributary, and 4 on the Mszanka main river (Fig. 1).

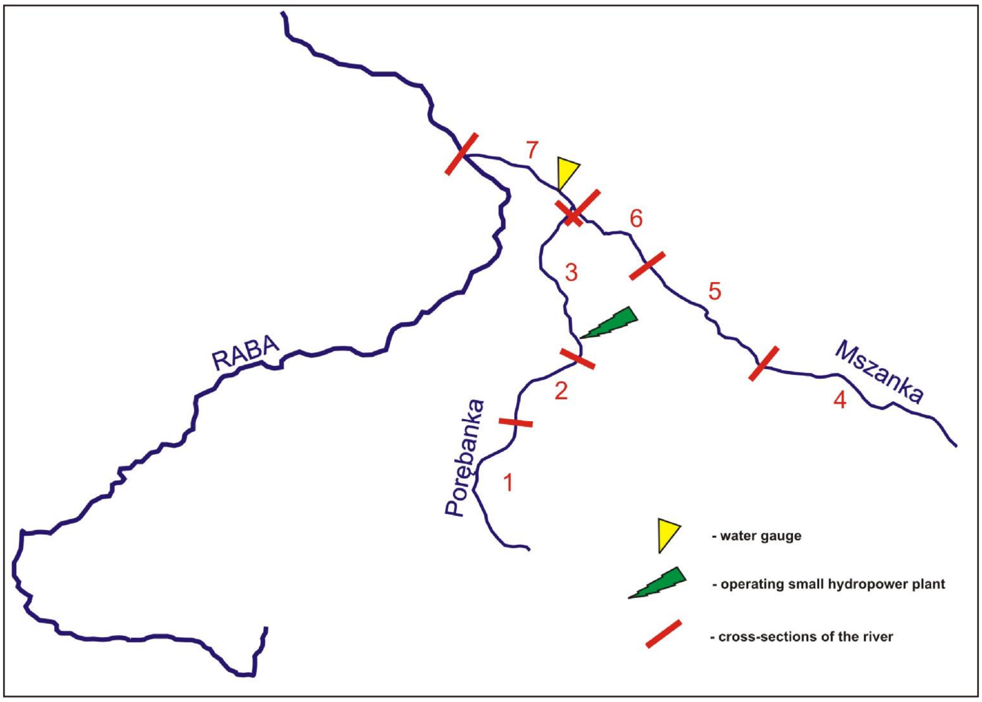

Fig. 1. The calculation sections of the Mszanka and Porębianka rivers

The average annual mean flow SSQ was calculated from the formula:

$$SSQ = 10^{-3} \cdot SSq \cdot A \ [m^3 \cdot s^{-1}] \quad (3)$$

Average annual minimum flow was calculated from the formula:

$$SSq = 0.00001151 \cdot P^{2,05576} \cdot I^{0,0647} \cdot N^{-0,04435} \ [l \cdot s^{-1} \cdot km^{-2}] \quad (4)$$

where: SSQ – average annual flow $[m^3 \cdot s^{-1}]$

SSq – average annual minimum flow $[l \cdot s^{-1} \cdot km^{-2}]$

A – basin area $[km^2]$

P – mean annual precipitation in the basin [mm]

N – soil impermeability index [%]

I – longitudinal gradient of the watercourse defined with the formula [‰] by (5)

$$I = \frac{\Delta W}{L} \ [‰] \quad (5)$$

where: ΔW – the difference of height between the highest sources of the river and the closing profile in the examined basin [m]

L – the distance from the closing cross-section to the farthest source in the basin [km]

For such designated fragments of the river, the value of theoretical resources was calculated according to the formula (2). For each of the sections, the average flow values were assumed as above, while the value of the H river section decline was adopted in accordance with separate calculations for each section of the river. The input data for the calculations and the results of theoretical potential calculations are presented in the following Table 2.

