Flow assessment downstream the water abstraction by integrating the ecological flow – an approach at the water body level

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Abstract. The hydrological regime of rivers is being altered due to water abstractions. Ensuring the maintenance of ecological flows by all water abstractions is a basic measure listed within the Programmes of Measures (PoMs) as part of the Water Framework Directive requirements. This paper presents an approach for a qualitative assessment of river waterbodies in terms of flow. The key elements of the approach are: the integration of the criteria related to ecological flow and consideration of the three scales of application, upscaling the assessment from local to water body level – the elementary unit for water management. In order to better highlight the approach, this paper shows a practical example on a river water body with five water abstractions for energy production (small hydropower plants). Certain river sectors were identified as having modified flow although the results at the water body level indicated good status. Our approach could be a viable option to extend the flow modifications due to water abstractions from local to water body level by using a combination of spatial scales of assessment (river section - river sector - water body). Furthermore, in the context of the water body impact assessment, the approach can be used as a tool for identifying the potential hydrological impact for future projects.
Key Words: ecological flow, hierarchy of spatial scale, hydrological assessment, modified flow.

Introduction. The critical role of water quantity and dynamics in supporting the quality of aquatic ecosystems and the achievement of the environmental objectives was acknowledged by the EU legislation. The structure and functioning of aquatic ecosystems are largely supported by different types of flows (low flows, high flows, etc.) which vary throughout time. Therefore, the hydrological regime consistent with the achievement of the environmental objectives in natural surface water bodies (ecological flow) should be dynamic, variable across space and time, so that the full range of natural variability in the hydrological regime should support the natural habitats for biota (EC 2015).

The hydrological alterations are related to pressures that are causing changes to the hydrological regime, i.e. quantity and dynamics of water flow and connection to groundwater bodies. The water abstractions were recognized as the main hydrological pressure types within the Danube River Basin. The key water uses causing significant alterations through water abstractions are mainly hydropower generation (96%), public water supply (1%), agriculture (1%) and others (2%) (ICPDR 2021).

The flow assessment of rivers is an important part of the hydro-morphological assessment required by the Water Framework Directive 2000/60/EU (WFD) for water status assessment. Many methods have been developed worldwide for rivers hydro-morphological assessment, the majority of them analyzing the flow, but only few being exclusively dedicated to the hydrological regime alteration assessment (Rinaldi et al 2013). Even if there was a progress in the integration of ecological flows assessments between the 1st and 2nd River Basin Management Plans, some countries still do not include ecological flows in their assessments (EC 2019).

The Romanian river hydromorphological assessment methodology (HYMO_RO) has been developed according to the WFD principle in 2015 (Moldoveanu et al 2015; Galie et al 2016; Moldoveanu et al 2017; Zaharia et al 2018) and updated in 2022, with the efforts of the experts from Romanian National Institute of Hydrology and Water Management (NIHWM). The updated version was mainly developed as a result of the approval of Romanian ecological flow (RoEflow) method by a governmental decision (Governmental Decision No. 148/2020 for the approval of the method of determining and calculating the ecological flow). According to the new Eflow Romanian legislation, the ecological flow must be ensured downstream from all water abstractions having the possibility of exemptions if the disproportionately costs or technical feasibility is proved.

The Downstream Water Abstractions Flow Indicator (DWAFI) is a new indicator aiming at considering the ecological flow in terms of ensuring or not ensuring it on a certain river sector.

For the purpose of this paper, a river water body with water abstraction for energy production (small hydropower plants) was selected as an example to highlight the applicability of the DWAFI.

Material and Method

Description of the study site. The Buda and tributaries water body is located in central part of Romania, at high altitudes in the Fagaras Mountains (Southern Carpathians) (Figure 1). The water body was designated from the headwaters of Buda River and its tributaries (Izvorul Mircea, Museteica, Otic) to the Vidraru Reservoir. It covers a drainage area of about 102 km^2, with an elevation ranging from 850 to 2502 m and a high mean slope (> 85‰) (AQUAPROIECT 1992). The water body has a total length of 41.95 m, out of which: Buda River has 19.42 km, Izvorul Mircea River has 7.28 km, Museteica River has 8.77 km and Otic River has 6.48 km.

