ГОДИШНИК НА УНИВЕРСИТЕТА ПО АРХИТЕКТУРА, СТРОИТЕЛСТВО И ГЕОДЕЗИЯ
СОФИЯ

Том
Volume 52 | 2019 | Брой
Issue S1

ANNUAL OF THE UNIVERSITY OF ARCHITECTURE, CIVIL ENGINEERING AND GEODESY
SOFIA

Получена: 03.06.2019 г.
Приета: 17.06.2019 г.

IMPACT OF HYDROLOGICAL HAZARDS ON THE ECOLOGICAL STATUS OF RIVERS ACCORDING TO THE EU-WFD

I. Schnauder[1]

Keywords: *European Water Framework Directive (EU-WFD), ecological quality components, environmental impact, disturbance of aquatic ecosystems, resilience of aquatic ecosystems*

ABSTRACT

Hydrological hazards have a dynamic impact on the fluxes of matter in rivers – including water, sediments, particulate or solute contaminants. Whenever the fluxes change due to such disturbances, both the physical and biological river systems develop towards new equilibrium conditions.

It is obvious that hydrological hazards potentially affect the biological, physical and chemical quality components of rivers and thus their ecological status according to the EU-WFD (EU Water Framework Directive). However, the parameter assessment and evaluation methods within the EU-WFD are not specifically targeting hazardous events, disturbances or alternate equilibrium regimes.

To give an overview and to introduce the ecological perspective on hydrological hazards, we give a summary of the actual ecological status of rivers in Austria and the main requirements for achieving the EU-WFD goals. Further, we will deduce near-future challenges to the EU-WFD due to expected climatic changes and weather extremes. If such challenges may be handled, the Austrian way of implementation of the EU-WFD will be reviewed based on the national guidelines for evaluating the biological quality components.

[1] Ingo Schnauder, Univ. Ass. Dr.-Ing., Dept. „Hydraulic Engineering“, TU Wien, Karlsplatz 12/222, A-1040 Vienna, e-mail: ingo.schnauder@tuwien.ac.at

1. Introduction

"Nature knows no catastrophes, only man does – if he survives." Max Frisch's statement can be transferred to hydrological hazards – they require hydrological extreme events for one part but also the damage of personal or property on the other. One would consider firstly floods with such characteristics, but the summer of 2018 has reminded us that also droughts have significant damage potential in central Europe. Unlike floods, the summer droughts clearly revealed the ecological damage – most visibly in the mass mortality of fish (Fig. 1).

Figure 1. Evident ecological damages of droughts: a dried up river and fish mortality in the Alps during the summer 2018 [Source: https://www.cipra.org/de/news/ausgetrocknete-alpen]

After severe disturbances like extreme floods and droughts, ecology needs time to recover and eventually reach the pre-event conditions again. While for some species this process only takes relatively short time, others require longer periods or is even irreversible – e.g. the age structure in fish populations, which reflects periods of mortality during extreme events.

The EU-Water Framework Directive (EU-WFD) is the central legislation for surveying, monitoring and improving the ecological status of our rivers. Facing climatic change and more extreme weather conditions in the near future, it should be equipped to tackle extreme disturbances due to hydrological hazards.

In this review article, we will focus on two main aspects:

I. What ecological impacts and damages come along with hydrological hazards in Austria in the next few decades?

II. Does the implementation of EU-WFD in Austria consider the impact of hydrological hazards on ecology and how may the ecological status of rivers be affected?

2. Ecological and Legal Basics

2.1. The Natural Flow Regime, Disturbance and Resilience

Hydrological hazards first of all change the fluxes of water and thus the flow in the river. Aquatic organisms are adapted to a natural flow regime with local dynamics and make use of it in their life cycle. Examples are riparian forests which require periodic flooding events and the input of nutrients from the river. Several fish species use the increased lateral connectivity during flood events to reach their spawning habitats. Bunn and Arthington (2002) postulated the importance of discharge and discharge dynamics for aquatic ecology in four statements:

1. Flow is a major determinant of physical habitat in streams, which in turn is a major determinant of biotic composition. Modified flow regimes alter habitat at varying spatial scales and influence the distribution and abundance of species and the composition and diversity of aquatic communities.