Table 2

Theoretical potential of Mszanka and Porębianka rivers

no. of section on Porębianka	SSQ, $[m^3 \cdot s^{-1}]$	gradient, [‰]	longht, [km]	H, [m]	P, [kW] acc. (2)	A_{th}, [kWh] acc. (1)
1	0.5	64	5.7	368	1850	15811800
2	1.0	19	2.9	54	530	4642800
3	1.44	11	7.0	78	1102	9653520
no. of section on Mszanka						
4	0.5	35	7.0	247	1212	10617120
5	1.0	13	5.0	63	618	5413680
6	1.5	13	3.1	40	589	5159640
7	3.46	6.4	3.9	25	849	7437240
totally					**6705**	**58735800**

The theoretical installable power for the Mszanka River with its Porębianka tributary is 6.7 MW, with the annual production of energy from this renewable source theoretically amounting to 58.736 MWh.

2.4. Technical potential assessment

When considering the issue of RE resources, it should be remembered that not all energy theoretically produced from a given source can be fully utilized. Therefore, the previously estimated theoretical resources of the Mszanka River should be reduced based on the possibilities of their technical acquisition. Technical resources are resources available from a given source that can be obtained with the best processing technologies, taking into account, above all, spatial constraints. The technical potential, also referred to as the net potential, is understood as the potential that can be obtained from damming constructions and HPPs as a result of the technically possible implementation of these structures. Technical potential is numerically smaller than theoretical one, because it is associated with many limitations and losses, the most important of which are:

- irregularity of natural flows over time (the need to take into account flood periods, when there is an obligation to leave the damming and periods when the available flow is too low for turbine start-up);
- variation of heads depending on river flow;
- the efficiency of the equipment used;
- non-returnable water intakes for non-energy purposes;
- the need to ensure the inviolable flow (in the main riverbed for the derivative power plants and in the fish pass).

In the designated 7 fragments of the Mszanka River, along with its tributary, Porębianka, the technical potential was calculated taking into account the above limitations. It was recognized that it is technically possible to build damming constructions and power plants even in places where currently such hydrotechnical constructions do not exist. The actual operating time of turbines during the year, necessary to determine the actual annual production, depends strictly on the selected mechanical equipment and the conditions for running flows in the river. This value also varies due to annual rainfall, i.e. wet years and dry years. To account for this variability in order to estimate the technical potential, the average turbine operation time was assumed to be 280 days based on a typical distribution of flows in the average year. The graphical distribution of the Mszanka River flows in the Mszana Dolna section in the annual distribution for the average year based on the observations from the years 1961–1970 is presented in Fig. 2 [19].