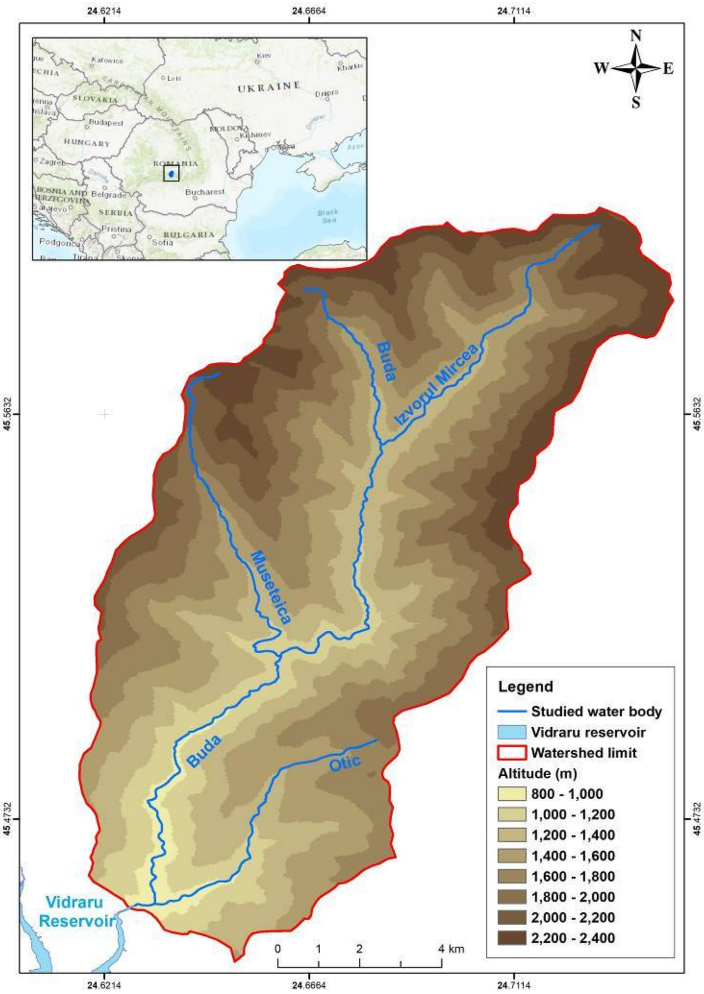

Figure 1. The location of study area in Romania.

The Argeș-Vedea River Management Plans (NARW 2009, 2021) mentions the Buda and tributaries water body as a high land river typology (Romanian river typology code: RO 01), with a substrate consisting mostly of rocks, boulders and gravel and providing habitat for a specific potential aquatic fauna, with the brown trout (*Salmo trutta fario*) as dominant fish species. As no relevant significant anthropogenic pressures (e.g., human settlements, agriculture) were mentioned and environmental objectives (good ecological and good chemical status) have been achieved, this water body was considered a natural one within the river basin management plans. The environmental objectives are more important considering that this water body is located entirely within the Natura 2000 protected areas network, namely, in the ROSCI0122 Muntii Fagaras and partially in other national-level protected areas: RONPA0122 Golul alpin Moldoveanu – Capra, RONPA0138 Lacul Buda and RONPA0139 Lacul Izvorul – Mușeteica.

The Fagaras Mountains are characterized by a relatively high precipitation rate, in relation to the altitude: 900-1000 mm on the lower altitudes and 1300-1400 mm in the alpine areas. Most of the annual precipitation is represented by snow, with an annual cumulated layer of 8-9 m, but rainfall is especially important in May-June. The mean annual temperature is also influenced by the altitude, with 4-6°C in the lower areas and -2-0°C in the alpine areas (MEWF 2016).

The water works which can lead to changes in hydrological regime of the Buda River and the Otic River are represented by the water abstractions for hydropower generation. Five small hydropower plants (SHPs) are acting within the study area, abstracting water from: Izvorul Mircea River (SHP Buda I), Buda River (SHP Buda II, SHP Buda III and SHP Buda IV) and Otic River (SHP Otic). The location of the water abstraction points and SHPs powerhouse are presented in the Figure 2.