2. Aquatic species have evolved life-history strategies primarily in direct response to the natural flow regime. Flow pattern has a major influence on shaping the life-history strategies of aquatic species, and alterations of flow regimes can lead to recruitment failure and loss of biodiversity of native species.

3. Maintaining natural patterns of longitudinal and lateral connectivity is essential to the vitality of populations of many riverine species. Loss of longitudinal and lateral connectivity can lead to isolation of populations, failed recruitment, and local extinction of fish and other aquatic biota.

4. The invasion and success of exotic and translocated species in rivers is facilitated by the alteration of flow regimes. Flow regulation can affect the establishment, spread, and persistence of introduced species.

Herein, the definition of “natural flow regime” is crucial. Poff et al. (1997) used the characteristic pattern of a river flow quantity, timing and variability, expressed by five parameters: magnitude, frequency, duration, timing, and rate of change or ‘flashiness’. These parameters can be used to characterize the entire range of flows and specific hydrologic phenomena, such as floods or droughts, that are critical to the integrity of river ecosystems.

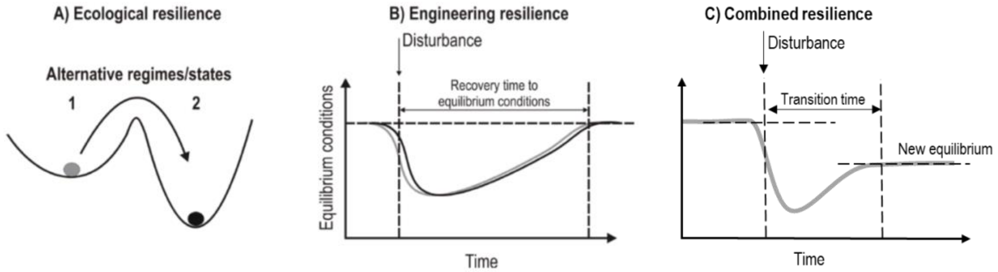

Figure 2. Comparison of different resilience concepts. Ecological resilience (A) considers that ecological systems can exist in alternative system states, while engineering resilience (B) focuses on recovery time after disturbances [from Angeler, 2013]. (C) represents the combination of (A) and (B) where an alternate equilibrium state is achieved after a transition time

The response of the river ecosystem to alterations of the natural flow is described by the concept of resilience in ecology. In literature, ecological and engineering resilience are differentiated (see Fig. 2). Both require the definition of steady-state conditions or equilibrium and a disturbance which leads to a change of steady-state (ecological resilience) or a recovery phase until steady-state is reached again (engineering resilience). Both can be combined to describe the transition between two different steady-states after a disturbance (combined resilience of metastable systems).

2.2. Ecological Quality Components of the EU-WFD

According to the EU-WFD, the biological quality components for running waters are:

- Phytoplankton (algae);
- Macrophytes and phytobenthos (trophy, saprobity and reference species);
- Benthic invertebrate fauna (saprobity / general degradation);
- Fish fauna (Fish index Austria).

In addition, hydromorphological quality elements, which take into account the habitat conditions for the aquatic flora and fauna, are considered in the EU-WFD. They thus enable for an indirect assessment of the ecological quality of running waters:

- Hydrological regime;
- Morphology;
- River continuity.

For achieving the very good ecological status, the hydromorphological quality elements have the same weight as any of the other elements. For a good ecological status, requirements for hydromorphology were softened in the sense, that they do not prohibit the achievement of a good ecological status.

The "hydrological regime" according to EU-WFD incorporates the regime type (12 classes from glacial to pluvial regimes) and the mean annual discharge (MQ). It is therefore substantially less information than required to define a natural flow regime (see 2.1). In particular, medium and high-frequency events like floods and droughts are thus not considered in hydromorphology.

Further limitations apply to "morphology" according to the EU-WFD, which is evaluated with a static approach of the structural inventory of the rivers. "Morphology" does not consider morphodynamics and sediment transport – which are the governing parameters particularly with regard to aquatic ecology.