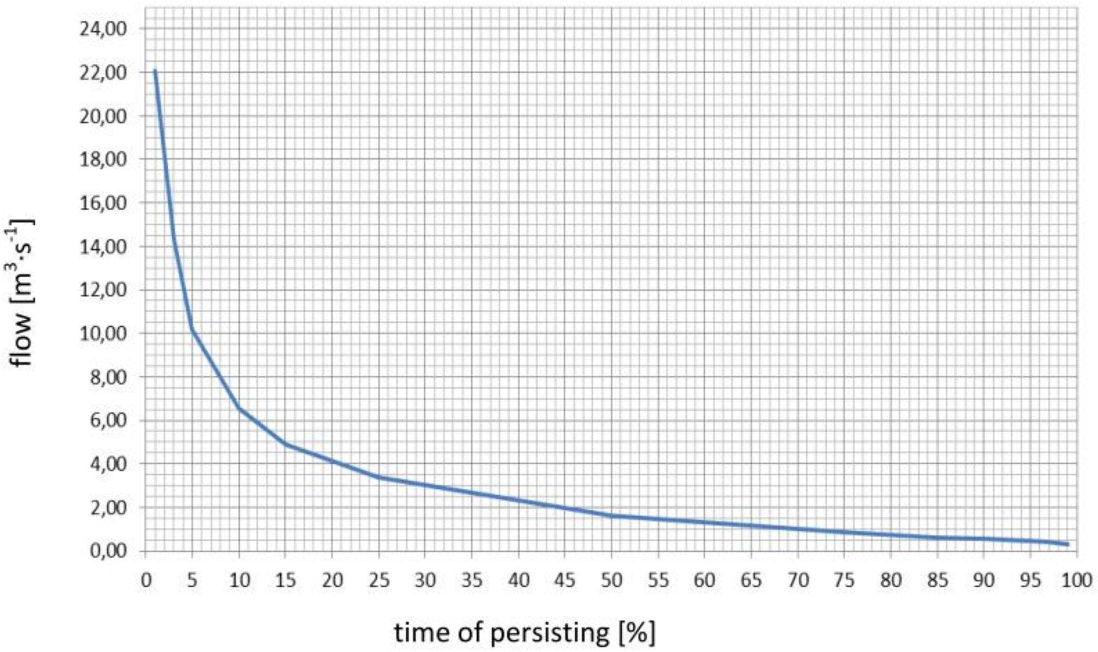

Fig. 2. The sum of the duration of flows along with higher values for the Mszana Dolna water gauge on the Mszanka river from the years 1961–70 [19]

A correction was made regarding the efficiency of the installed equipment in the form of the coefficient of 0.8, ie equal to 80 % of the efficiency of the whole power plant.

The necessity of leaving the inviolable flow as extremely environmentally important is not subject to economic criteria. Thus, it is the amount of water that cannot be used for energy purposes. In this study, the value of the inviolable flow was calculated according to the so-called Kostrzewa method [20] based on the hydrobiological criterion, commonly used in Poland. The confirmed dependence between intact flow and medium annual low flow (SNQ) is expressed in the correlation between the hydrological type of the river (lowland, transitional, submontane, mountain) and surface basin, and SNQ. For mountain watercourses with small basin areas, this method may be a barrier to the economic viability of some investments [17, 21, 22]. Inviolable flow is determined as one year-round value according to the following formula [23, 24]:

$$Q_n = k \cdot SNQ\ [m^3 \cdot s^{-1}]\ ;$$
$$\text{assumed } Q_n \geq NNQ \quad (6)$$

where: Q_n – inviolable flow $[m^3 \cdot s^{-1}]$; k – empirical parameter selected from the tables for the given river type and the size of the basin closed with the calculation cross-section; SNQ – average annual minimum flow for the calculation cross-section $[m^3 \cdot s^{-1}]$; NNQ – minimum of annual minimum flows for the calculation cross-section $[m^3 \cdot s^{-1}]$.

Finally, the technical potential of the Mszanka river was calculated, including the Porębianka tributary, according to the data provided in Table 3, according to the formula:

$$A_{tch} = 6720 \cdot P\ [kWh] \quad (7)$$

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

$$P = 9.81 \cdot Q_d \cdot H \cdot 0.8 \text{ [kW]} \quad (8)$$

where: 9.81 – the value of normal acceleration [$m \cdot s^{-2}$],

Q_d – available flow taking into account inviolable flow:

$$Q_d = SSQ - Q_n \text{ } [m^3 \cdot s^{-1}] \quad (9)$$

where: H – the head of the river section [m]; 0.8 – power plant efficiency equal to 80 %.

The input data for the above formula and the results of the calculations are given in Table 3.

The technical total power for the sections of the Mszanka River listed in Table 3 and shown in Fig. 1, along with its Porębianka tributary, is 4.6 MW, and the annual production of energy from this renewable source would be 31,127 MWh.

Table 3

Technical potential of Mszanka and Porębianka rivers

no. of section on Porębianka	SSQ [$m^3 \cdot s^{-1}$]	Q_n [$m^3 \cdot s^{-1}$]	Q_d [$m^3 \cdot s^{-1}$]	H [m]	P [kW] acc. (8)	A_{tch} [kWh] acc. (7)
1	0.5	0.08	0.42	368	1213	8151360
2	1.0	0.16	0.84	54	356	2392320
3	1.44	0.18	1.26	78	771	5181120
no. of section on Mszanka						
4	0.5	0.07	0.43	247	834	5604480
5	1.0	0.13	0.87	63	430	2889600
6	1.5	0.17	1.33	40	418	2808960
7	3.46	0.35	3.11	25	610	4099200
totally					**4632**	**31127040**

2.5. Effective potential assesment

The introduced term of the actual potential does not take into account the (highly individualized) economic analysis, but it is determined based on the actual current understanding of the procedures and constraints applicable for the implementation of the hydro-energetic development of the given river [17]. This analysis allows to estimate the river's energy production that is closest to the actual possibilities of new small HPPs. The actual potential is closely related to national regulations in the field of water management and the use of water for energy purposes. The following is an analysis for the Mszanka River based on the Polish conditions for the implementation of hydroelectric power plants in the Upper Vistula Water Region, ie in the area administered by Państwowe Gospodarstwo Wodne Polskie Wody – Regionalny Zarząd Gospodarki Wodnej in Kraków.

