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# ENVIRONMENTAL CONDITIONS OF HYDRO-ELECTRIC POWER STATION DEVELOPMENT BASED ON EXAMPLE OF RIVER BÓBR

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**Summary.** Reasonable exploitation of energy from renewable sources like energy of rivers, wind, geothermal or biomasses as well as solar radiation is a significant component of sustainable development strategy which is included in the Strategy of Renewable Energy Development in Poland. Renewable energy can have a significant share in energy balance, and thus ensure energy safety. Existing hydropower objects do not fully exploit the energy capacity of river Bóbr and its tributaries. The paper presents legal and economic conditions of building a hydropower plants. The energy capacity of the river has been assessed with regard to influence of hydropower on the environment.

**Key words**: renewable energy, hydropower, small water power stations, environment protection

## INTRODUCTION

Decreasing resources of fossil fuels and environment protection are the primary reasons for development of renewable energy technology. Energy generated from natural resources like sunlight, wind, water, geothermal heat is considered as naturally replenished and clean fuel source. In 2006, about 18% of global energy production came from renewable sources [EERE 2009, OFF-grid 2009]. The management of water resources has been dated for thousands of years. Power of water was used to grind flour, saw wood and power textile mills as well as manufacturing plants. In the late 19th century the force of falling water was used to generate electricity. So far, Itaipu Dam (in Brazil and Paraguay) was considered the biggest hydro-electric power station. It has been built between 1975 and 1991. Currently, the biggest one is The Three Gorges Dam on Yangtze River (in China). According to the Polish Central Statistical Office there is an annual growth of renewable energy share in total energy consumption. The oldest kind of renewable energy is the energy of water which has been used for irrigation or in various machines, such as watermills, sawmills, or lately hydro-electric power stations. The oldest paper concerning Polish water management dates back to year 1071 [Laudyn *et al.* 2000, Kowalewski 2005]. At that time power plants burning coal were producing electricity cheaper than hydro-electric power station.

Hydro-electric power stations generate at least 50% of electricity production in 65 countries, and at least 80% in 32 countries. About half of this capacity is generated in Europe and North America [ESHA 2009]. Hydro-electric power stations are often perceived as critical for the supply of electricity and as a symbol of economic development and prosperity [Łosoś 1995, Gołębiewski and Krzemień 1998, Chudy 2004, IHA 2009, ESHA 2009]. However, they have significant impact on the environment. The biggest disadvantage of hydro-electric power stations is the possibility of flooding lands and losing existing biodiversity.

There are significant differences in estimation of renewable energy sources potential. The hydro-energy potential in Poland is considered low mostly because of lowland terrain type, permeable bedrock, and low precipitation. However, hydroenergy objects like small hydropower plants (SHPP) are becoming more common. They are located usually on existing stage of fall. The SHPPs are considered as renewable energy source, and they exploit local energy production capacity. On the other hand, each new hydoenergy object has a significant influence on the environment. Fear of disrupting natural river valleys limits hydropower development. Damming up a river for the purpose of hydro-power generation divides the river and makes ichthyofauna free migration down the river more difficult or downright impossible. This leads to noticeable limitation of its numbers.

The impact of hydro-electric power stations on the environment is considered to be connected with the power plant size. Therefore it is considered low in the case of hydro-electric power stations with capacity less than 0.1 MW [Hoffman 1987, Kasperek *et al*. 2008]. Large hydropower plants have the reputation of structures vastly degrading the natural environment.

There is no limit of SHPP capacity specified in EU. Some countries like Portugal, Spain, Ireland, Greece and Belgium, accept 10 MW as the upper limit for installed capacity. In Italy the limit is fixed at 3 MW, in Sweden 1.5 MW, in France 12 MW [ESHA 2009]. According to Polish regulations, a hydro-electric power station which is defined as power plant producing up to 5 MW is considered as a small hydro-electric power plant [RZGWwW 1993, RDW 2000, RMTiGM 2000, POŚ 2001, PW 2001, RMŚ 2006, RMŚ 2007, OMG 2008, PE 2009].