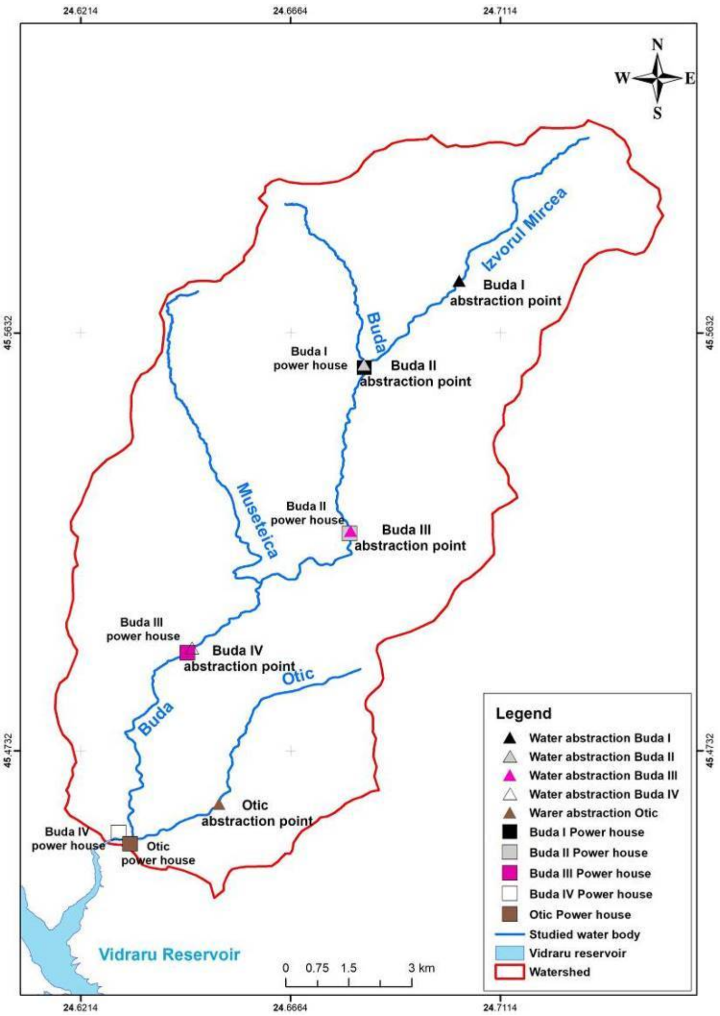

Figure 2. The location of the water abstractions – SHPs within the study area.

Hydrological data. The hydrological data is related to the water abstractions existing at water body level. The following hydrological parameters were used: the flows downstream water abstractions ($Q_{downstream}$), the ecological flows (Q_{eco}), and the multiannual average natural flow (Q_{maaf}).

The values of the above parameters used for the case study were computed within the NIHWM for each water abstraction point. Initially, these values were used in another study requested by the Romanian Ministry of Environment, Water and Forests, in 2019 with a different purpose (MEWF 2019). The flows downstream of some abstraction points were not available due to the high water depth and velocity and also to a landslide that blocked the road and prevented the access (MEWF 2019).

Spatial data. Point and line-feature data were used in this paper (Table 1). Point features represented the location of the water abstraction and water restitution points (SHP's powerhouse). Line features represented the analyzed water body. The source of the point features data is the above-mentioned study (MEWF 2019) and the line feature data used was obtained from the NIHWM database.

Table 1

Data used for the assessment of downstream water abstractions flow indicator

Type of data	*Data*	*Description*	*Source*
Hydrological	Q_{eco}	Ecological flow determined for each of the SHPs abstraction points.	NIHWM
	$Q_{downstream}$	Flow measured downstream of each of the SHPs abstraction points.	NIHWM
	Q_{maaf}	The multiannual average natural or renaturalized discharge*, computed in case of each water abstraction points and at the end of the water body.	NIHWM
Spatial	L_{river_sector}	The length of the river sector with modified flow as a result of each of the SHPs abstraction points.	Generated

* Averaged for all data recorded.

Flow assessment approach. DWAFI assesses the flow downstream water abstractions in a qualitative manner by using criteria related to ecological flow (Table 2). The Romanian legislation (Governmental Decision No. 148/2020, Water Law 107/1996) clearly defines the ecological flow as the required flow, in terms of quantity and dynamics, that ensures the protection of aquatic habitats in order to achieve the environmental objectives for surface water bodies.

According to the RoEFlow method there are three values of ecological flows corresponding to the three types of hydrological regime: high flows - $Q_{eco\ high\ flow}$, average flows - $Q_{eco\ average\ flow}$ and low flows - $Q_{eco\ low\ flow}$.

The indicator was designed to get an assessment at water body level (the WFD water management unit) by integrating different spatial scales: river section, river sector and water body. The assessment integrates five quality classes which are related to the 5 WFD status classes: class I (high status), class II (good status), class III (moderate status), class IV (poor status) and class V (bad status).

