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Comparative Assessment of the Hydromorphological Status of the Rivers Odra, Bystrzyca, and Ślęza Using the RHS, LAWA, QBR, and HEM Methods above and below the Hydropower Plants

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Abstract: The purpose of this paper is to assess the hydromorphological status of watercourses above and below the hydropower plants. To this end, four methods were selected which represent various groups of methods used in various member states of the EU. Particular focus was on the RHS method (assessment of the physical habitats—the method used in Poland). The following methods were also used: LAWA (assessment of physical habitats, Germany), QBR (assessment of bank habitats, Spain), and HEM (comprehensive morphological assessment, the Czech Republic). For each of these methods, appropriate hydromorphological status indicators were calculated (assessment on a five grade scale). The analysis revealed that despite the different assumptions, the methods lead to similar results and can be used in various countries, especially in Europe. Because of the broad spectrum of space and time data used in the analysis, the results of HEM are the most reliable; however, this method is also the most difficult to use. All the methods meet the requirements of the Water Framework Directive, which calls for rational water management. Based on the hydromorphological assessment, the results obtained helped us to evaluate the environmental changes on the river sections above and below the hydropower plants.

Keywords: hydropower plants; hydromorphology; ecological state; water quality; rivers

1. Introduction

The hydromorphological status is one of the complementary elements in the assessment of the ecological condition of surface water bodies. As such, it is a necessary part of the water quality monitoring process as per the Water Framework Directive, which has been ratified by Poland and which assumes rational water management, especially in environmentally valuable areas, in which water resources are used (e.g., for power generation or for ensuring the energy security of the country, with particular focus on harmonizing the environmental requirements with the economical development). While the assessment of the biological elements is decisive, the physicochemical elements are only complementary [1–4].

In Poland the assessment of the hydromorphological elements is carried out using the River Habitat Survey (RHS) method, which assumes an assessment of basic morphological features of both the channel and the banks in 10 profiles, as well as a synthetic assessment of the entire watercourse section [5]. In other European countries the classification of hydromorphological elements is based on different assumptions, which account for different factors related to the morphology in the river sections under study. In Germany, a group of methods of physical habitat assessment is used—LAWA, in Spain—a group of methods of bank habitat assessment—QBR and in the Czech Republic—a group of methods of morphological assessment—HEM. Additionally, the methods of watercourse longitudinal continuity assessment for the presence of fish are used. All these methods meet the requirements of the Water Framework Directive [5–13]. Currently, the methods of hydromorphological flow change assessment are not in use in the EU [6].

The assessment of the physical habitats, such as for example RHS, is used to describe the physical conditions in the habitats (however, some methods also allow for an overall characterization), their heterogeneity (diversity), and the structure of the ecosystems. Such methods are commonly used and allow one to compare the ecological characteristics of individual regions under study. However, due to the limited interpretation framework (adoption of the research sections), the limitations associated with the implementation of these methods are as follows: the diversity of specific habitats is often not sufficiently accounted for (short test sections are often insufficient for a diagnosis), dynamics of various phenomena are not taken into account (in short sections they are usually static and simplify the array of all the hydromorphological elements), the location of research should be identified in detail; usually, the tests can only be carried out in the field (due to the space and time limitations for the analysis), the physical processes are being simplified. Physical assessment alone is not enough for overall hydromorphological assessment. Despite the undoubted minuses, such methods are most often used in the European Union, i.e., in the following countries: Austria, Denmark (DHQI—Danish Habitat Quality Index), England and Wales (RHS), France (CarHyCe—hydromorphological characteristics of rivers), Germany (LAWA—habitat assessment for rivers), Ireland (RHAT—hydromorphological assessment of rivers), Italy (CARAVAGGIO—basic assessment of the river habitat and hydromorphological conditions), Portugal (RHS to Portuguese conditions), Slovakia (Hydromorphological Assessment Protocol for the Republic of Slovakia), and Spain (IHF—an indicator for the assessment of fluvial habitats in rivers of the Mediterranean Sea) [5,6,12,13].

The method of assessing riverside habitats on the banks of watercourses has similar applications and limitations as the method described previously (time and space limitations in research and simplification of the physical processes); however, it interprets the links between the watercourse and vegetation, especially the riparian one, in a much better way. They complement said habitat methods in connection with the assessment of the banks, while physical methods focus on the river bed. The method can be, to some extent, integrated with GPS and remote sensing methods, it is not limited to field tests. It has been introduced to a much lesser extent than the physical habitat assessment method, mainly in South European countries (Spain, Italy), but is treated as one of the reference methods for the hydromorphological evaluation of watercourses—i.e., QBR = the riparian forest quality indicator only in Spain [5–9].

When it comes to the assessment of the hydromorphological status, the morphological assessment methods are the most comprehensive—they take into account the space and time variability of phenomena, and the GPS and remote sensing methods can be used. The main limitation may be the poor availability of data, which would enable a comprehensive assessment and explain the phenomena encountered. This method must be carried out by qualified specialists due to its complexity and the multiplicity of information that must be combined and connected to obtain a complete characterization in water bodies. In this case, there are no orderly morphological characteristics, which may be a hindrance. This group of methods is used in many European countries, i.e.,: the Czech Republic (HEM—hydroecological monitoring method), France (SYRAH-CE and AURAH-CE—control of hydromorphology), Italy (MQI—hydromorphological quality index), Latvia and Scotland (MImAS—Morphological Impact Assessment System) [5,6,10,11].

The watercourse longitudinal continuity assessment methods for the presence of fish consist in assessing the conditions for the movement of aquatic organisms and potential barriers in the flow path. They focus mainly on these organisms. This assessment could also apply to the conditions for the development of inland navigation as well as the transport of sediments. It is also useful for the development of river restoration programs. Currently, the evaluations are performed on a small scale and it would be worthwhile to increase their scope—this, however, requires one to learn the biology of aquatic species, the ecological diversity of the watercourse, or the processes that form in the course of the river. Further research is required to integrate the method at the catchment level and to take into account a number of factors that affect the continuity of watercourses. The only country in the European Union that uses the group of methods described in accordance with the Water Framework Directive is France—i.e., ROE (National Database on Continuity Barriers) and ICE (Information on Ecological Continuity) [5,6,14].