A distinction is often made for the ‘Mini-hydro’ subgroup which comprises units between 100 kW and 1 MW. Sometimes the term Mini-hydro is used to refer to units in the range of 100–300 kW which feed local loads, not connected to the distribution network, and which are usually located in rural areas [Leonardo-energy 2009].

SHPPs can be further divided into mini hydro-power plants, units around 1 MW in capacity, and micro hydro-power plants with units as large as 100 kW down to a couple of kW [IHA 2009, ESHA 2009].

**Exploiting of hydroelectric sources**

A hydro-electric power station converts the energy of flowing water into electricity. The generated quantity of electricity is determined by the volume of water flow and the amount of head created by the dam. The greater the flow and head, the more electricity is produced [ELSP 2009]. The dam stores water and creates the head, penstocks carry water from the reservoir to turbines inside the powerhouse, the water rotates the turbines which drive generators that produce electricity. The electricity is then transmitted to a substation where transformers increase voltage to allow transmission to consumers [Juniewicz and Michałowski 1957, Hoffman 1987, 1992, Kucowski *et. al.* 1997, Laudyn *et al.* 2000, Marecki 2000, TRMEW 2009].

Parameters like the hydraulic head and the rate of fluid flow should be taken into account when a new location of hydropower is analysed. The basic characteristics that are important for designing hydro-electric power stations are river hydrology, ground slope and existing permeable bedrock.

## CHARACTERISTICS OF RIVER BÓBR

River Bóbr is situated in the south-western part of Poland and is the biggest tributary of river Odra. The length of river Bóbr is about 272 km (270 km in Poland, 2 km in Czech Republic). The river flows through Lower Silesia and Lubus Land. The spring of the river is located at elevation of 780 m above sea level in the Karkonosze mountain range. The estuary of the river is at 516.2 km of river Odra.

The waters of river Bóbr are qualified in the 3$^{rd}$ category [Andruszkiewicz (ed.) 2008]. The river has variable character, from typically mountain river to lowland section at inflow. Slope steepness in the mountain part vastly increases the flooding risk.

River Bóbr is one of greatest Polish rivers in terms of the flood risk and has hydro-energy potential at the same time. Dams have been built on river Bóbr for flood protection, among other reasons. There are also a few hydro-electric power stations located down the river. The existing weirs cascade allowed the construction of over 24 hydro-electric power stations with total power of 110 MW [Kowalewski 2005]. Stabilisation of the river channel is possible by constructing special weirs with gates. Existing stabilisation of river banks could be used for the location of new hydro-electric power stations. The design of the weirs creates the possibility of using the heads (difference in height between the turbines in the power plant and the water surface) for hydro-energy generation. It has been proposed to construct small hydroelectric power plants (SHPP) which would operate during low and average discharges.

There are also some hydraulic barrages in the outflow to river Odra. The construction of large hydraulic barriers has resulted in increased low and average discharge, and can cause environmental damage [Mokwa and Wiśniewolski (eds) 2006].

## MATERIAL AND METHODS

Selection of potential locations for new hydro-electric power stations has to be preceded by topographic map analysis, atmospheric precipitation evaluation, and flow discharge calculation. Hydrological balance of the river is determined by precipitation and its spatial and time distribution. The annual precipitation in the Bóbr catchment varies and extreme precipitations have been recorded between 686 to 1380 mm. The average value of water flow in the estuary of the river is 9.24 $dm^3km^{-2}s^{-1}$. An overview of the Bóbr flow and the respective gauge evaluations are presented in Table 1.