2.5.1. Hydrotechnical development

To determine the actual real potential, the possibility of energy management of solely the existing reservoirs, both in operation and intended for reconstruction / modernization, was adopted. For this purpose, an inventory of such reserves was carried out as part of the Restor-Hydro project [25]. In Poland, the planned use of water must take into account the requirements of morphological continuity. This does not directly prohibit the construction of new hydrotechnical structures that block watercourses, but in practice, the construction of a new dam for purely energy purposes is extremely difficult. Excessive development of watercourses with new barriers for the migration of organisms is in conflict with the principle of sustainable development and creates an additional risk of unfavourable and often irreversible environmental changes in the future [17]. Therefore, based on the respect for the use of water by subsequent generations, the existing hydrotechnical structures have priority in terms of energy use. As the initial criterion, a minimum (existing or achievable) head of 1.0 m was assumed.

On the basis of the above procedure, 6 sites were selected for the construction of new potential small HPPs. Initially it was estimated that they can be operated independently, ie the backflow of any of them does not reach the one located higher. The location of selected sites of potential small HPPs based on the Restor-Hydro map and field recognition is shown in Fig. 3 and their parameters are summarized in Table 4.

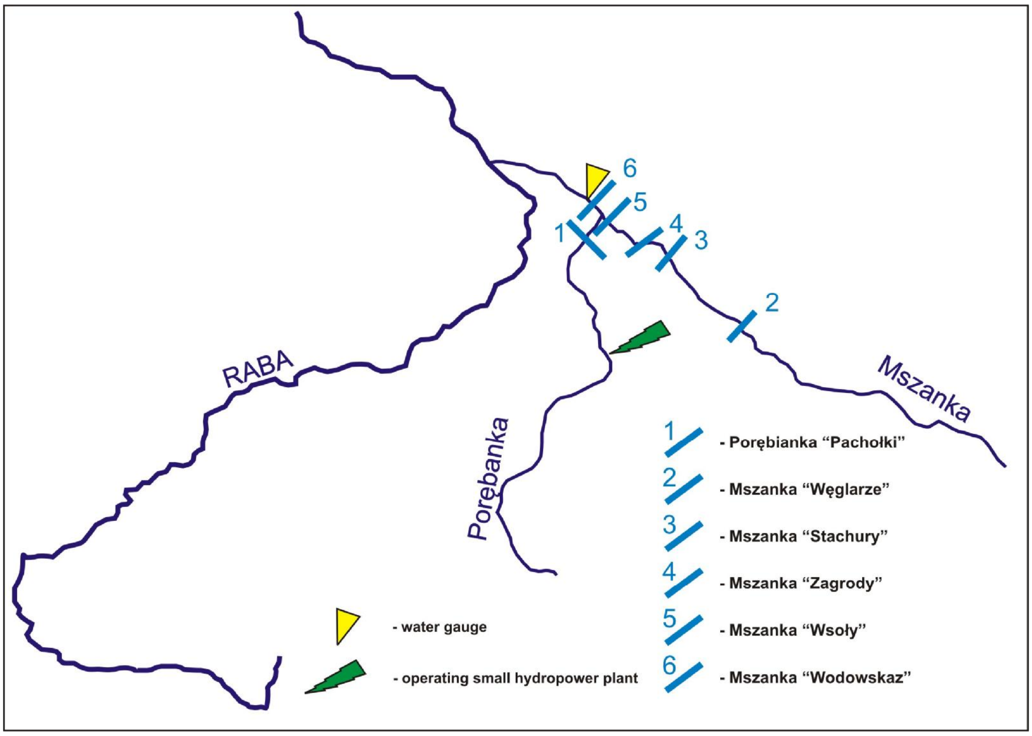

Fig. 3. Location of potential small HPPs on the Mszanka and Porębianka rivers

2.5.2 Environmental conditions according to the Water Framework Directive

For the countries of the European Union, the Water Framework Directive effective since 22 December 2000 is an obligatory document, the most important message of which is the protection of water resources for the future of generations. The main objective of the WFD is identical to the policy of sustainable development. The operational goal is to achieve a good condition of all surface and ground waters. Good water condition means the condition as close to natural as possible, ie when the smallest human interference is visible, as well as water flowing in a naturally shaped riverbed. For natural homogeneous water bodies (rivers, lakes, transitional and coastal waters) good ecological and chemical condition should be achieved, for artificial and heavily modified water bodies – good ecological potential and good chemical condition.

Under the WFD, water management planning is carried out by district basins. The analysed Mszanka River is located in the area of the Vistula River basin. For the Vistula river basin area, the Water Management Plan is in force in the area of the Vistula river basin, according to which the Mszanka River was covered by one uniform surface water body, the characteristics of which are presented in Table 4.

The above USWB Mszanka unit has not been entered in the list of watercourses threatened by failure to achieve environmental objectives. All hydropower projects carried out must comply with the environmental objective set for the USWB unit within which they will be implemented. Their implementation is possible, but it is extremely important to determine the impact of the planned small hydroplants on the status of surface waters and the implementation of environmental objectives taking into account biological elements, morphological, physicochemical and chemical. Due to the reverse nature of water abstraction and emission-free operation of small HPPs, the greatest importance is often related to morphological changes and patency of the watercourse for ichthyofauna. Therefore, it is justified to design new projects with already existing sections that are fitted with devices for fish migration, or will be retrofitted as part of the project.