Last but not least, general physico-chemical quality elements (GPCs) and specific pollutants (SP) are defined for the ecological status of rivers according to EU-WFD:

• Thermal conditions • Oxygenation conditions • Acidification conditions • Nutrient conditions • Salt content	GPCs
• Specific synthetic pollutants • Specific non-synthetic pollutants	Specific pollutants (SP)

Similar to the hydromorphologic components, the very good ecological status of rivers requires that the GPCs and SPs are in compliance with the given thresholds. How the GPCs affect the evaluation of the good ecological status leaves more space for interpretation and is illustrated in the flow chart in Fig. 3.

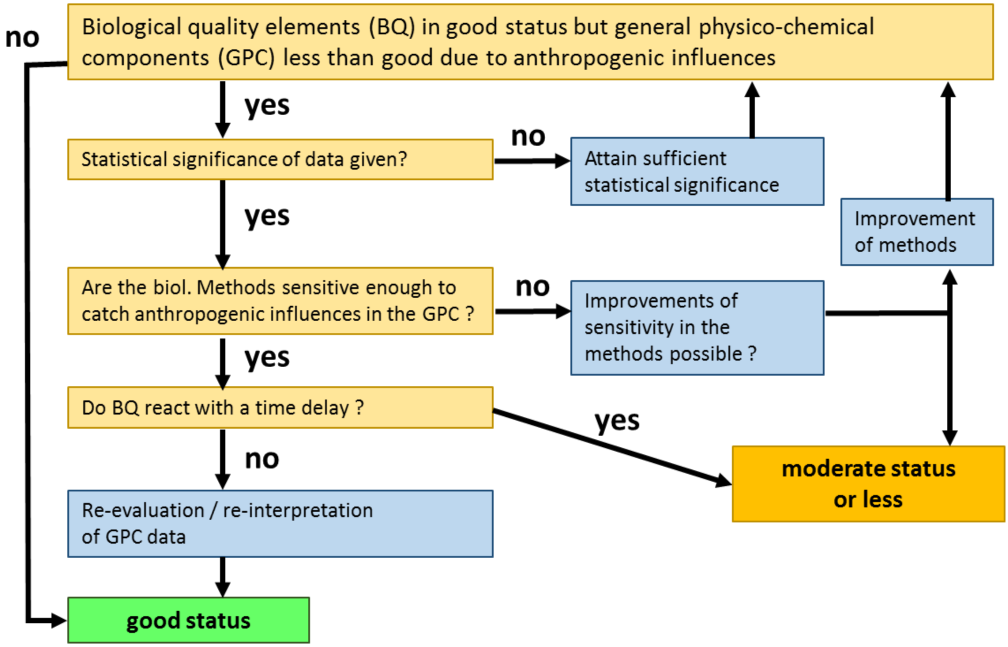

Figure 3. Flow chart for evaluation of the status when the general physico-chemical quality elements (GPC) are less than good but the biological quality components (BQ) are good [modified from Leitfaden APC, 2015]

2.3. Pressures on Ecological Quality Components

In general, pressures and disturbances impact the quality elements of the EU-WFD in many ways. Some examples including pressures due to floods and droughts are given in Tab. 1.

During droughts, fish are suffering mainly from temperature conditions, residual flow and the interruption of lateral and longitudinal continuity. Benthic invertebrates are a bit more robust towards these components, and suffer mainly from low oxygen concentrations during droughts.

During floods, the main pressures on fish are morphological changes due to increased flow – similar to the effects of hydropeaking. Temperature regimes may also play a role if warmer runoff water mixes with colder rivers. Benthic invertebrates are also primary affected by morphological changes to the streambed. Incipient motion of grains leading to sediment transport causes downstream drift of most benthic invertebrates.

Combined anthropogenic pressures, e.g. during stormwater overflows, when untreated waste water is discharged into the rivers, are not included in Tab. 1. Here, high nutrient concentrations often cause a rapid oxygen depletion and sudden fish mortality. The same can happen during droughts, when even treated wastewater enters the rivers. Due to the lack of river water for dilution, concentrations of nutrients, salts or other pollutants in the wastewater may be high enough to have toxic effects on ecology.