The main purpose of this paper is to assess the hydromorphological status of waters above and below the hydropower plants on the rivers Bystrzyca, Ślęza, and Odra, Poland, using the above mentioned methods, with particular focus on the RHS method. The results obtained will contribute to the assessment of environmental changes on the transformed river sections below the hydropower plants. These changes are mainly related to the erosion processes below the dam and the sediment accumulation on dams, which is usually combined with the simplification of the hydromorphological forms in watercourses, the more frequent appearance of invasive species or the ongoing changes in species structure and diversity. Sometimes, these changes have a positive effect related to the formation of new environmental equilibrium [5,8,10,12,14–20].

2. Study Area

For the purpose of our research, four plants were selected (for the river Odra, the same sections above and below the power plants Wrocław I and Wrocław II were chosen) located in the south-west of Poland, within the agglomeration of Wrocław, south of Poland. They are the following flow-through hydropower plants: Wrocław I—on the Southern Odra river; Wrocław II—on the Northern Odra river (both are part of the City Water Node in Wrocław); Marszowice—on the Bystrzyca river and the "Sobolewski" hydropower plant on the river Ślęza. All these plants are small hydropower plants (SHPs). In Poland, Germany, and the Czech Republic, a plant is considered a SHP if its power does not exceed 5 MW, in Spain its power may not exceed 10 MW [21]. The location of the research sections, (with the river kilometers) is shown in Figure 1.

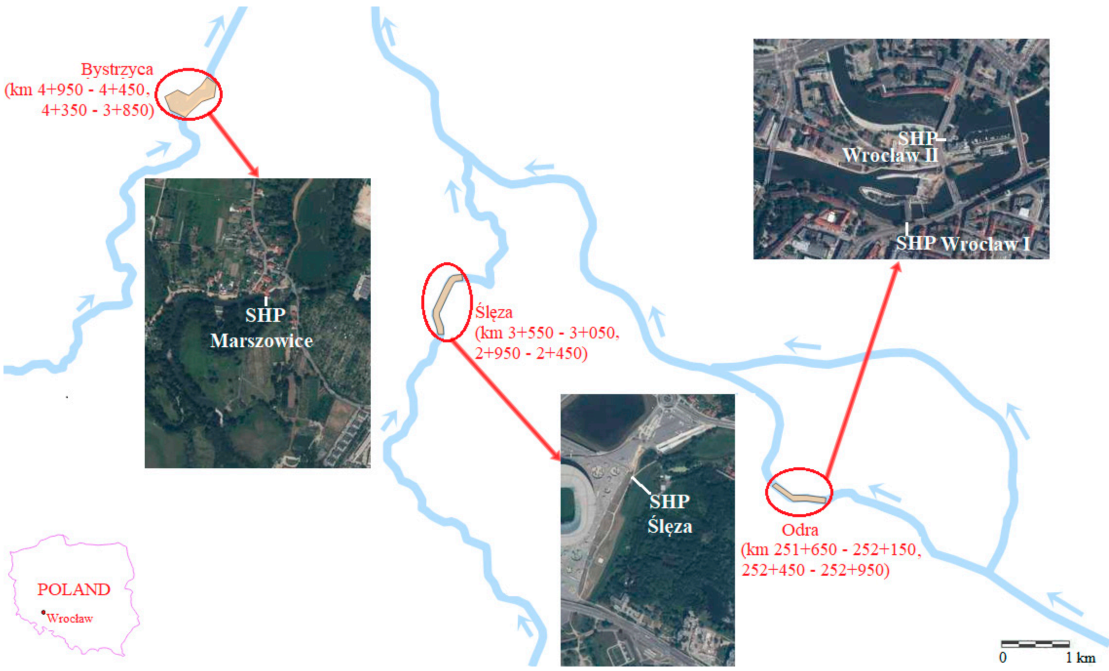

Figure 1. The location of the research sections in RHS—above and below the SHP (the rivers Odra, Ślęza, and Bystrzyca).

3. Research Methods

The hydromorphological elements were investigated using the River Habitat Survey (RHS) method in August, September, and November 2016 and at the turn of April and May 2017 (field measurements during the growing season and additional measurements outside the growing season for comparison). On the rivers Ślęza and Bystrzyca—i.e., rivers with only slightly disturbed hydromorphology (the Odra near power plants Wrocław I and Wrocław II does not change over the year due to the artificial materials used in the riverbed and on adjacent land)—an assessment of the hydromorphological conditions was carried out both above and below the plants. In this method, a 500 m long river section is chosen and 10 profiles are determined, every 50 m. Based on the description of basic morphological properties of the channel and banks (up to 50 m from the bank) and a synthetic description of the entire RHS section, several hundred parameters are obtained that characterize the hydromorphological conditions of this section, as well as synthetic indicators (the information is recorded on a special form)—Habitat Modification Score (HMS) and Habitat Quality Assessment (HQA). These indicators are synthetic. The Habitat Quality Assessment (HQA) reflects the behavior of natural hydromorphological elements of the river valley accounting for their presence and diversity. In the overall assessment, value intervals for this indicator are defined (percentage of the highest values). These intervals are given in Table 1 [5]. The Habitat Modification Score (HMS) shows to which extent the watercourses are hydromorphologically transformed. For this indicator, two classes are defined—Table 1 [5,22]. Eventually, the hydromorphology is assessed on a two point scale (on a five point scale for the RHS), i.e., I—natural sections, II—artificial or strongly transformed sections. The final result of the RHS method is obtained by selecting the weaker hydromorphological status with reference to HQA and HMS (the same procedure in the LAWA method). This is in line with the requirements set out in the implementing provisions of the Water Resources Law, which transposes the provisions on the monitoring of individual water quality elements as mentioned above. Other methods in the European Union also assume an assessment on a five point scale for the hydromorphological status and on a two point scale for the overall assessment. However, other hydromorphological elements are also taken into account—e.g., an assessment of bank habitats or capacity for migrations of water organisms [5,8].