Table 4

Uniform surface water bodies of the Mszanka River

European USWB code	USWB name	USWB type	status	environmental objective
PLRW 2000122138299	Mszanka	flysch stream (12)	strongly changed part of waters	good water potential

2.5.3. Protected areas

Potential locations of new small HPPs in Poland may be in areas under national protection (National Parks, Landscape Parks, Reserves, Protected Landscape Areas) or in protected areas within the European

Ecological Network Natura 2000. Among the listed, small HPPs in reserves is extremely difficult, or often completely impossible [26]. In other areas, the undertaking is associated with the risk of not obtaining a positive environmental decision, depending on the main objective of setting the protection and prohibitions in force in these areas [17].

The locations of small HPPs selected in chapter 2.5.2. are not in reserve areas, nor directly in other protected areas, and thus their implementation is considered possible and probable.

2.5.4. Watercourse patency

The Mszanka River is not an important waterway for the migration of bi-environmental fish. In design practice this means that it is not obligatory to design fish passes. From the point of view of the real potential, this does not introduce the need to calculate the inviolable flow and further calculations were carried out according to the more favourable scenario, ie without the implementation of the fish pass. Table 5 presents SSQ flow values for each of the selected potential small HPPs. For the Mszanka River and its tributary Porębianka, which were not designated as essential for migration of bi-environmental fish, the calculation of flow through the fish pass was abandoned. This does not mean, however, that the need to carry out a pass cannot be employed in the course of the project. The upper section of the river was considered of little perspective value due to the lack of existing infrastructure and very low flows. The distance between power plants on the same of the watercourse was defined by the reach of backwater. The exact calculation of the backwater range was omitted, but this criterion was used to indicate potential locations of small HPPs. 3 water thresholds were to be raised by 1 m, ie Mszanka “Zagrody”, Mszanka “Wsoły”, and Mszanka “Wodowskaz”, in order to rise water up to 2 m, to increase the energy possibilities of the adopted locations of small HPPs.

Table 5

The list of parameters of hydrotechnical objects possible for energy use

no. acc. Fig. 3	river/name of location	head [m]	SSQ [$m^3 \cdot s^{-1}$]	P [kW] acc. (8)	A_e [kWh] acc. (7)
1	Porębianka/Pachołki	1.5	1.44	16.95	113904
2	Mszanka/Węglarze	3.0	1.0	23.54	158189
3	Mszanka/Stachury	2.6	1.3	26.53	178282
4	Mszanka/Zagrody	2.0	1.4	22.00	147840
5	Mszanka/Wsoły	2.0	1.5	23.054	158189
6	Mszanka/Wodowskaz	2.0	3.35	52.58	353338
totally				**165.14**	**1109742**

The actual installable power for the Mszanka River with its Porębianka tributary (on the existing damming facilities) is thus 0.17 MW, with the annual production of energy from this renewable source at 1.110 MWh.