Table 1. Significance of pressures on running waters and effects on quality components. Pressures associated with floods and droughts are indicated [modified from QZV Ökologie OG, Annex B]

Quality components / Pressures	Physical and chemical quality elements	Hydromorphological quality elements	Phytoplankton *	Phytobenthos	Makrophytes	Benthic invertebrate fauna	Fish fauna	
Material pollution								
Nutrient	x		(x)	x	(x)	(x)		floods and droughts
Oxygenation conditions	x			(x)		x	(x)	floods and droughts
Temperature	x					(x)	x	floods and droughts
Salinization**	x			(x)		(x)	(x)	
Acidification	x			(x)	(x)	x	(x)	
Pollutants	x							
Hydromorphological pressures								
Morphological changes		x			(x)	(x)	x	floods
Only changes in the streambed		x				x	(x)	floods
Residual flow		x			(x)	(x)	x	droughts
Hydropeaking		x			(x)	(x)	x	floods
Impoundment		x			(x)	x	(x)	
Continuity interruption		x				(x)	x	droughts

x – highest significance,
(x) – lower, yet still pronounced significance.

3. EU-WFD in Austria

3.1. Actual Status of Austrian Rivers

River water bodies with catchment areas larger than 10 km² have to be assessed and reported according to the standards of the EU-WFD. In Austria, this involves 75% of the rivers or a river length of around 33,000 km (Fig. 4). Within these, 88 % have been declared natural water bodies, the remaining 12 % of water bodies are subdivided into heavily modified by human interventions (HMWB) or artificial (AWB).

In comparison across Europe, the ecological status of Austrian rivers falls below the average, with 37% in good or better condition and 63% in moderate or worse (Fig. 5). The primary deficits are related to hydromorphology – connectivity and hydropeaking – and diffuse pollution from agricultural sources.

Fig. 6 shows how the evaluation results changed between 2009 and 2015. More rivers were upgraded from good to very good and moderate to good status, as well as downgraded from moderate to poor and from poor to bad. This leads to an overall decrease of rivers in moderate condition. The evaluation of hydromorphology plays an important role – hereby, the refinement of assessment techniques leads to a significant changes which are reflected in the total evaluation.

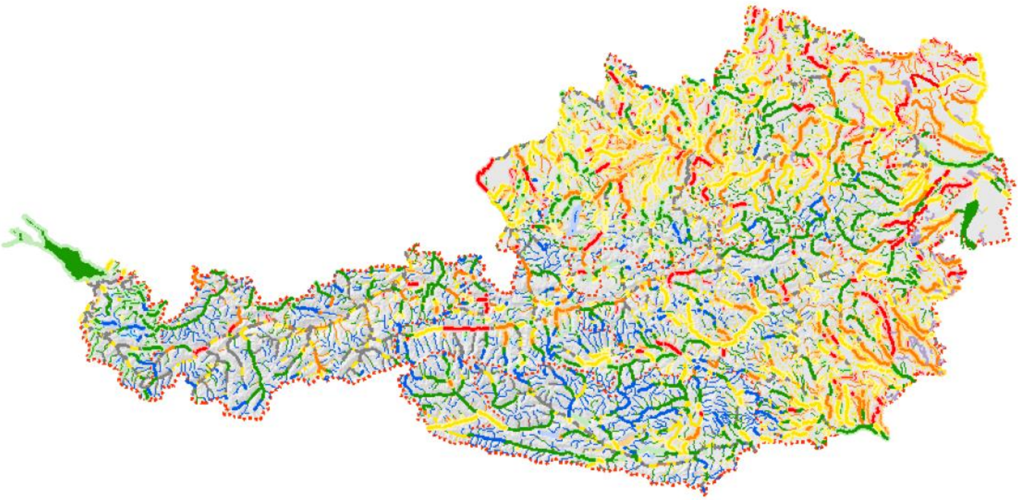

Figure 4. Austrian rivers and their ecologic status in 2015 (colour scale: blue – very good/high, green – good, yellow – moderate, orange – poor, red – bad) [Source: https://maps.wisa.bmnt.gv.at]