Table 1. Ranges of values of the Habitat Quality Assessment (HQA) and the Habitat Modification Score (HMS) for the classes of hydromorphological status [5].

HQA			HMS		
Class	**% from Max Pt. (136)**	**Class Description (Hydromorphological Status)**	**Class**	**Nr of Pts.**	**Class Description (Hydromorphological Status)**
I	0–20	very natural	I	0–2	natural
II	21–40	natural	II	3–8	weakly transformed
III	41–60	moderately natural	III	9–20	moderately transformed
IV	61–80	weakly natural	IV	21–44	considerably transformed
V	81–100	little natural	V	from 45	strongly transformed

The RHS method presented above was compared to the methods representing three different groups, i.e.,:

- LAWA, belonging to the group of methods that assess the physical habitat, describe the physical conditions of habitats, their heterogeneity and structure (Germany);
- QBR, belonging to the group of methods that assess the bank habitat and focus on the relationships between a watercourse and its vegetation, especially riparian (Spain);
- HEM, the group of methods that assess the morphology, in which the space and time variability is taken into account and teledetection is used (the Czech Republic).

Because of similar assumptions, the procedure in the LAWA method is similar to that in the RHS. In this case, one selects a section that is 100, 500, or 1000 m long and the hydromorphological properties within this section, both of natural and anthropogenic origin, are used. The assessment is made in six groups, namely: channel and bank shape, longitudinal profile characteristics, cross section parameters, bed material, structure of banks, and area usage. In each group, smaller subpoints are added, and points (from 1 to 7 pts.) are awarded within each subpoint for each element. In order to use the results, an average is taken from the individual results from each group, next these averages are calculated as the overall average for a given research section. Results are given on a seven-point scale; however, for the purpose of the Water Framework Directive (WFD) the number of intervals was reduced to five (see Table 2; the higher the grade on the scale, the better the quality in terms of hydromorphological elements). One should add that the results may illustrate, depending on the approach, the degree of naturalness or transformation of the hydromorphological status.

Table 2. Classification of the hydromorphological status according to LAWA (Germany and WFD).

Germany			Water Framework Directive		
Class	**Nr of Pts.**	**Class Description (Hydromorphological Status)**	**Class**	**Nr of Pts.**	**Class Description (Hydromorphological Status)**
I	1.0–1.7	unchanged (natural)	I	1.0–2.2	very natural (natural)
II	1.8–2.6	little changed (almost natural)	II	2.3–3.4	natural (weakly altered)
III	2.7–3.5	moderately changed (moderately natural)	III	3.5–4.6	moderately natural (moderately altered)
IV	3.6–4.4	clearly changed (clearly artificial)	IV	4.7–5.8	weakly natural (considerably altered)
V	4.5–5.3	undeniably changed (undeniably artificial)	V	5.9–7.0	little natural (strongly altered)
VI	5.4–6.2	strongly changed (strongly artificial)			
VII	6.3–7.0	totally changed (little natural)			

The QBR method, used in Spain, is based on different assumptions than LAWA and RHS. In this case there are no strictly defined research sections (there is only a recommendation that the optimal section length should be 100 m) and the analysis does not focus on the physical assessment of the channel and the surrounding area, as before, but on the bank vegetation, assumed to be all the vegetation growing on the flooded areas (limits are given by the probability of flooding once every 100 years (max) and once every 2 years (min). The bank vegetation mainly consists of trees (riparian forest), but also includes bushes and shrubs and lower plants, excluding annual plants. The classification includes four categories, i.e., overall bank vegetation cover, structure of cover, quality of cover and changes in the riverbed, in each of these groups one can assign from 0 to 25 points (with a five point interval), according to methodological criteria—hence the overall score can be from 0 to 100 points. The method uses a classification which is in line with the Water Framework Directive (WFD), with five classes of hydromorphological elements status (the classes in Spain coincide with those used in the European Union) with respect to bank habitats—more details are given in Table 3. Similar to the previous cases, one can speak of the degree of naturalness or transformation of the hydromorphological status.

Table 3. Classification of the hydromorphological status according to QBR (agreement with WFD).

Class	Nr of Pts.	Hydromorphological Status	Class Description
I	95–100	very natural (natural)	very good
II	75–90	natural (weakly altered)	some alterations, good quality
III	55–70	moderately natural (moderately altered)	significant alterations, average quality
IV	30–50	weakly natural (considerably altered)	strong changes, bad quality
V	0–25	little natural (strongly altered)	extreme degradation, very bad quality

The HEM method is based on the assessment of indicators in four groups (zones), which characterize the channel and flow conditions, the riverbed, the bank and flooded areas, and the flow and hydrological regime. This assessment comprises all the elements of the methods characterized above and allows for the most comprehensive assessment of the hydromorphological status of watercourses (the value ranges for given classes of hydromorphological status can be found in Table 4—similar to others, in this method there are five classes which correspond with different degrees of naturalness or transformation).