First, an analysis at water body level is necessary for identifying the transversal water works and water abstractions. Afterwards, a three-step approach should be followed:

Step 1 - assessing the indicator at local level (river section level) by using a set of criteria, conventionally considered, listed in Table 2. The river sections classified in classes II-V were considered as having modified flow.

Table 2

The criteria conventionally considered for the DWAFI assessment – river section level (local level)

WFD 5 cass system	*Description*
Class I (high status)	There are no transversal water works or water abstractions on the water body OR The transversal water works or water abstractions are operating for short periods of time ensuring downstream the ecological flow AND the downstream flow represent more than 60% of the multiannual average natural flow averaged for a 30 years characteristic period ($Q_{downstream}>0.6* Q_{maaf}$)
Class II (good status)	The transversal water works or water abstractions provides the ecological flow downstream ($Q_{downstream} \cong Q_{eco}$) OR The flow downstream the transversal water works or water abstractions is between $Q_{eco\ average\ flow}$ and 60% of the multiannual average natural flow averaged for a 30 years characteristic period ($Q_{eco\ average\ flow} > Q_{downstream} > 0.6* Q_{maaf}$)
Class III (moderate status)	The flow downstream the transversal water works or water abstractions is less than the ecological flow, but not less than 50% of the ecological flow ($Q_{downstream} > 0.5* Q_{eco}$)
Class IV (poor status)	The flow downstream the transversal water works or water abstractions is less than 50% of the ecological flow ($Q_{downstream} < 0.5*Q_{eco}$)
Class V (bad status)	The transversal water works or water abstractions cannot provide downstream flow (for example, for reasons related to technical feasibility and /or disproportionate cots ($Q_{downstream} \cong 0$)

Step 2 - assessing the indicator at river sector level by considering the quality classes from step 1 (classes II, III, IV or V) as being the same for the river sector established downstream of each water abstraction. The water body was split into sectors, downstream each point features location (water abstractions, restitutions, confluences), as described below, in order to have the river sectors with different quality classes. The river sectors were established downstream of each water abstraction by taking into account the following possible situations:

a) between the abstraction and restitution points (Figure 3a);
b) between the abstraction and the first confluence of which catchment area (F) is at least 50% of the catchment area corresponding to the abstraction point (river section) (Figure 3b);
c) between the abstraction point and the confluence with the main river (if the abstraction point is located on a tributary) (Figure 3c);
d) between the abstraction point and the end of the water body; in this case, the river sector with modified flow continues in the downstream river water body (Figure 3d).

The river sectors with the same quality class are summed, then divided to the total length of the water body and expressed as a percentage. Therefore, a maximum of 4 values expressed in percentages will be obtained corresponding to 4 quality classes (II, III, IV or V). The rest of the water body, in terms of percentages, up to 100% is conventionally considered as having unmodified/unaltered flow and it is considered in class I (high status).