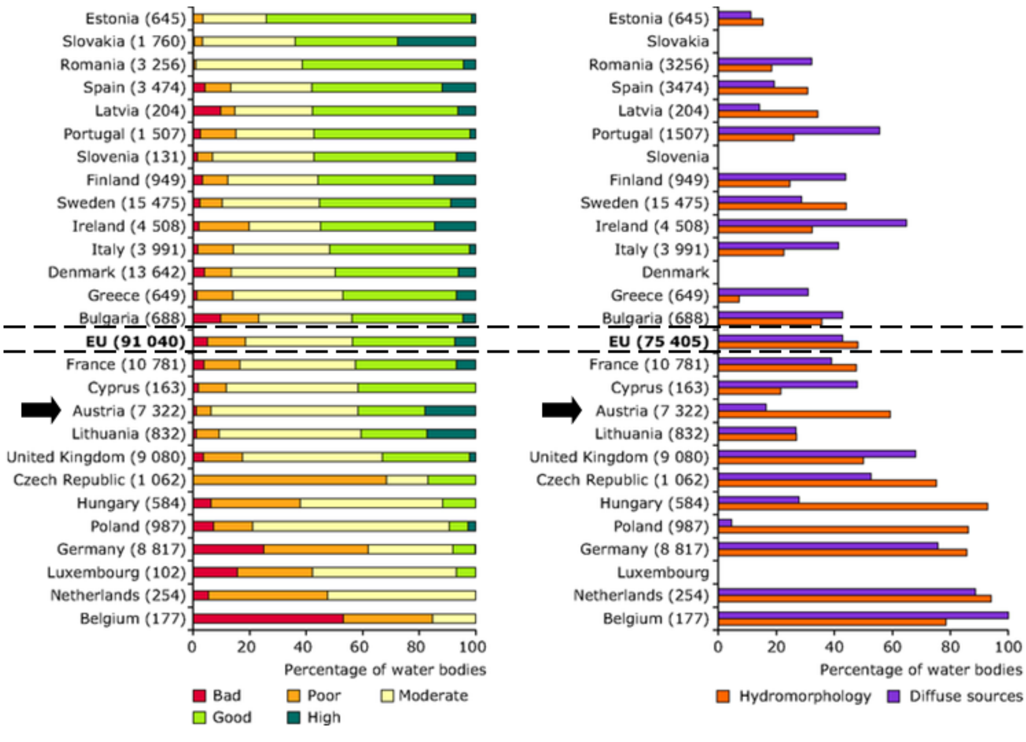

Figure 5. Ecological status / potential of river water bodies (left) and percentage affected by diffuse pollution and deficits in hydromorphology (right)
[data of 2009, Source: https://www.eea.europa.eu]

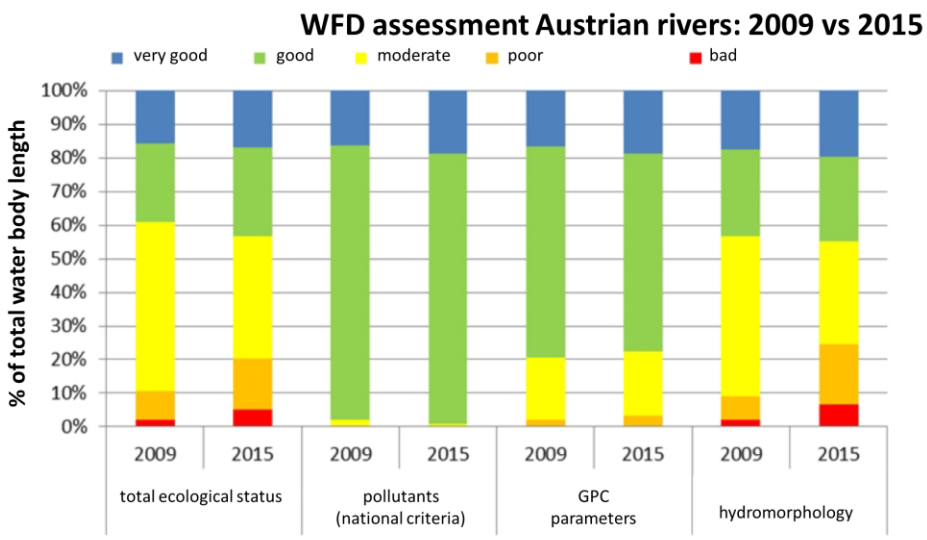

Figure 6. Results of EU-WFD assessments 2009 vs. 2015 divided by components [modified from NGP 2015 (2016)]

70% of Austrian water bodies suffer from more than one source of pressures, e.g. hydromorphology plus pollutants (Tab. 2). The coexistence of pressures can be interpreted as an additional degree of degradation which hinders the achievement of the good ecological status. For larger water bodies (> 100 km² catchment area) the percentage is even higher and up to 80%.