In this method, the so called sections are used, i.e., intervals of similar morphological characteristics, which are at least 50 m long for rivers that are no wider than 10 m (the Ślęza on the sections under study) or at least 100 m long if the river is broader than 10 m (the Bystrzyca and the Odra). There are 17 indicators to be assessed over a section (described in Table 10), each on a scale from 1 (best quality) to 5 (worst quality). Among the possible variants one is required to choose the one which is the least favorable. The second stage consists in calculating the average of indicators among each of the four groups (weighted average) based on the following formulae:

- KOR (channel and flow conditions) = 0.3TRA (flow path) + 0.3PPK (longitudinal profile capacity) + 0.15VSK (channel width variability) + 0.10VHL (longitudinal profile depth variability) + 0.15VHP (cross section depth variability)
- DNO (ground) = 0.3STD (riverbed structures) + 0.2DNS (riverbed substrate) + 0.3UDN (riverbed modifications) + 0.2MDK (dead wood in the river)
- NIV (bank and flooded areas) = 0.3UBR (bank modifications) + 0.3BVG (bank vegetation) + 0.25VPZ (usage of bank areas) + 0.15VNI (usage of the river floodplain valley)
- HYD (flow and hydrological regime) = 0.3CPR (nature of flow) + 0.3OHP (influence of hydrological regime) + 0.2PRI (variability of floodplain area) + 0.2VPR (variability of flow)

The value of the hydromorphological status (HMK) indicator is calculated as the arithmetic average of the previously calculated values for each group, i.e.,: HMK = (KOR + DNO + NIV + HYD)/4.

Table 4. Classification of the hydromorphological status according to HEM (agreement with WFD).

Class	Nr of Pts.	Hydromorphological Status	Class Description (HMK)
I	1.0–1.7	very natural (natural)	very good status
II	1.8–2.5	natural (weakly altered)	good status
III	2.6–3.4	moderately natural (moderately altered)	moderate status
IV	3.5–4.2	weakly natural (considerably altered)	poor status
V	4.3–5.0	little natural (strongly altered)	bad hydromorphological status

The results of hydromorphological research (in line with both the EU and national documents—the Water Law Act in Poland, the Federal Water Act in Germany, the Act on Water in the Czech Republic, and the Reformed Water Law in Spain) are a complementary element of the surface water quality assessment. This research was carried out on the river sections above and below the hydropower plants in Wrocław on the rivers Bystrzyca, Odra, and Ślęza [2,23–25].

The assessment of the hydromorphological status was carried out according to the guidelines given in the "River Habitat Survey in Britain and Ireland—Field Survey Manual", Environment Agency, 2003, adapted to Polish conditions [5,22]. The ecological status (simplified assessment, with two classes of hydromorphological status: I—natural section, II—transformed or artificial section) was assessed based on the Regulation of the Minister of Environment of 21 July 2016 on the method of classification of water bodies and according to the environmental quality standards for the priority substances (Dz. U. 2016 poz. 1187).

4. Results

4.1. The Bystrzyca

4.1.1. Habitat Quality Assessment (HQA)

In the case of the HQA on the watercourse sections under study, the following morphological elements—which confirm its natural character—are taken into account: natural bank material, natural riverbed material, natural bank and channel morphological elements, type of flow, groups of water plants, natural bank profiles, area usage, the structure of vegetation on the top and slopes of banks, and the trees.

The value of HQA Marszowice ranges from 42 to 45 above the hydropower plant and from 32 to 40 below it. This means that the channel is more natural above the hydrotechnical structure, so the structure has an adverse effect on the hydromorphological status of the river Bystrzyca. The status above the dam is moderately natural, whereas it is only weakly natural below the dam. At the end of the chapter, in Tables 1 and 2, the components of indicators of natural state HQA and of habitat transformation HMS in the investigated locations are given. Table 2 presents the assessment of the hydromorphological status above and below the hydropower plants on the rivers Bystrzyca, Ślęza, and Odra.

4.1.2. Habitat Modification Score (HMS)

The HMS measures the anthropopression in the channel and on the banks. Every transformation has a given influence on the environment—small, medium, or large. Based on this estimation the HMS was calculated. This is the reason why the values are slightly different above and below the dam. The indicator ranged from 9 to 10 above the hydropower plant and from 8 to 11 below it. Therefore, the transformation is on a similar level, although below the hydropower plant it is a bit higher. The sections near the poorest result may be classified as moderately transformed, i.e., Class III of the hydromorphological status.

4.2. The Ślęza

Similar to the measurements on the Bystrzyca, the hydromorphological measurements on the Ślęza were carried out three times—in August and December 2016, and in May 2017. Consequently, the data will be compared from above and below the hydropower plant as well as between subsequent measurements.

4.2.1. Habitat Quality Assessment (HQA)

The value of HQA ranged from 42 to 45 above the hydropower plant and from 25 to 29 below it. The status above the dam corresponded with Class III, i.e., moderately natural, whereas the status was only weakly natural (Class IV) below the dam. Because of the proximity of the research sections to the hydropower plant, one may conclude that it adversely affects the hydromorphological status of the Ślęza.

4.2.2. Habitat Modification Score (HMS)

On the section above the hydropower plant the value recorded was 16, whereas on the section below the value recorded was 13. Consequently, the section above the hydropower plant is slightly more transformed; however, both can be classified as the hydromorphological status Class III, i.e., moderately altered.

4.3. The Odra

The hydromorphological measurements for the Odra were carried out only in May 2017. Two research sections were chosen—above and below the hydropower plants Wrocław I and II (since these plants are located close to one another, four research sections were not needed).

4.3.1. Habitat Quality Assessment (HQA)

The hydromorphological status, both above and below the hydropower plants was classified as Class V, i.e., strongly altered. The river is less natural below the dam.

4.3.2. Habitat Modification Score (HMS)

The values of HMS differ only a little—29 and 28, above and below the dam, respectively. This means that the section above the hydropower plants is slightly more transformed. Both sections may be classified as the hydromorphological status Class IV, i.e., moderately altered. The results obtained confirm that the human impact on the hydromorphological status is strong, which is due to the sections location in the city center of Wrocław, where the environment is strongly transformed.