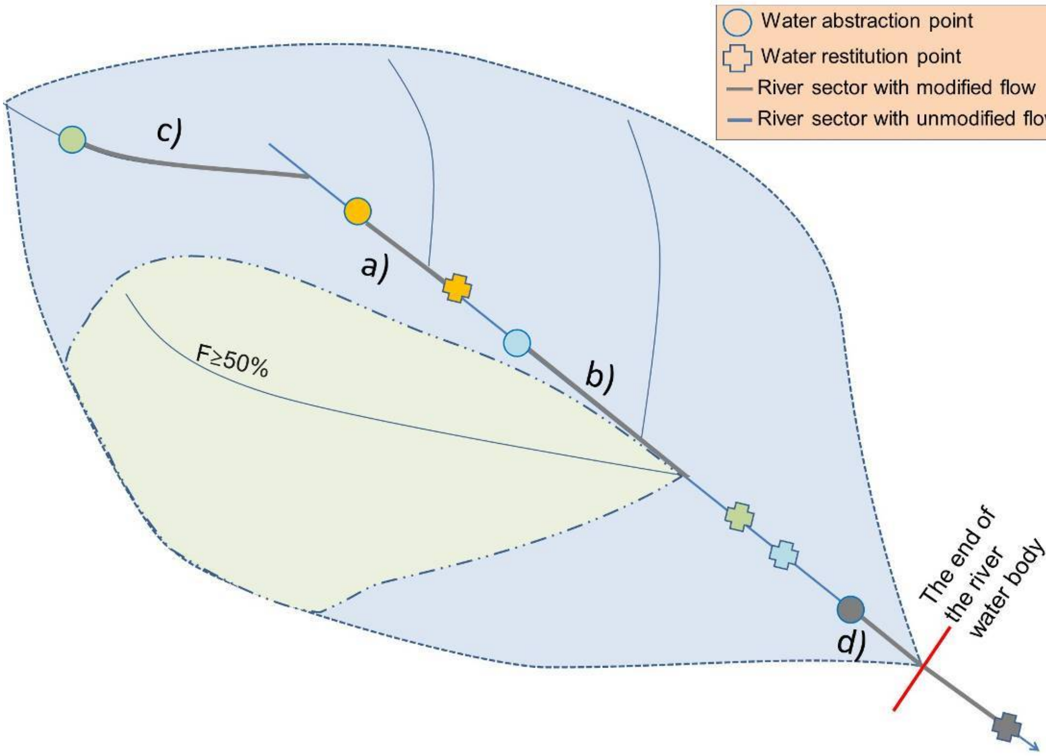

Figure 3. River sectors with modified flow – schematic representation.

Step 3 – the results of Step 2, respectively the 4 values (%) corresponding to 4 quality classes (II, III, IV or V), are supporting the assessment at water body level based on the following assumptions:

a) If one of the percentages values obtained at step 2 exceeds 30% of the total length of the water body, then the corresponding quality class will be considered for the entire water body;
b) If more than one percentage values obtained at step 2 exceeds 30%, the quality class corresponding to the higher value (%) classifies at water body level;
c) If the sum of the percentage values obtained at step 2 is higher than 30% (more than 30% of the length of the water body has modified flow), then the better-quality class classifies at water body level;
d) If the sum of the percentage values obtained at step 2 is less than 30% (that less than 30% of the length of the water body has modified flow), then the better-quality class classifies at water body level;
e) If within step 2 resulted only the class II (good status) and the corresponding river sector represent less than 30% of the length of the water body, then the water body will be classified in class I (high status);
f) If within step 2, was resulted only class II (good status) and the corresponding river sector represent more than 30% of the length of the water body, then the water body will be classified in class II (good status).

Results. The three-step approach has been used in order to apply the Downstream Water Abstractions Flow Indicator (DWAFI) in the case of Buda and tributaries water body and the results are summarized in Figure 4.

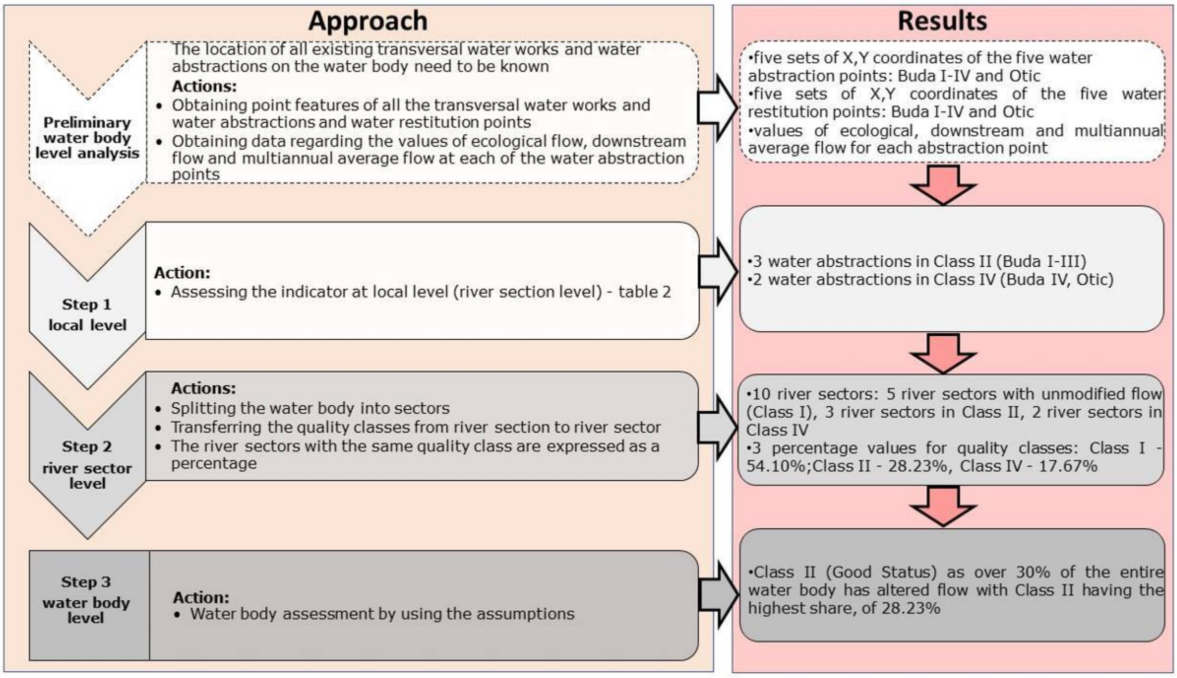

Figure 4. Three-step approach for assessing DWAFI and the results in the case of the selected river water body.