3. Results and discussion

The estimated theoretical potential of the Mszanka River along the entire length of the main watercourse, along with the largest tributary of Porębianka, is 6.705 kW of installable power and 58.735.800 kWh of energy produced. The technical potential (taking into account fluctuations of flows, the efficiency of a small HPP) would be 4.632 kW of installable capacity and 31.127.040 kWh of energy produced, respectively. The term ‘real potential’ primarily took into account the environmental objectives set for the subject of the watercourse based on the EU Water Framework Directive and its derivative national regulations resulting from the implementation. All existing water structures have been taken into account. It was recognized that the construction of new reserves only for hydro-energy purposes under Polish conditions is extremely difficult to implement. The existing restrictions on the use of water and the practice and experience in the implementation of small HPPs allowed to quantify the actual potential of the Mszanka River, ie the one whose implementation is highly probable. The value of installed capacity in new small hydro power plants is 165.14 kW, and the electricity produced there will be at 1109742 kWh. A graphical comparison of the results obtained is shown in Fig. 4.

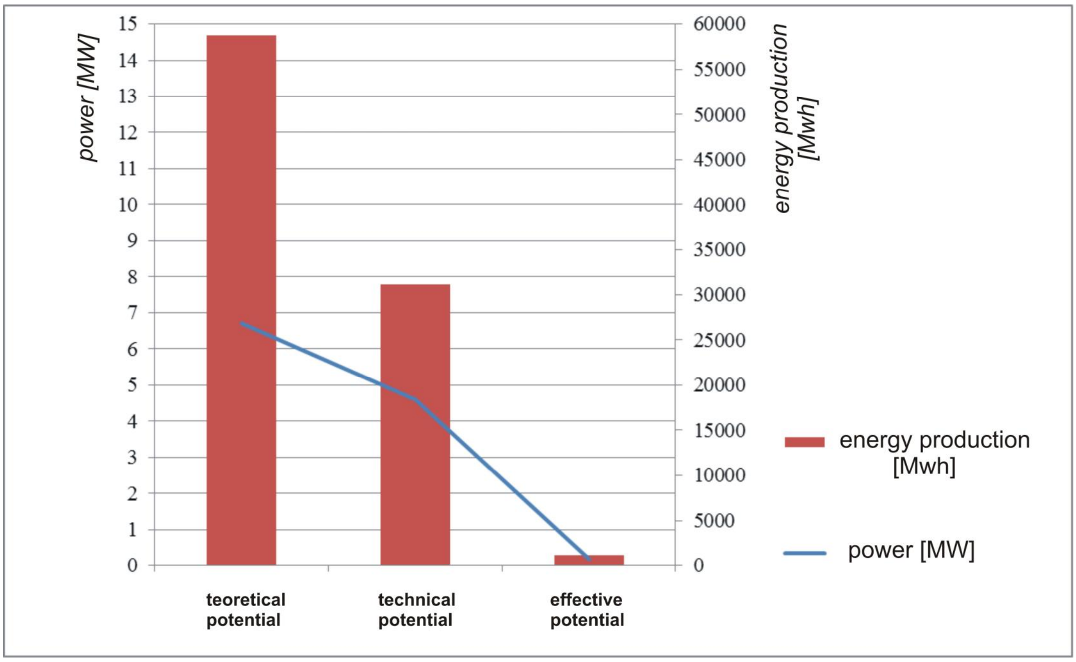

Fig. 4. Comparison of the installable and produced energy capacity based on theoretical, technical and real hydropower potential

By comparisons and assuming the estimated theoretical potential for 100 % of the river's energy potential, the technical potential is almost 70 % of the theoretical potential, and the real potential is only less than 2 %. In relation to the value of the technical potential, effective potential is less than 4 % of its value (Fig. 5). This is an extremely low value and shows clearly how much the potential values are overestimated by the generally accepted formulas, without critical reference to real-life situation.