4.4. Assessment of the Hydromorphological Status Using RHS

Based of the above information, several conclusions can be drawn:

- The highest degree of transformation and the least natural condition were recorded on the Odra below and above the hydropower plants Wrocław I and Wrocław II: HMS—28 and 29, HQA—15 and 7, the river is slightly less transformed above the hydrotechnical structures; this is caused by the high degree of urbanization and river training in this section;
- Among the sections under study, the most natural and the least transformed was the section on the Bystrzyca, with medium HQA—39.67 (values ranging from 32 to 45), medium HMS—9.5 (from 8 to 11). In each test the degree of transformation below the hydropower plant was higher, so the plant does influence the hydromorphological status of the watercourse on this section (in August 2016 and in May 2017 a drop from Class III to Class IV occurred, following the passage through the plant, no changes were recorded in December, but the values were less favorable);
- The situation on the river Ślęza on the sections below and above the hydropower plant is somewhere in between of the above: the average value of HQA is 35.16 (from 25 to 44) and the average value of HMS is 14 (values ranging from 12 to 16, in each case constant on the same sections); the river habitat quality assessment and the habitat modification score are higher above the plant, yet, in two cases the hydromorphological status worsened from Class III to Class IV, following the passage through the hydropower plant—worse result is taken into account (in September and December 2016, in May 2017 this trend was not observed); in this case, the highest unfavorable change in HQA was observed between the value above and below the plant: by 43.18% (the maximum change for the Bystrzyca was 28.89%).

The hydropower plants on the rivers Bystrzyca and Ślęza contribute to the worsening of hydromorphological conditions, especially in the summer (in both these rivers the natural character of habitats decreased at the turn of August and September 2016). In the Odra, the change is not visible due to the high degree of anthropogenic transformation and other factors that deteriorate the hydromorphological status.

The assessment of the hydromorphological status for individual hydropower plants during the research period is shown in Table 5. Tables 6 and 7 present the components of the natural state indicator and the habitat transformation indicator (minimum: 0 pts.; maximum: 136 pts.—HQA, 100 pts.—HMS).

In all the cases, river sediment accumulation on dams was observed; moreover, invasive species (which drive the native species out) were more frequently seen below the hydropower plants, particularly in summer—especially various species of knotweeds (Reynoutria) and goldenrods (Solidago) (particularly below the hydropower plants on the rivers Ślęza and Bystrzyca). Moreover, below the hydropower plants on the Odra, at the peak of the growing season, eutrophication processes could be observed, especially below the SHP Wrocław I.

Table 5. Assessment of the hydromorphological status based on the calculated values of HQA and HMS over the research period.

Watercourse	Date	Location	HQA	HMS	Class	RHS Assessment
Bystrzyca	3 September 2016	Above SHP	42	10	III	moderately natural
Bystrzyca	3 September 2016	Below SHP	34	11	IV	weakly natural
Bystrzyca	8 December 2016	Above SHP	45	9	III	moderately natural
Bystrzyca	8 December 2016	Below SHP	40	8	III	moderately natural
Bystrzyca	10 May 2017	Above SHP	45	10	III	moderately natural
Bystrzyca	10 May 2017	Below SHP	32	9	IV	weakly natural
Ślęza	19 August 2016	Above SHP	42	16	III	moderately natural
Ślęza	19 August 2016	Below SHP	26	12	IV	weakly natural
Ślęza	3 December 2016	Above SHP	44	16	III	moderately natural
Ślęza	3 December 2016	Below SHP	25	12	IV	weakly natural
Ślęza	9 May 2017	Above SHP	45	16	III	moderately natural
Ślęza	9 May 2017	Below SHP	29	12	III	moderately natural
Odra	9 May 2017	Above SHP	15	29	V	considerably transformed
Odra	9 May 2017	Below SHP	7	28	V	considerably transformed

Table 6. Component and average values of the habitat natural state index (HQA) above and below the hydropower plants on the rivers Bystrzyca, Ślęza, and Odra.

Components of HQA (Max Pts.)	1	2	3	4	5	6
Types of flow (13)	3	4	3	3	3	3
Riverbed material of the channel (10)	1	5	0	1	1	1
Morphological elements of the channel (18)	0	0	2	0	0	0
Morphological elements of the banks (31)	12	5	8	1	3	0
Structure of bank vegetation (12)	1	0	0	7	3	0
Occurrence of meander river bars (2)	2	2	2	0	0	0
Vegetation of the channel (12)	6	12	6	6	4	3
Usage of the area up to 50 m (14)	4	0	7	4	0	0
Trees and related morphological elements (19)	10	3	10	5	1	0
Environmentally valuable river habitat elements (5)	5	5	6	0	0	0
Summary value of HQA (136)	44	36	44	27	15	7
Class	III	IV	III	IV	V	V

Note: 1—Bystrzyca above SHP, 2—Bystrzyca below SHP, 3—Ślęza above SHP, 4—Ślęza below SHP, 5—Odra above SHP, 6—Odra below SHP.

Table 7. Component and average values of the habitat transformation index (HMS) above and below the hydropower plants on the rivers Bystrzyca, Ślęza, and Odra.

Components of HMS	1	2	3	4	5	6
Bank reinforcement	2	4	4	6	13	12
Reinforced channel bed	0	0	2	0	0	0
Profiling of banks or bed	0	1	1	0	2	2
Embankment on bank slope	0	0	0	0	4	2
Footbridge	0	0	0	0	2	2
Road and railway bridges	3	3	3	3	2	2
Dam, crossing	2	0	2	2	2	1
Groyne	2	0	1	0	0	0
Bed material of anthropogenic origin	0	0	0	0	1	2
Strengthened bank profile (entire)	0	0	2	0	0	2
Strengthened bank crown or base (only)	0	2	0	0	1	1
Profiled bank	0	0	0	0	1	1
Embankment out of the bank slope	1	0	0	0	0	0
Sectional bank profile	0	0	0	1	0	0
Mowing of banks	0	0	1	0	1	1
Summary value of HMS (max 100 pts.)	10	10	16	12	29	28
Class	III	III	III	III	IV	IV

Note: 1—Bystrzyca above SHP, 2—Bystrzyca below SHP, 3—Ślęza above SHP, 4—Ślęza below SHP, 5—Odra above SHP, 6—Odra below SHP.