Table 1. Characteristics of discharge in river Bóbr [Kasperek *et al.* 2008]

| Water gauge | km | Catchment area, $km^2$ | SSW, cm | SSQ, $m^3s^{-1}$ | SNQ, $m^3s^{-1}$ |
|---|---|---|---|---|---|
| Bukówka | 263.1 | 58.5 | 98 | 1.01 | 0.43 |
| Błażkowa | 255.7 | 104 | 82 | - | - |
| Kamienna Góra | 248.0 | 190 | 82 | 3.31 | 1.23 |
| Sędzisław | 243.1 | 426 | 56 | - | - |
| Wojanów | 218.0 | 535 | 151 | 7.10 | 3.02 |
| Jelenia Góra | 205.1 | 1049 | 106 | 16.6 | 8.68 |
| Pilchowice | 191.9 | 1209 | 42 | 18.3 | 5.90 |
| Dąbrowa Bolesławiecka | 132.5 | 1910 | 141 | 19.9 | 5.79 |
| Szprotawa | 97.0 | 2878 | 124 | 32.1 | 16.78 |
| Żagań | 74.5 | 4254 | 310 | 39.3 | 13.9 |
| Dobroszów Wielki | 52.1 | 5365 | 119 | - | - |

The pressure for using renewable resources leads to modernisation of old weirs and designing new objects. In the case of river Bóbr, modernisation of the weirs Zagan I, Zielisko, Bukowka, Przysieka, Sobolice, Gubin and other hydraulic structures of the Krzywaniec-Dychow-Raduszec Stary system has already been done [Green-trust.org 2009]. The biggest hydropower plant on the Bóbr is the Dychów Water Power Plant (Tab. 2). It is a complex object which is composed of two power plants on rivers Bóbr and Nysa Łużycka. The Dychow pumped storage power plant plays the primary role here. Apart from Dychów, there are 16 other SHPPs [Green-trust.org 2009]. There are also some case studies that evaluate flood risk and possibilities of implementation of new SHPPs [Błachuta *et al.* 2006, Mokwa and Malczewska 2006, Kasperek *et al.* 2008].

Table 2. The biggest hydropower plants on river Bóbr [Kasperek *et al*. 2008]

| Name | Effective power, MW | Year of putting into motion | Plant rating, MW | Hydropower type |
|---|---|---|---|---|
| Dychów | 79.5 | 1934–1936 | 79.5 | pumped-storage power station |
| Małomice | 0.450 | 1992 | 0.8 | river hydro-plant |
| Żagań I | 0.915 | 1939<br>1956 | 0.928 | river hydro-plant |
| Żagań II | 0.920 | 1963 | 0,910 | river hydro-plant |
| Grajówka | 2.600 | 1922 | 2.93 | river hydro-plant |
| Gorzupia I | 0.600 | 1924 | 0.71 | river hydro-plant |
| Raduszec Stary | 2.940 | 1936 | 2.94 | river hydro-plant |
| Szprotawa | | 1998 | 0.634 | river hydro-plant |
| Gorzupia II | | 1998 | 1.680 | river hydro-plant |

## DISCUSSION OF RESULTS

New locations of SHPPs are restricted in national parks and nature reserves. There are also some limitations for other locations, with other forms of environmental protection such as landscape parks, areas of Natura 2000 programme, monuments of nature. The ecological aspects should be taken into consideration because they have significant a influence on the maintenance of existing SHPPs or developing new ones.

There should be a plan which assumes a possibility of general malfunction of SHPP. Such a situation would cause a change of SHPP efficiency and would contribute to a flood risk. The turbines work properly when the head and flow discharge are at designed level. Any deviation from these parameters must be compensated by opening or closing the control devices. The head can usually be considered constant, but the flow varies over the year [ESHA 2009].

The Third Conference of the Parties to the United Nations Framework Convention on Climate Change, where climate changes were discussed, was held in Kyoto in December 1997. The conference resulted in the decision to start preventing global warming by limiting emission of greenhouse gases. The European Union recognised renewable sources of energy as an important alternative for energy sources based on fossil fuels, and this idea was subsequently drafted. The European Commission has set an objective of 14 000 MW by 2010 that should be achievable, and that SHPPs would be the second largest contributor next to wind power [RDW 2000]. Therefore, regarding sustainable development, hydro-power plants are essential for Poland, even though their potential in Poland is considered as low.