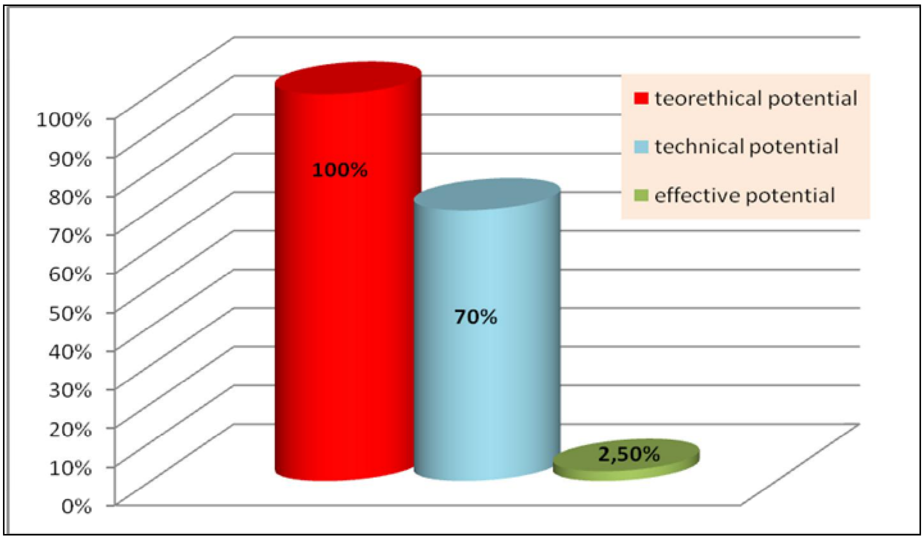

Fig. 5. Comparison of the % share of the theoretical, technical and actual potential of the Mszanka River

Conclusion

The real potential is a value showing the actual real potential achievable in a relatively short time. The estimated value is subject to strong individualization based on the legal regulations, environmental conditions, experience, and existing and manageable hydro-technical infrastructure that is obligatory for the watercourse. This value is significantly lower than the theoretical or technical potential. It does not include an economic analysis, as this was considered highly dependent on the expectations and potential of the prospective investor. In studies in the field of RE, often the value of the potential of a given section of the river is exaggerated, which allows too optimistic prognosis. In short-term and several-year considerations, the term of 'real potential' should be used, which realistically reflects the possibilities of hydropower development of the watercourse and energy production from this type of renewable source.

In real-life conditions, the implementation of small HPPs encounters various procedural obstacles, both environmental, technical and socio-economic. The greatest controversy in the implementation of small HPPs is the need to implement a new hydrotechnical structure permanently crossing the bed of the watercourse in order to obtain the head necessary for the operation of commonly used turbines. Therefore, the best chance of success is for projects that develop the existing infrastructure, where the condition of the environment can be considered stable.

The value of the real potential shows the actual possibilities of hydropower development of the Mszanka River under the conditions of the existing legal regulations. The construction of small HPPs on the Mszanka River and its Porębianka tributary with a total capacity of about 165 kW is likely and feasible in a relatively short time. This clearly does not preclude further energy management of waters flowing in the watercourse, with the need to build new dams and the risk of obtaining a decision on the environmental conditions of consent for their implementation.

The course of action presented in the work aimed at providing the numerical value of effective potential should be used in all considerations of hydropower management of flowing waters. It avoids over-optimistic overestimation of results. The course of proceedings is universal, in the case of implementation in other countries than Poland, it requires adjustment based on the legal regulations applicable there.

References:

[1] Allwood J. M., V. Bosetti, N. K. Dubash, L. Gómez-Echeverri, von Stechow C.: Glossary. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA 2014.

[2] Stangeland A., Grini G.: The potential and barriers for RE. Bellona Paper, Oslo, Norway, 2007.

[3] Hoogwijk M., Graus W.: Global potential of RES: a literature assessment. Background report prepared by order of REN21. Ecofys, PECSNL072975, 2008.

[4] Krewitt W., Simon S., Pregger T.: RE deployment potentials in large economies. DLR (German Aerospace Center), 2008.