5. Comparison of Results Obtained from the Various Methods of Assessment of the Hydromorphological Status: RHS, LAWA, QBR, and HEM

5.1. The LAWA Method (Germany)

By analyzing the data obtained from RHS, which was compared with the results obtained in LAWA, we may conclude that the results are similar—in each case, the hydromorphological status below the hydropower plants worsened (classification according to WFD): the Bystrzyca—from II to III, the Ślęza—from II to III, and the Odra—from IV to V. In the German classification: from Class III to Class IV in the first two cases and the same classification for the Odra above and below the SHP (Table 8). It is worth noting that the hydromorphological status can be analyzed in each of the six groups by using the same scale as in the overall assessment. The results obtained make us conclude that the RHS and LAWA produce similar results and can be successfully applied to Polish conditions. The discrepancies are insignificant and mainly due to the span of classes.

Table 8. Results of the hydromorphological status testing in the research sections under analysis based on the LAWA method.

Classification by Groups—LAWA \ Research Sections	1	2	3	4	5	6
I (channel and bank shape)	2	3.5	3	2.75	4.75	5.75
II (longitudinal profile characteristics)	3.75	4.6	3.75	3.75	5	5.8
III (cross section parameters)	2.75	4.25	2.75	3.75	5.25	6
IV (riverbed material)	3	1.5	3.5	3.5	5.38	5.5
V (structure of banks)	3.15	3.35	2.8	3.67	6	6
VI (area usage)	3.23	4.31	3.19	4.58	5.92	6.33
Average	3	3.6	3.2	3.7	5.4	5.9
Class—WFD	II	III	II	III	IV	V
Class—Germany	III	IV	III	IV	V	V

Note: 1—Bystrzyca above SHP, 2—Bystrzyca below SHP, 3—Ślęza above SHP, 4—Ślęza below SHP, 5—Odra above SHP, 6—Odra below SHP.

5.2. The QBR Method (Spain)

Referring the data obtained from field work to the method being described, one should conclude that despite the differences between RHS and QBR, the latter method gives similar results as the method in use in Poland. In the cases under study, the hydromorphological status below the hydropower plants gets visibly worse; the Bystrzyca—from Class II to III, the Ślęza—from Class III to IV, the Odra—although the class remains the same (V), the indicator in points decreases below the hydropower plants (the status worsens). This is illustrated in Table 9. Hence, one may conclude that despite focusing on another element of hydromorphological assessment of watercourses, the results for these sections are in good agreement with those obtained from RHS.

Table 9. Results of the hydromorphological status testing in the research sections under analysis based on the QBR method.

Classification by Groups—QBR \ Research Sections	1	2	3	4	5	6
(1) Overall bank vegetation cover	20	25	15	5	0	0
(2) Structure of cover	20	20	15	10	0	0
(3) Quality of cover	15	10	15	10	15	10
(4) Changes in the riverbed	25	15	15	10	0	0
Sum	80	70	60	35	15	10
Class	II	III	III	IV	V	V

Note: 1—Bystrzyca above SHP, 2—Bystrzyca below SHP, 3—Ślęza above SHP, 4—Ślęza below SHP, 5—Odra above SHP, 6—Odra below SHP.

5.3. The HEM Method (Czech Republic)

The values for the indicators on the research sections being analyzed are given in Table 10. Table 11 shows the final hydromorphological status (HMK) results based on the assumed classes and the four above mentioned groups. The value of this indicator is calculated as the arithmetic average of the previously calculated values for each group, i.e.,: HMK = (KOR + DNO + NIV + HYD)/4.

As can be seen, despite a much more comprehensive approach, the results obtained in this method are similar to those derived from other methods. In all the cases below the hydropower plants the overall hydromorphological status indicator worsens and the classes change to worse: the Bystrzyca—from Class II to Class III, the Ślęza—from Class III to Class IV, the Odra—no changes (Class V in both cases). Because of a much broader scope of analysis in this method compared to the previous methods, this method is recommended most for the assessment of the hydromorphological status in the context of the requirements of WFD.

Table 10. Results of the hydromorphological status testing in the research sections under analysis based on the HEM method (Stage I—assessment of the indicators in groups).

Group No. (Abbrev.)	No.	Indicator (Description)	Research Sections					
			1	2	3	4	5	6
I (KOR)	(1)	TRA (flow path)	3	4	3	3	5	5
	(2)	PPK (longitudinal profile capacity)	2	3	2	4	5	5
	(3)	VSK (channel width variability)	2	2	2	2	1	1
	(4)	VHL (longitudinal profile depth variability)	3	3	4	2	5	5
	(5)	VHP (cross section depth variability)	2	1	3	2	1	1
II (DNO)	(6)	STD (riverbed structures)	3	3	4	3	4	5
	(7)	DNS (riverbed substrate)	2	2.5	3	2.5	4.5	4.5
	(8)	UDN (riverbed modifications)	1	3	2	4	5	5
	(9)	MDK (dead wood in the river)	4	3	4	3	4	5
III (NIV)	(10)	UBR (bank modifications)	2	3	4	5	5	5
	(11)	BVG (bank vegetation)	3	4	4	4	5	5
	(12)	VPZ (usage of bank areas)	3	4	4	4	5	5
	(13)	VNI (usage of the river floodplain valley)	3	3	4	5	5	5
IV (HYD)	(14)	CPR (nature of flow)	2	1	3	3	2	2
	(15)	OHR (influence of hydrological regime)	2	3	3	5	5	5
	(16)	PRI (variability of floodplain area)	3	5	5	5	5	5
	(17)	VPR (variability of flow)	2	1	4	3	4	4

Note: 1—Bystrzyca above SHP, 2—Bystrzyca below SHP, 3—Ślęza above SHP, 4—Ślęza below SHP, 5—Odra above SHP, 6—Odra below SHP.