Turbines convert water energy into electricity. The most common impulse turbine is the Pelton. The development of technology that allowed to maximise the use of hydropower resources was brought by the Kaplan turbine, where working fluid changes pressure as it moves through the turbine and gives up its energy. The design combines radial and axial features. There are also Francis, Propeller, Bulb, Tube, Straflo turbines. However, they are very expensive to design, manufacture and install. Water turbines associated with dams have a negative influence on ichthyofauna, because they obstruct the path of fish on their migration journey [Mokwa and Malczewska 2008]. Fish mortality on Francis turbines is estimated at between 5 and 90% for small salmon; in the case of Kaplan turbines it is between 5 and 20% [Mokwa and Malczewska 2008, Mokwa and Wiśniewolski (eds) 2008]

The costs of SHPP installations vary considerably because the sites, conditions and sizes are different. The main cost is connected with the design and the construction of buildings – up to 75% of total cost; another important factor is assessment of impact on the environment. The maintenance of hydropower plant is planned for up to 50 years at most. It reduces the total cost of operation since it is connected with periodic maintenance. Hydropower plant building costs are between 1541 to 6985 USD/kWe (average 3623 USD/kWe) depending on hydro-power plant capacity and size [Michalski 2006]. Another important (and commonly neglected) issue is resolving claims to the property right of the land.

Development of hydro-electric power stations can have a negative impact on water quality: soil erosion and landslides cause drifting of sediments which can lead to clogging up streams [Mosony 1963, Morris and Fan 1998]. Spilling of water over spillways can result in supersaturation of water with gases from air [Marecki 2000, Chudy 2004, Kowalewski 2005]. On the other hand, SHPPs improve ground moisture and raise ground water level.

The most suitable locations are ones which had exploited water energy, such as mills or sawmills in the past. The best solution is available where parts of old buildings are still present. The weirs allow getting medium and high head, so water can be conveyed to the turbines via a pressure pipe or penstock. SHPPs can be defined as environment-friendly when a stabilising dam gets rebuilt or uses former facilities – especially at low damming – with modern technologies like fish passes. The reservoir connected with hydro-electric power station is considered to have low impact on the environment when it is located in mountain regions. However, in the case of river Bóbr, the high head is in the Karkonosze National Park so it is also a matter of location in protected areas.

## Environmental problems

Hydropower plants can have a significant impact on the surrounding areas. Reservoir formed behind the dam can cover the area of a small town. It changes scenic location and farmland and also affects fish and wildlife habitats. Even though hydropower offers advantages over energy sources based on fossil fuels and is considered as essentially emission-free, it also brings about undesirable environmental changes such as downstream water quality degradation.

The development of SHPPs can change the environment of fish (fish injury and mortality from passage through turbines). Advanced hydropower turbine technology could minimise the adverse effects and preserve the ability to generate electricity from this important renewable resource [Hydropower 2009]. Fish passage facilities (ladders, locks, lifts, trucking) should be a supplement to all SHPPs, above all.

**Advantages and disadvantages of hydropower**

Developing hydroelectric sources allow diversification of energy sources. Generally, when a dam with SHPP is constructed, electricity can be produced at a constant rate. Dams are designed to last long term, therefore they can contribute to generation of electricity for many years. The lake which is formed behind the dam can be used for increasing water-retention capacity. To some extent, it can also be temporary storage for contaminants that can improve self-purification of streams. Moreover, it can be used as tourist attraction. Hydropower plants can improve local climate, therefore they can be helpful to support biodiversity by providing new habitats. The flow over the damming structures induces oxygenation of the water. These structures can be considered as an enrichment of landscape. On the other hand, regulation and damming of rivers have closed fish access to spawning-grounds [Chudy 2004, Kowalewski 2005, Błachuta 2006, Mokwa and Malczewska 2008, ESHA 2009]. Fish injury caused by passing through turbine blades is one of the reasons of high fish mortality. Fish is also exposed to stresses associated with pressure changes and dissolved gas supersaturation. These are the reasons for species annihilation. Therefore, protective structures such as bars are required before hydro-electric power stations. Another important factor which should be analysed is abrasion of the river channel. Flood waters can lower the ground surface near damming structures by removing upper layers of soil, which is dangerous for peopled areas located near the river and has an important influence on flow discharge. Abovementioned reasons are the root cause why hydro-power plants are considered as environmentally questionable projects.