Table 2. Multiple pressures on Austrian water bodies of different catchment size [modified from NGP 2015 (2016)]

Quantity of coexisting pressure types for one waterbody	% of water bodies with less than good status	% of water bodies < 100 km² catchment area with less than good status	% of water bodies > 100 km² catchment area with less than good status
Only one type	29	34	19
Two types	36	36	35
Three types	28	25	35
Four types	6	4	10
No data	1	1	2

3.2. Expected Climatic Changes in Austria

The main hydrological trends for projections into 2021 – 2050 are summarised by Blöschl et al. (2018):

- Strong precipitation events may remain in frequency but increase in magnitude, causing an increase in flood discharges.
- In the lowlands in eastern and south-eastern Austria, low discharges as well as mean annual discharges may decrease (Fig. 7). Consequently, groundwater recharge over the year may tend to decrease, particularly in the east.

- Low discharges during winter will increase in the Alps (Fig. 7). Groundwater recharge will thus remain constant or increase.

- Floods due to pluvial surface runoff will become increasingly important.

Beside these general trends, evaporation has increased by 80 mm/a within the last three decades on average throughout Austria. Deficits in the climatic water balance were compensated by increased precipitation in the same order of magnitude, keeping annual averages stable. However, the increased evaporation stands for increased fluxes of water in the hydrosphere. This is likely to feedback into altered temporal dynamics and spatial distributions of precipitation patterns. Consequently, magnitude and frequency of local hydrologic extremes in the future are likely to increase – even though annual averages remain stable.

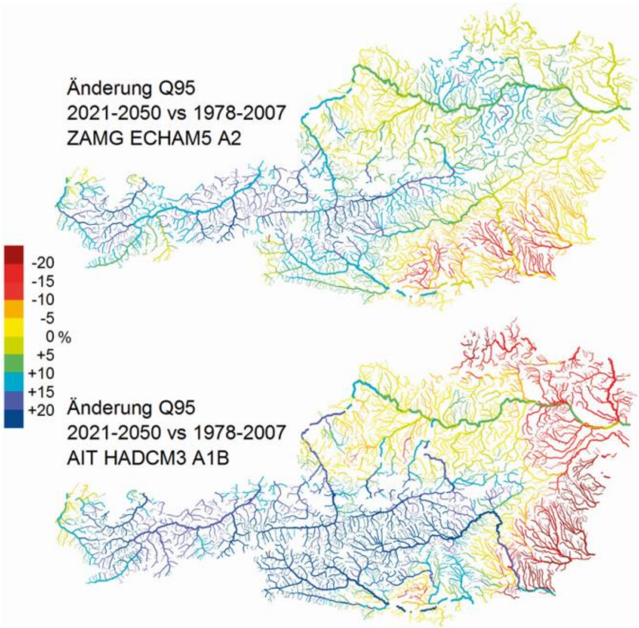

Figure 7. Modelled changes in low discharge Q95 (discharge which is exceeded 95% of the year) in the period 1978-2007 (top) and 2021-2050 (bottom) [Lahaa et al. (2014) in Blöschl et al. (2018)]

3.3. Potential Environmental Impact of Climatic Change

Climatic projections into the near-future are already quite difficult and inherit many uncertainties (see 4.2). Even more difficult are predictions of their impact on ecology and the ecological state parameters used in the EU-WFD. However, some general statements for the ecological impacts of climatic change on Austrian rivers seem justified and realistic with regard to the experiences from previous years:

- Increases in flood discharges and flashiness of floods due to higher magnitudes of local precipitation are likely to increase soil erosion and fluxes of fine sediments and nutrients into the rivers.

- Periods of low flows will become more pronounced in the lowlands in eastern and south-eastern Austria. The intensity of droughts will increase and rivers running dry will more be the case – like in summer 2018. Groundwater exfiltration into the rivers will tend to decrease and alter nutrient and temperature regimes due to the lacking dilution.

- Low discharges and droughts may also occur during winter in the Alps. The decrease in groundwater exfiltration into the rivers will decrease and alter flow and temperature regimes.