Table 11. Results of the hydromorphological status testing in the research sections under analysis based on the HEM method (Stage II—indicators calculated for groups and sections, classification to status classes).

Groups (Abbrev.)	Group Name (Specification)	Research Sections					
		1	2	3	4	5	6
I (KOR)	Channel and flow conditions	2.25	2.9	2.75	2.9	4.0	4.0
II (DNO)	Ground (riverbed)	2.5	2.9	3.2	3.2	4.4	4.9
III (NIV)	Bank and flooded areas	2.7	3.55	4.0	4.45	5.0	5.0
IV (HYD)	Flow and hydrological regime	2.2	2.4	3.6	4.0	3.9	3.9
Average (HMK)	Hydromorphological quality of the section	2.4	2.9	3.4	3.6	4.3	4.5
Class	Hydromorphological status (WFD)	II	III	III	IV	V	V

5.4. Comparison of Results—the RHS, LAWA, QBR, and HEM Methods

The analysis of each of the groups of methods for the assessment of the hydromorphological status leads us to believe that, despite the differences in the procedure and the different elements of assessment, the methods produce similar results in terms of the hydromorphological status assessment and at least on the measuring sections on the rivers Bystrzyca, Ślęza, and Odra. A diagram of the hydromorphological status assessment process is shown in Figure 2.

The research methods used allowed us to achieve a good agreement in terms of the classes of hydromorphological status on the measuring sections being analyzed (Figure 3). The diagram shows that in the case of the Odra below the hydropower plants all the methods indicate the same class of hydromorphological status (V); above the hydropower plants on the Odra and in the case of the research sections on the Ślęza—three methods coincide (RHS, QBR, and HEM)—Class V on the Odra, Class III above the hydropower plant on the Ślęza and Class IV below it; the LAWA method lowered the results by one class in all the cases). In the case of the Bystrzyca, three methods coincide; however, in this case the RHS method produced different results (Class II above the hydropower plant on the Bystrzyca and Class III below according to LAWA, QBR, and HEM; RHS—Class III and IV, respectively).

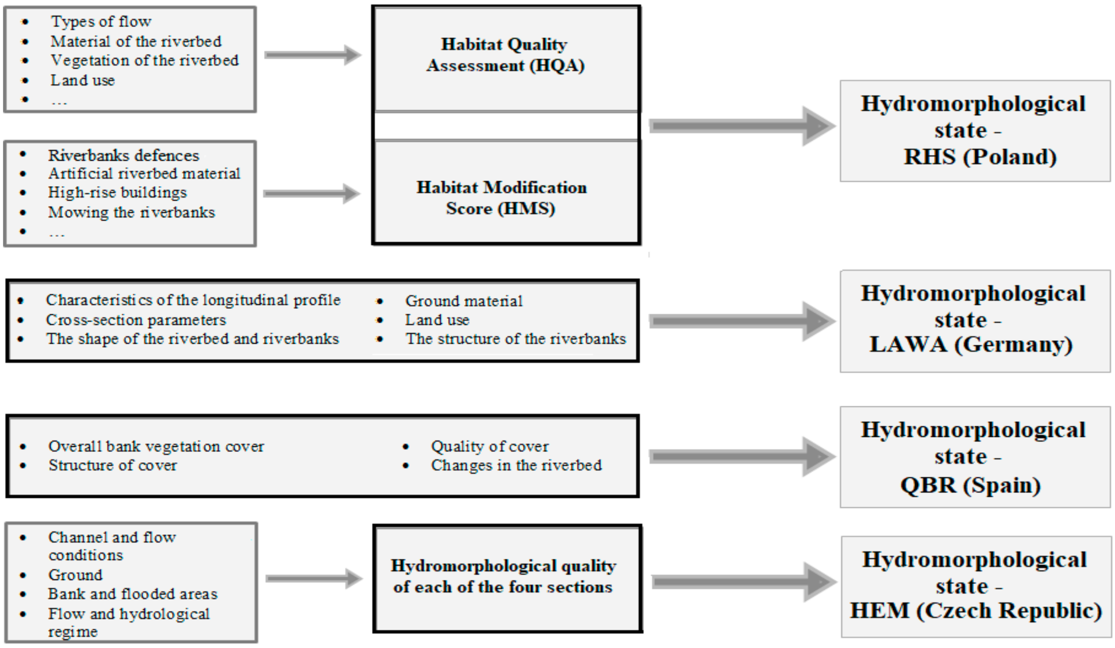

Figure 2. Diagram of the hydromorphological status analysis process for the described methods (own work).

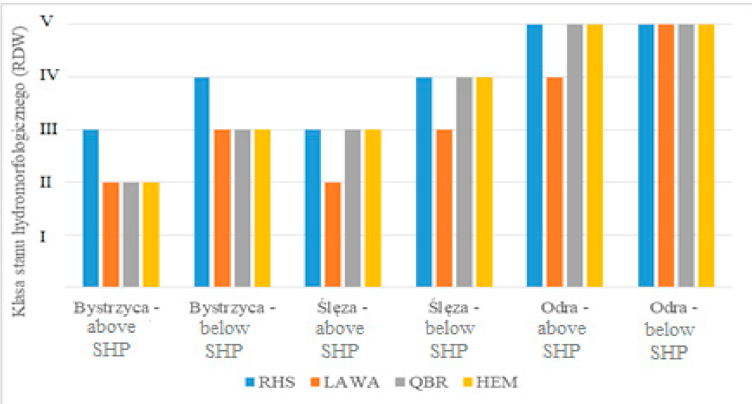

Figure 3. Hydromorphological status assessment—comparison of results using RHS, LAWA, QBR, and HEM.