## CONCLUSION

The use of water is one of the ways that leads to more sustainable development. The development of energy from renewable resources is a very important step in the reduction of $CO_2$ emissions.

The progress in designing new locations for SHPPs proves that even in highly restrictive environmental conditions sustainable coexistence of hydropower and the environment is possible. Moreover, they enable producing clean, renewable energy and contribute to extending national power grid.

Most of the suitable locations for hydrotechnical facilities on river Bobr have already been taken. Still, growing interest in SHPPs and high energy prices draw more attention to building new ones. New SHPPs can be created around existing dammings, particularly mountain dammings where steep slopes can be found easily. Each case of building new SHPP should be analysed separately, with respect to existing natural resources.

## REFERENCES

Andruszkiewicz K. (ed.), 2008. Report on the state of the environment in the Lower Silesia Province in 2007 (in Polish). Wydawnictwo Inspekcji Ochrony Środowiska, Wrocław.

Błachuta J. Jankowski W, Okińczyc M., Poprawski L., Świerkosz K., 2009. Environmental conditions for the realization of small water retention program in the Lower Silesia Province – forecast (in Polish). Środowiskowe uwarunkowania realizacji programu małej retencji wodnej w województwie dolnośląskim – prognoza – Wrocław. Urząd Marszałkowski Województwa Dolnośląskiego.

Chudy Ł., 2004. Small hydroelectric plants in the environment and the economy (in Polish), Gospodarka Wodna, 7, 272–277.

EERE 2009. Department of Energy, Energy efficiency and renewable energy U.S. http://www1.eere.energy.gov/windandhydro/wind_potential.html (8.02.2010)

ELSP 2009. PGE Energia odnawialna spółka akcyjna: http://www.elsp.com.pl/ (8.02.2010)

ESHA 2009. Guide on how to develop a small hydropower plant: http://www.esha.be-/fileadmin/esha_files/documents/publications/publications/part_1_guide_on_how_to_develop_a_small_hydropower_plant-_final.pdf (8.02.2010)

Green-trust.org 2009. http://www.green-trust.org/hydro.htm (8.02.2010)

Gołębiewski S., Krzemień Z., 1998. Guide for the small hydropower plant investor (in Polish). Wydawnictwo Fundacja Poszanowania Energii, Warszawa.

Hoffman M., 1987. Operation manual for small hydropower plant (in Polish). Instytut Energetyki – Ośrodek Normalizacji, Warszawa.

Hoffman M., 1992. Small hydropower plants (in Polish). Wydawnictwa. Nabba sp. z o.o., Warszawa.

Hydropower 2009. http://hydropower.id.doe.gov/turbines/index.shtml (8.02.2010)

IHA 2009. The International Hydropower Association (IHA): http://www.hydropower.org/ (6.04.2010)

Juniewicz S., Michałowski S., 1957. Hydropower plants (in Polish). PWT, Warszawa.

Kasperek R., Czaban S., Głowski R., Malczewska B., Sołtys J., Schauer I., Wiatkowski M., 2008. Analysis of rivers of the Lower Silesia and Opole Provinces in the aspect of locations for the construction of dams for hydropower generation on existing weirs, 2008/2009 (in Polish). UP Wrocław, typescript.

Kowalewski Z., 2005. Utilisation of hydropower as an element of development of renewable power generation (in Polish), Wiad. Melior. Łąk. 2, 87–91.

Kucowski J., Laudyn D., Przekwas M., 1997. Energy generation and environmental protection (in Polish). WNT, Warszawa.

Laudyn D., Pawlik M., Strzelczyk F., 2000. Power plants (in Polish). WNT, Warszawa.

Leonardo-energy 2009. http://www.leonardo-energy.org/ (8.02.2010).

Łosoś J., 1995. Selected problems of the future of hydro engineering in Poland (in Polish), Gospodarka Wodna 11, 304–308.

Marecki J., 2000. Foundations for transformations in power generation (in Polish). WNT, Warszawa.