[5] Resch G., Held A., Faber T., Panzer C., Toro F., Haas R., 2008. Energy Policy, 2008, 36 (11), 4048. doi:10.1016/j.enpol.2008.06.029

[6] Verbruggen A., Fischedick M., Moomaw W., Weir T., Nadai A., Nilsson L. J., Nyboer J., Sathaye J., Energy Policy, 2010, 38 (2), 850.

[7] Ataei, A., Biglari, M., Nedaei, M., Assareh, E., Choi, J.-K., Yoo, C. and Adaramola, M. S. Environ. Prog. Sustainable Energy 2015, 34, 1521. https://doi.org/10.1002/ep.12121

[8] Esen H., Mustafa I., Esen M. Building and Environment, 2007, 42(5), 1955. DOI:10.1016/j.buildenv.2006.04.007

[9] Izadyar N., Ong Ch. H., Chong W. T., Leong K. Y. Renewable and Sustainable Energy Reviews. 2016, 62, 908. doi:10.1016/j.rser.2016.05.005

[10] Resch G., Held A., Faber T., Panzer Ch., Toro F., Haas R. Energy Policy, 2008, 36 (11), 4048. doi:10.1016/j.enpol. 2008.06.029

[11] Zimny J., Michalak P., Bielik S., Szczotka K. Renewable and Sustainable Energy Reviews, 2013, 21, 117. doi:10.1016/j.rser.2012.12.049

[12] Ferreira J. H. I., Camacho J. R. C., Malagoli J. A., Guimaraes JR. S. C. Renewable and Sustainable Energy Reviews, 2016, 56, 380. doi:10.1016/j.rser.2015.11.035

[13] Farooq M. K., Kumar S. Renew. Sustain. Energy Rev, 2013, 20, 240. doi:10.1016/j.rser.2012.09.042

[14] Painuly J. P. Renew Energy, 2001, 24 (1), 73. doi:10.1016/S0960-1481(00)00186-5

[15] Sample J. E., Duncan N., Ferguson M., Cooksley S. Renewable and Sustainable Energy Reviews, 2015, 52, 111. doi:10.1016/j.rser.2015.07.071

[16] Morales S., Alvares C., Acevedo C., Diaz C., Rodriguez M., Pacheco L. Renewable and Sustainable Energy Reviews, 2015, 50, 1650. doi:10.1016/j.rser.2015.06.026

[17] Operacz, A. Renewable and Sustainable Energy Reviews, 2017, 75 (9), 1453. https://doi.org/10.1016/j.rser.2016.11.141

[18] Resolution no 4/2014 of the RZGW Director in Krakow [in Polish] https://bip.malopolska.pl/rzgwkrakow/Article/get/ id,848610.html

[19] IMGW 1980: Przepływy charakterystyczne rzek Polski w latach 1951–1970. WKiŁ., Warszawa [in Polish].

[20] Grela J., Stochliński T. 2005: O metodach wyznaczenia wielkości przepływu nienaruszalnego. "Aura" no. 6. [in Polish]

[21] Operacz A., Wałęga A., Cupak A., Tomaszewska B. Journal of Cleaner Production, 2018, 193, 575. https://doi.org/10.1016/j.jclepro.2018.05.098

[22] Operacz A. Economics and Environment, 2015, 1(52), 100. [in Polish] http://ekonomiaisrodowisko.pl/uploads/ ekonomiaisrodowisko52/06_operacz.pdf

[23] Kostrzewa H. 2005: Weryfikacja kryteriów i wielkości przepływu nienaruszalnego dla rzek Polski. Materiały Badawcze, Seria Gospodarka Wodna i Ochrona Wód., Warszawa. [in Polish]

[24] Wałęga A., Młyński D., Kokoszka R., Miernik W. 2014. Polish Journal of Environmental Studies, 24 (6), 2663–2676. DOI: https://doi.org/10.15244/pjoes/59294

[25] Restor-Hydro map, http://www.restor-hydro.eu/ en/tools/mills-map/

[26] Kaczor G., Bergel T., Bugajski P., Pijanowski J. 2015. Polish Journal of Environmental Studies, Hard Olsztyn. Vol. 24, No. 1, 107–114. [DOI: 10.15244/pjoes/28355]