The Table 3 shows the results of DWAFI applied at the local level (river section level). The values of ecological flows (Q_{eco}), the flow downstream of each water abstraction point ($Q_{downstream}$) and the multiannual average natural flow (Q_{maaf}) were used. In the case of three abstraction points (SHP Buda I-III) where $Q_{downstream}$ was not available, it has been assumed that the criteria related to class II were met. Therefore, the indicator classifies in class II and IV at local level.

Table 3

The results of DWAFI (river section level)

No.	*SHP abstraction*	*Q_{eco} (m^3 s^{-1})*			*$Q_{downstream}$ (m^3 s^{-1})*	*Q_{maaf} (m^3 s^{-1})*	*Class*
		$Q_{eco\ low\ flow}$	*$Q_{eco\ average\ flow}$*	*$Q_{eco\ high\ flow}$*			
1	SHP Buda I	0.158	0.193	0.384	-	0.668	II
2	SHP Buda II	0.290	0.355	0.706	-	1.256	II
3	SHP Buda III	0.401	0.491	0.977	-	1.789	II
4	SHP Buda IV	0.647	0.792	1.574	0.332	2.972	IV
5	SHP Otic	0.058	0.071	0.140	0.017	0.295	IV

Notes: green = class II (good status); orange = class IV (poor status).

Ten river sectors were established with the length ranging from 0.22 km to 8.77 km. Half of the river sectors had unmodified flow (class I), representing 54.10% out of the total length of the water body. The river sectors considered in class II and IV were representing 28.23% and 17.67%, respectively (Table 4, Figure 5).

Table 4

The results of DWAFI (river sector level)

No.	*River*	*River sector*				*Quality classes*
		Upstream boundary	*Downstream boundary*	*Length (km)*	*Percentage (%)*	
1	Izvorul Mircea	Headwaters	SHP Buda I (abstraction)	4.55	10.85	I
2		SHP Buda I (abstraction)	Confluence with Buda	2.73	6.51	II

3	Buda	Headwaters	SHP Buda II (abstraction)	4.60	10.97	I
4		SHP Buda II (abstraction)	SHP Buda III (abstraction)	4.20	10.01	II
5		SHP Buda III (abstraction)	SHP Buda IV (abstraction)	4.91	11.71	II
6		SHP Buda IV (abstraction)	SHP Buda IV (restitution)	5.49	13.09	IV
7		SHP Buda IV (restitution)	Vidraru Reservoir	0.22	0.51	I
8	Otic	Headwaters	SHP Otic (abstraction)	4.56	10.88	I
9		SHP Otic (abstraction)	Confluence with Buda R.	1.92	4.58	IV
10	Museteica	Headwaters	Confluence with Buda R.	8.77	20.89	I
		TOTAL		22.70	54.10	I
				11.84	28.23	II
				7.41	17.67	IV

Notes: blue = class I (high status); green = class II (good status); orange = class IV (poor status).