Michalski M.Ł., 2006. When fossils are exhausted – there will be no choice... (in Polish) www.gigawat.info (24.08.2006).

Mokwa M., Malczewska B., 2008. Electro-electronic barriers protecting ichthyofauna against hydro-electric power station turbines. Polish Journal of Environmental Studies, 17 (3a), pp. 419–422,

Mokwa M., Wiśniewolski W. (eds), 2008. The protection of ichthyofauna in rivers with hydrotechnical structures (in Polish), Dolnośląskie Wydawnictwo Edukacyjne, Wrocław.

Mokwa M, Radczuk L., Kasperek R., Markowska J., Olearczyk D., Gromada O., Malczewska B., Pikul K., 2006. Estimation of flood losses and risks of river Bóbr (in Polish). UP Wrocław, typescript.

Morris G.L., Fan J., 1998. Reservoir sedimentation handbook. Design and management of dams, reservoirs and watersheds for sustainable use McGraw-hill. New York.

Mosony I.E., 1963. Water Power Development, vol. I and II. Publishing House of the Hungarian Academy of Sciences.

OFF-grid 2009. http://www.off-grid.net/2008/08/29/renewable-energy-101/

OMG 2008. Announcement of the Minister of Economy, of 21st April 2008, On the report on the realization of quantitative objectives and achieved effects in the field of electric power generation from renewable sources (in Polish). M.P. of 9th July 2008.

PE 2009, Energy Law. Act of 10th April 1997, Dz. U. nr 54, Uniform text of 20th September 2006 with subsequent revisions (in Polish).

POŚ 2001. Environmental Protection Law. Act of 27th April 2001 with revisions (in Polish).

PW 2001. Water Law. Act of 18th July 2001 with subsequent revisions (in Polish).

RDW 2000. Framework Water Directive. Directive No. 2000/60/EC.

RZGWwW 1993. Regionalny Zarząd Gospodarki Wodnej we Wrocławiu, Gospodarka zasobami wodnymi dorzecza górnej i środkowej Odry. RZGW, Wrocław 1993.

RMŚ 2007. Regulation by the Minister of Environment, of 20th April 2007, On the technical requirements for hydrotechnical structures and their location (in Polish). Dz. U. nr 86, poz. 579.

RMTiGM 2000. Regulation by the Minister of Transport and Marine Economy, of 30th May 2000, On the technical requirements for road engineering objects and their situation (in Polish). Dz. U. nr 63.

RMŚ 2006. Regulation by the Minister of Environment, of 17th August 2006, On the scope of instructions for water management (in Polish). Dz. U. nr 150.

TRMEW 2009. Towarzystwo Rozwoju Małych Elektrowni Wodnych, www.trmew.pl, (8.02.2010), Biuletyn TRMEW, 2009, Wydawca Towarzystwo Rozwoju Małych Elektrowni Wodnych.

## UWARUNKOWANIA ŚRODOWISKOWE ROZWOJU ENERGETYKI WODNEJ NA PRZYKŁADZIE RZEKI BÓBR

**Streszczenie.** Racjonalne wykorzystanie energii pochodzącej ze źródeł odnawialnych, takich jak energia spadku wody w rzekach, energia wiatru, geotermalna lub biomasy, a także promieniowania słonecznego, jest istotnym składnikiem powstających strategii rozwoju, wpisanych do Strategii rozwoju energetyki odnawialnej w Polsce. Odnawialne źródła energii mogą mieć znaczący udział w bilansie energetycznym, a tym samym zapewniać bezpieczeństwo energetyczne kraju. Istniejące elektrownie wodne nie wykorzystują w pełni potencjału energetycznego rzeki Bóbr i jej dopływów. W artykule przedstawiono prawne i ekonomiczne warunki budowy elektrowni wodnych. Energetyczny potencjał rzeki został oceniony ze szczególnym uwzględnieniem jego wpływu na środowisko wodne.

**Słowa kluczowe:** odnawialne źródła energii, elektrownie wodne, małe elektrownie wodne, ochrona środowiska