4. How Does the EU-WFD Consider Hydrological Hazards?

The EU-WFD was implemented into the Austrian national legislation via “Wasserrechtsgesetz” (WRG). Supporting documents for the practical implementation were published by the Ministry for the Environment (Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft). The “Leitfäden” are guidelines for the evaluation of the biological quality components [6 – 12]. In Tab. 3, the main statements and recommendations in the guidelines considering floods and droughts are summarised.

Table 3. Summary on the statements and recommendations of the Austrian guidelines for evaluation of the ecological status of rivers with special regard to floods and droughts

Components	**Recommendations in the guidelines (Leitfaden)**
Biological components according to [6]	Potential causes for implausible results have to be evaluated and documented. • Extreme weather conditions (heat waves or strong rain) may lead to drying, heating, increase in salt concentrations, oxygen depletion of the water bodies or floods. • These extreme conditions may cause a wrong interpretations and results, because they are not accounted for in the implementation of the WFD. • In case of extreme conditions – specifically droughts and floods – sampling and data collection have to be repeated afterwards and used for a re-evaluation of the ecological status. • In severe cases (e.g. lack of time for sampling), an expert judgement is a sufficient base for the re-evaluation.
Fish according to [7]	Fish populations also respond to natural flow extremes (droughts, floods) which alter age structure and abundances. These parameters vary across the years. • Extreme conditions (e.g. droughts, floods, pollution spills) up to 3 years prior to the sampling have to be researched and documented. Results have to be taken into account in the evaluation. • Expert judgment is the final base for the evaluation of results.
Benthic invertebrates according to [8]	In general, sampling is prohibited under the following circumstances: • During floods and within a period of minimum 4 – 6 weeks after floods to enable re-establishment of the benthic fauna. • During or immediately after dry periods of intermittent water bodies. A minimum of 4 weeks is required to re-establish the benthic fauna. • During or immediately after anthropogenic disturbances, which bias sampling (e.g. turbidity due to construction works)

Phytobenthos according to [9]	The optimal condition for sampling is at the end of natural low water periods of each water body. One reason is practicability of the sampling (clear water conditions, low water levels for wading). More importantly, high flows have not occurred for a longer period and thus the phytobenthos communities are fully developed. Typically, this is the (late) winter from January to March. • In particular floods have to be considered prior to the sampling. 3 – 4 weeks of recovery are required for the phytobenthos to re-establish, in this period sampling is omitted. • Decisive of the benthic algae is if significant sediment transport occurred during flood events. In Austrian gravel-bed rivers, this is typically the case for floods larger than HQ1 (annual highest discharge).
Macrophytes according to [10]	Results from macrophyte mapping during floods are not representative. A minimum recovery period of 4 weeks is required after floods and before sampling. Flow tendencies during the sampling (high, medium, low) should be stated.
GPC parameters according to [11]	No specific recommendations for GPC sampling during floods or droughts are given. Instead, the GPC guidelines refer to the fish guidelines [7] but only the parameter temperature is considered: • In rivers, fish are the most sensitive ecological components with regard to temperature changes. • Evaluation based on fish should consider the individual life cycles of fish species. • Significant parameters are the maximum tolerable temperatures during short periods in summer as well as the temperature requirements for spawning and egg development.
Hydromorphology according to [12]	No statements or recommendations how to deal with floods and droughts or alterations of the natural flow regime or morphodynamically relevant discharges.

5. Synthesis and Conclusion

In this paper we highlighted the potential of floods and droughts to alter the ecological status of Austrian rivers according to EU-WFD. With an increase of flood magnitudes and flashiness as well as more pronounced periods of low flows, the pressures on the aquatic ecosystems will increase in the near future. It is not unlikely, that aquatic species are lost due to increased or shifted dynamics in the fluxes of water, sediments and nutrients. Almost two thirds of the Austrian rivers have deficits in the biological quality components and fail the good status according to the EU-WFD until now. Considering additional pressures due to hydrological hazards in the near future, improvements or fulfillment becomes even less realistic.