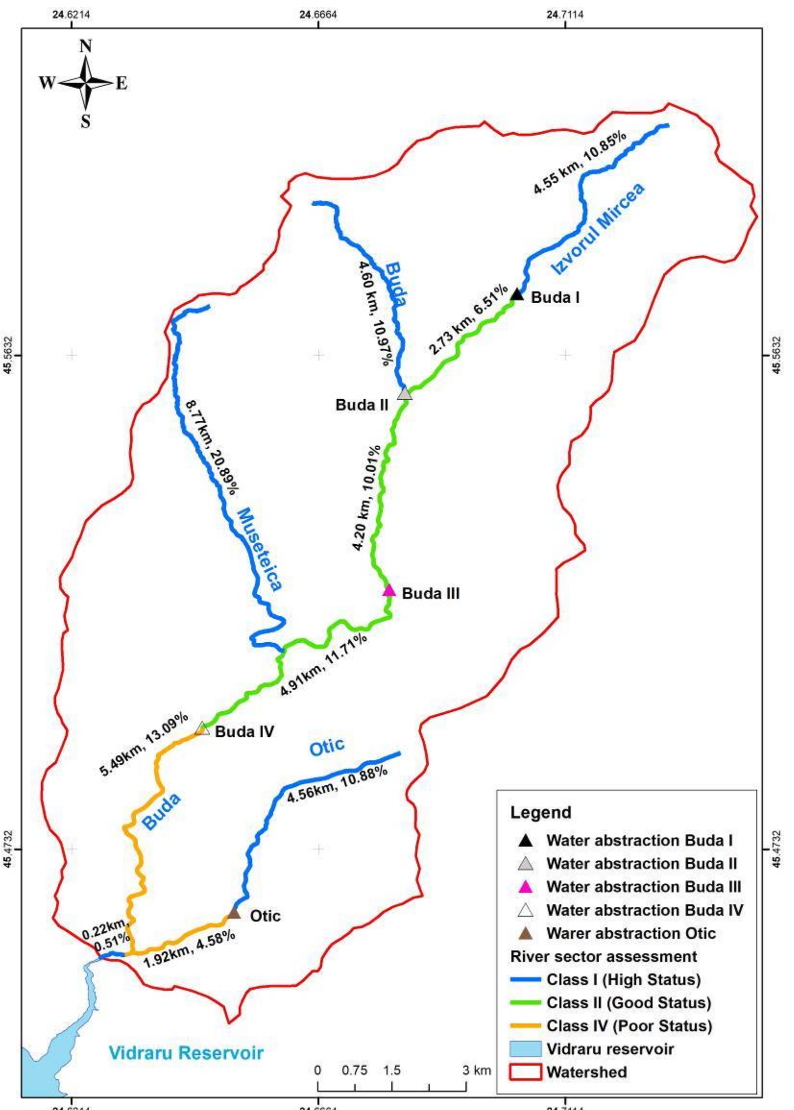

Figure 5. Representation of the river sectors identified on the analyzed water body and the corresponding quality class.

DWAFI was classified in class II (good status) at the water body level as more than 30% of the water body length has modified flow (28.23% class II and 17.67% class IV) according to the assumptions condition c) (see Step 3 of the approach).

Discussion. The approach for assessing DWAFI takes into account the ecological flow as the Romanian legislation currently uses this term and the method of determining and calculating the ecological flow (RoEflow method) has been recently approved by a governmental decision.

Using the hierarchy of spatial scale (river section–river sector–water body) the approach allows the qualitative assessment of the flow downstream water abstractions by using some criteria related to the ecological flow.

The application of the approach on a case study allows the identification of certain river sectors with modified flow although the results at the water body level indicated the achievement of the environmental objective (good status). Thus, because the water body level classification was influenced by the river sectors in class II (good status) that had a higher percentage than the river sectors in class IV (poor status).

A limitation of the DWAFI is that it has been applied on few river waterbodies in order to test the applicability of the approach in a research study developed by the NIHWM in 2022. In the next period, the indicator should be applied at national level with the support of the national and local water authorities. Therefore, the list of possible situations used to establish the river sectors with modified/unmodified flow may be extended. Similarly, a national-wide application of the approach may reveal the need to also consider other useful assumptions for a water body level assessment.

The frequency of the DWAFI application should be correlated with the new water users as identifying rivers' hydromorphological pressures is an ongoing activity in the process of the WFD implementation and River Basin Management Plans elaboration/ updating (EC 2000). Therefore, the results of indicator should be updated whenever the water permits for new water abstractions are approved by the local water authorities.

This approach has the advantage of identifying river sectors with modified/altered flow and could be used in the process of prioritizing the location that need the technical solutions to ensure the ecological flow.

Furthermore, the approach can be used as a tool to highlight the hydrological impact that can be generated by the existing or future water abstraction works, as in Romania recent legislation requires water body impact assessment (including the cumulative impact) for future projects.

Conclusions. In this paper, we highlighted an approach for assessing the flow downstream the water abstraction by integrating the ecological flow, showing the results of its application for one water body with water abstractions for energy production (small hydropower plants). This approach demonstrated that a combination of spatial scales of analyses could provide a viable option in order to quantify spatial extension of the hydrological (flow) modification from local to river sector and river water body level. Decision makers at different levels that influence water resources and water status and also the environmental consultants and water users, may find our approach to be useful in assessing the hydrological impact of a certain planned water-related investments. Further application of the Downstream Water Abstractions Flow Indicator (DWAFI) may better clarify and refine the approach.