By analyzing the results obtained one can clearly notice that the RHS method coincides with QBR and HEM in two-thirds of cases and only in one-sixth of cases with LAWA. The results obtained from QBR and HEM are in a 100% agreement. A comparison between QBR and HEM with LAWA yields a 50% compatibility. This kind of compatibility of the methods used in the European Union and applicable to various different conditions is mentioned by several authors [6,9,12]. Despite that it can be seen that the differences in classification are by up to one class and the methods as such are to some extent dependent on the subjective judgment of the person who carries the work out.

The research results obtained from the four methods used in the EU countries confirm that the hydromorphological status on the sections located below the hydropower plants is less favorable than that on the sections above the hydropower plants. Despite the different indicators used for the assessment and despite the different value ranges for the classes of hydromorphological status, each of the methods used leads to similar results. This confirms that SHPs affect the river ecosystems and that each structure of this kind alters the environment and disrupts the watercourse hydromorphological continuity. A river is fragmented (divided into independent sections), which adversely affects the diversity of its fauna. Moreover, the river velocity changes, although the key factor here is the damming height (the difference between the water level above and below the power plant). The higher the damming height of the power plant, the slower the velocities at the inlet and outlet of the power plant. This has a positive aspect: the flow of the river calms down and the phenomena of bed and side erosion are brought to a halt [26,27].

In order to perform a statistical evaluation of the results obtained from the hydromorphological state classification based on the methods RHS, LAWA, QBR, and HEM, Kruskal–Wallis one-way analysis of variance by ranks (Kruskal–Wallis ANOVA rank) and median test was used [28,29]. This test was used to verify the hypothesis about the irrelevance of the differences between the medians obtained from the hydromorphological status classification of the measurement sections by four methods (Table 12).

Table 12. Test results and multiple comparisons for Kruskal–Wallis.

Kruskal–Wallis ANOVA Rank Kruskal–Wallis Test: H(3, N = 24) = 1.761894 $p = 0.0623$			The p Value for Multiple Comparisons Kruskal–Wallis Test: H(3, N = 24) = 1.761894 $p = 0.062$				
Method	**Sum of Ranks**	**Average Rank**	**Method**	**RHS**	**LAWA**	**QBR**	**HEM**
RHS	89.000	14.833	RHS		0.051 *	0.706	0.706
LAWA	58.000	9.667	LAWA	0.051 *		0.510	0.510
QBR	76.500	12.750	QBR	0.706	0.510		1.000
HEM	76.500	12.750	HEM	0.706	0.510	1.000	

Note: *—significance level $p < 0.05$.

As can be seen from Table 12, the null hypothesis about the equality of all the medians should be rejected ($p = 0.062$). The difference between the results from the RHS and LAWA classification is statistically significant ($p = 0.051$ *) and the medians for the other methods are not significantly different (Table 12). In order to interpret the graphical distribution of hydromorphological status classes, a frame-mustache chart was prepared for a comparison between RHS, LAWA, QBR, and HEM (Figure 4).

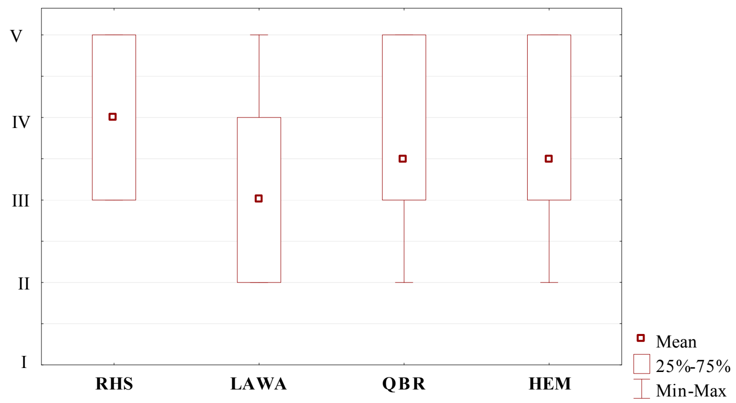

Figure 4. Graphical interpretation of hydromorphological state class distribution based on RHS, LAWA, QBR, and HEM methods.

Figure 4 shows that more than 75% of the research sections classified by the RHS have the hydromorphological status Class IV or V. In contrast, 75% of the research sections classified using LAWA have the hydromorphological status Class II or III. On the other hand, the classification based on QBR and HEM shows that 50% of the research sections have the hydromorphological status Class IV or V and 50% of them have the hydromorphological status Class II or III.

6. Conclusions

As can be seen from the analysis and despite the different assumptions, the RHS method which is in use in Poland gives similar results to those obtained from other methods used in the European Union (LAWA—Germany, QBR—Spain, HEM—the Czech Republic) (Figure 2) (the results differ by a maximum of one class of hydromorphological status on a five point scale). Consequently, all these methods can be successfully implemented in the monitoring of hydromorphological elements in surface water bodies also in other countries, especially in Europe. However, because of its comprehensiveness—i.e., the number of elements taken into account and accounting for the space and time variability of the phenomena—it is recommended to use the HEM method from the Czech Republic. On the other hand, a big advantage of RHS is that it accounts for the HQA and HMS—this allows one to determine to what extent a given watercourse section is natural, and to what extent it is transformed. The remaining two methods also have their advantages: the data set required is not large and the hydromorphological status of a watercourse is easy to determine.

The hydromorphological status assessment results indicate that the status of sections below the hydropower plants changes compared to that of the sections above (the hydromorphological status of the sections below is less good than that of the sections above the hydropower plants). This confirms that SHPs affect the river ecosystems and influence the changes to the environment by disrupting the hydromorphological continuity of a watercourse. The results of the statistical analysis allow one to conclude that the applied classification methods have a statistically significant impact on the hydromorphological status assessment. The research results obtained from the four methods used in the EU will help to optimize the hydromorphological status assessment methods.

The authors believe that, because of the goals set out in the National Policy on Power Generation and in view of the provisions of the Water Framework Directive or the Bird and Habitat Directive, in which the approaches to the development of hydropower generation often differ considerably, further research is required on the changes in the hydromorphological status of watercourses in the vicinity of hydropower plants.

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