Further complications arise from the practical implementations of the EU-WFD which are largely based on static approaches and evaluation methods. Floods and droughts are considered as short-time disturbances with the underlying hypothesis, that ecosystems are resilient and reach the previous equilibrium conditions again. Otherwise, a redefinition of ecological reference conditions of rivers is required, which is not foreseen in the implementation schemes. Some striking points hereby are:

- The “hydrologic regime” according to the EU-WFD does not include all of the ecologically relevant parameters to characterize natural flow regimes and potential alterations due to floods and droughts.

- "Morphology" in the EU-WFD follows a static approach of the structural inventory of the rivers. It does not consider morphodynamics and sediment transport – which are strongly impacted by floods and droughts.
- The best practice according to the guidelines is to suspend sampling and data collection of biological quality components during and after floods and droughts – until representative (pre-event) conditions reestablish.

In this sense, a deterioration of the ecological status of rivers according to the EU-WFD may be expected in the near future. The tools and evaluation methods of the EU-WFD are not well prepared to account for ecosystem dynamics and alterations. Using the reference conditions prior to regime shifts as templates for the good ecological status of rivers thus seems problematic.

REFERENCES

1. *Angeler, D. J.* (2013) Resilience of Aquatic Ecosystems. https://pub.epsilon.slu.se/11371/3/angeler_d_140910.pdf.

2. *Blöschl, G., Blaschke, A. P., Haslinger, K., Hofstätter, M., Parajka, J., Salinas, J., Schöner, W.* (2018) Auswirkungen der Klimaänderung auf Österreichs Wasserwirtschaft – ein aktualisierter Statusbericht. Österreichische Wasser- und Abfallwirtschaft 70: pp. 462–473.

3. *Bunn, S. & Arthington, A.* (2002) Basic Principles and Ecological Consequences of Altered Flow Regimes for Aquatic Biodiversity. Environmental Management 30 (4): pp 492–507.

4. EU-WFD. The EU Water Framework Directive – Integrated River Basin Management for Europe. http://ec.europa.eu/environment/water/water-framework/ index_en.html.

5. *Laaha, G., Haslinger, K., Koffler, D., Parajka, M., Schöner, W., Viglione, A., Zehetgruber, J., Blöschl, G.* (2016): Ein Drei-Standbeine-Ansatz zur Ermittlung zukünftiger Niederwasserabflüsse in Österreich. Österreichische Wasser- und Abfallwirtschaft 68: pp. 54–57.

6. Leitfaden zur Erhebung der biologischen Qualitätselemente – Einleitung (2010). www.lebensministerium.at, ISBN: 978-3-85174-058-5.

7. Leitfaden zur Erhebung der biologischen Qualitätselemente Teil A1 – Fische (2010). www.lebensministerium.at, ISBN: 978-3-85174-059-2.

8. Leitfaden zur Erhebung der biologischen Qualitätselemente Teil A2 – Makrozoobenthos (2010). www.lebensministerium.at, ISBN: 978-3-85174-060-8.

9. Leitfaden zur Erhebung der biologischen Qualitätselemente Teil A3 – Phytobenthos (2013). www.lebensministerium.at, ISBN: 978-3-85174-061-5.

10. Leitfaden zur Erhebung der biologischen Qualitätselemente Teil A4 – Makrophyten (2013). www.lebensministerium.at, 978-3-85174-062-2.

11. Leitfaden zur typspezifischen Bewertung gemäß WRRL. Allgemein physikalisch-chemische Parameter in Fließgewässern (2015). www.lebensministerium.at, ISBN: 978-3-85174-068-4.

12. Leitfaden zur Zustandserhebung in Fließgewässern – Hydromorphologie (2013). www.lebensministerium.at, ISBN: 978-3-85174-067-7.

13. NGP – Nationaler Gewässerbewirtschaftungsplan 2015 (2016). Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, https://www.bmnt.gv.at/wasser/wisa/fachinformation/ngp/ngp-2015.

14. *Poff, N. L., Allan, J. D., Bain, M. B., Karr, J. R., Prestegaard, K. L., Richter, B. D., Sparks, R. E., Stromberg, J. C.* (1997) The Natural Flow Regime. BioScience 47 (11): pp. 769-784.

15. Qualitätszielverordnung Ökologie Oberflächengewässer – QZV Ökologie OG, Annex B (2010). Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, https://www.bmnt.gv.at/wasser/wasser-oesterreich/wasserrecht_national/planung/QZVOekologieOG.html.