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Conflict of interest. The authors declare that there is no conflict of interest.

References

AQUAPROIECT S.A. Bucharest, 1992 [Cadastral water atlas of Romania]. Unpublished, 327 pp. [in Romanian]

European Commission, Office for Official Publications of the European Communities, 2015, Guidance Document No. 31 - Ecological flows in the implementation of the Water Framework Directive.

European Commission, Directorate-General for Environment, Integrated assessment of the 2nd river basin management plans: EU-wide storyline report, Publications Office, 2019. Available at: https://data.europa.eu/doi/10.2779/640259. Accessed: December, 2022.

European Commission, Guidance Document No 3 Analysis of Pressures and Impacts. COMMON IMPLEMENTATION STRATEGY FOR THE WATER FRAMEWORK DIRECTIVE (2000/60/EC). Available at: https://www.eea.europa.eu/policy-documents/wfd-cis-guidance-document-no-3. Accessed: December, 2022.

Galie A. C., Moldoveanu M., Antonaru O., 2017 Hydro-morphological assessment of atypical lowland rivers - Romanian litoral basin case study. Carpathian Journal of Earth and Environmental Sciences 12(1):161-169.

Governmental Decision no. 148/2020 on the approval of the method of determining and calculating the ecological flow. [in Romanian]

International Commission for the Protection of the Danube River (ICPDR). Available at: https://www.icpdr.org/flowpaper/viewer/default/files/nodes/documents/drbmp_2021_final_hires.pdf. Accessed: December, 2022.

Law No. 107/1996 [Romanian Water Law with subsequent amendments and additions]. [in Romanian]

Ministry of Environment, Waters and Forests (MEWF) Romania, 2016 [Management Plan of ROSCI0122 Muntii Fagaras and ROSPA0098 Piemontul Fagaras Natura 2000 sites, approved by Order no. 1156/2016]. Available at: http://mmediu.ro/app/webroot/uploads/files/2016-03-23_Planul_Management_Muntii_Fagaras_Piemontul_Fagaras.pdf. Accessed: December, 2022. [in Romanian]

Ministry of Environment, Waters and Forests (MEWF) Romania, 2015 [Assessment of environmental impact regarding 17 small hydropower investments, subject to infringement cause no. 2015/4036 - Water - micro-hydropower plants in Romania, 2019]. Available at: http://www.mmediu.ro/articol/studiul-privind-evaluarea-impactului-asupra-mediului-a-constructiei-si-exploatarii-lucrarilor-de-amenajare-pentru-valorificarea-potentialului-hidroenergetic-prin-microhidrocentrale-amplasate-pe-cursurile-de-apa-capra-buda-otic-izvorul-mircea-cuca-cartisoar/4742. Accessed: December, 2022. [in Romanian]

Moldoveanu M., Galie A., Radulescu D., 2015 Methodology for hydromorphological assessment of Romanian rivers - results of testing. In: Proceedings of the 15th International Multidisciplinary Scientific Geoconference, Albena, Bulgaria, 18–24 June 2015; Book 3, Volume 1, pp. 427-436.

Moldoveanu M., Sarbu D., Galie A. C., Bojan V., Mezdroiu I., 2017 Assessment of river water quality using an integrated hydro-morphological, physico-chemical and biological approach. AES Bioflux 9(2):158-172.

National Administration „Romanian Waters" (NARW), Arges-Vedea Water Authority, 2009 [River Basin Management Plan of the Argeș-Vedea River Basin]. [in Romanian]

National Administration "Romanian Waters" (NARW), Argeș-Vedea Water Authority, 2021 [Project of the Updated (2021) River Basin Management Plan of the Argeș-Vedea River Basin]. [in Romanian]

Rinaldi M., Belletti B., Van de Bund W., Bertoldi W., Gurnell A., Buijse T., Mosselman E., 2013 Review on eco-hydromorphological methods - report. Available at: https://www.reformrivers.eu/system/files/1.1_REFORM_DeliverableD1.1_V8_Final.pdf. Accessed: November, 2022.

Zaharia L., Toroimac G. I., Morosanu G. A., Galie A. C., Moldoveanu M., Canjevac I., Belleudy P., Plantak M., Buzjak N., Bocic N., Legout C., Bigot S., Ciobotaru N., 2018 Review of national methodologies for rivers' hydromorphological assessment: a comparative approach in France, Romania, and Croatia. Journal of Environmental Management 217:735-746.

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