

Module Hydrology – a hydro-ecological assessment method

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Introduction

The efforts made in the domain of water protection in the last decades with the immense investments put into waste water drainage and purification led to a clear enhancement with respect to water quality in Switzerland. However, there was growing insight that for the overall ecological status of the water bodies, water quality is only one key factor. This is reflected in the new guidelines for sustainable watercourse management in Switzerland [1] with the three principal requirements for

- adequate water quality
- adequate space for water
- adequate water flows

The Swiss water protection act along with its ordinance set corresponding ecological objectives. These ecological objectives are however somewhat vaguely defined (mostly by requiring “near-natural conditions” with respect to a number of water body characteristics). This is in principal comparable to the “good ecological status” as required by the EU Water Framework Directive.

To support the cantons – being responsible for implementing the water protection legislation – for the evaluation of the ecological objectives, the so called Modular-Stepwise-Procedure [2] has been established. This is a concept serving as a common framework for developing assessment methods for evaluating the individual aspects of the ecological status. These aspects – called Modules – are pooled in three Module-groups, namely a) hydrodynamics and morphology, b) biology and c) chemical and toxic effects.

Within the first group the Module Hydrology – hereafter referred to as HYDMOD – aims at investigating and assessing the impacts of man-made interventions on the flow regime. In particular the alterations of the natural flow regime are to be classified according to the scheme illustrated in figure 1. It is however important to note that the assessment results are solely reflecting shifts in the flow regime but not indicating the overall ecological status. For the latter evaluation the synthesis with other aspects would be necessary (e.g. a shift in the flow regime can be aggravated if combined with a low eco-morphological status of the concerned river stretch, or on the contrary, if the river under scrutiny is in natural-like morphological condition the effect of the altered flow-regime on the overall ecologic status may be alleviated). Although the selected parameters characterising the flow regime have been chosen with strong ecological considerations, their alteration only tells something about the risk from a hydrological/flow regime perspective of not meeting a good ecological status. The very ecological status depends on the interplay with other ecologically relevant factors.






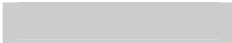
	1	natural / near-natural
	2	slightly altered
	3	considerably altered
	4	heavily altered
	5	artificial
		without assessment

Fig. 1. Assessment classes as to the alteration of the natural flow regime

A “grey” assessment-class is attributed to a river reach if a classification is – for what ever reason (missing data etc.) - not possible. In that case, however, a labeling of the kind of impact (i.e. the eminent hydrological phenomenon caused by interventions), is designed, e.g. designating residual-flow or hydro-peaking conditions.

The assessment’s object is the individual river reach. The study-area is the river network of a hydrologically defined river basin, since the status at a specific river reach is the result of all

upstream man-made interventions. In this paper a draft version of the HYDMOD-method, in particular its core elements, the procedure and some of the designed assessment approaches are presented. It is noteworthy to remark that the method is designed for application on a regional scale, i.e. to yield regional overviews of the flow regime status and not to provide design values for local scale projects or planning of measures.

Selecting parameters to characterise the flow regime

In order to assess the alteration of the flow regime the latter needs to be characterised by a set of pertinent hydrologic parameters. Their alterations serve as indicators for the natural status classification. Figure 2 shows a scheme, subdividing the flow regime in its low-flow, mean-flow and high-flow component along with a pool of characteristics.

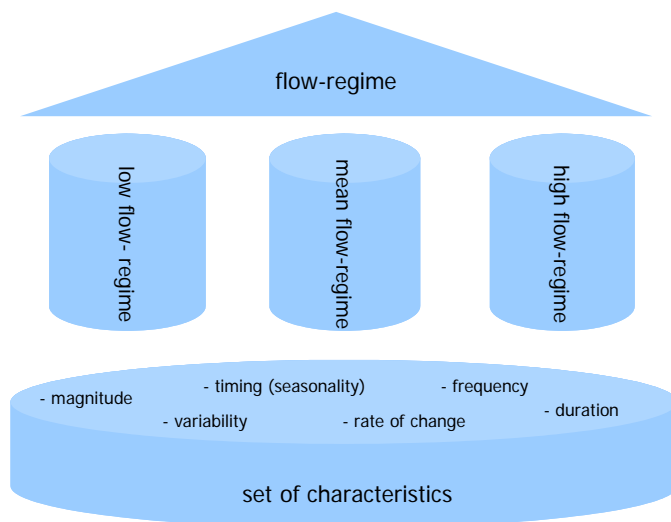


Fig. 2. Scheme breaking down the flow regime in its components and characteristics

Out of all possible parameters, the choice for the parameter selection to be used for the assessment was driven by the following criteria:

- to chose those parameters which are ecologically relevant
- to cover all principal flow regime domains (low-, mean- and high-flows)
- to select those parameters that are good indicators for the kind of phenomena (residual flow, hydro-peaking etc.) that are frequently caused in Switzerland by man-made interventions
- to consider parameters whose determination/estimation is deemed feasible also in cases where measured data are not available

These considerations – a compromise between ecological and pragmatic concerns - lead to the set of parameters shown in table 1.

alteration of the flow-regime		hydrological parameter
mean flow-regime (Q_m)	alteration of Q_m	Q_m
	seasonal shift of monthly discharges	Pardé-coefficients (PC_i)
high flow-regime (Q_h)	alteration of Q_h -frequency	number of flood-events per year
	alteration of Q_h -seasonality	Q_h -seasonality parameters
low flow-regime (Q_l)	alteration of Q_l -discharge	Q_{347}
	alteration of Q_l -seasonality	Q_l -seasonality parameters
	alteration of Q_l -duration	duration of Q_{347} -periods
hydro-peaking		hydro-peaking-indicator
flushing		flushing-indicator

Table 1. Set of selected parameters and indicators used to describe the flow regime and to assess flow regime alterations

As to the two phenomena hydro-peaking and flushing: although not having a natural correspondence but given their frequent occurrence in Switzerland, they need to be integrated with indicators for an assessment of the flow regime status.

For the selected hydrologic parameters the natural and the altered value has to be determined as input for the assessments, yielding a classification result.

The underlying rationale of the assessment and classification schemes (two examples of which will be outlined further below) is illustrated in figure 3. It consists basically of the comparison between the (hypothetical and to be estimated) natural and the (through anthropogenic interventions) altered flow-regime. That comparison is concretised on the basis of the selected parameters characterising the flow regime. In particular the classification depends on where the altered regime (respectively its characterising parameters) is located relative to the natural regime's expected parameter values and corresponding variability. It can be argued that an altered status but close to the expected natural value can be regarded as natural-like. But even if it is still within the range of natural variability (e.g. represented by the coefficient of variation, CV, of the considered parameter) it cannot be regarded as heavily altered. Whereas the more it falls beyond the range of natural variability the worse it has to be classified with respect to the degree of naturalness.

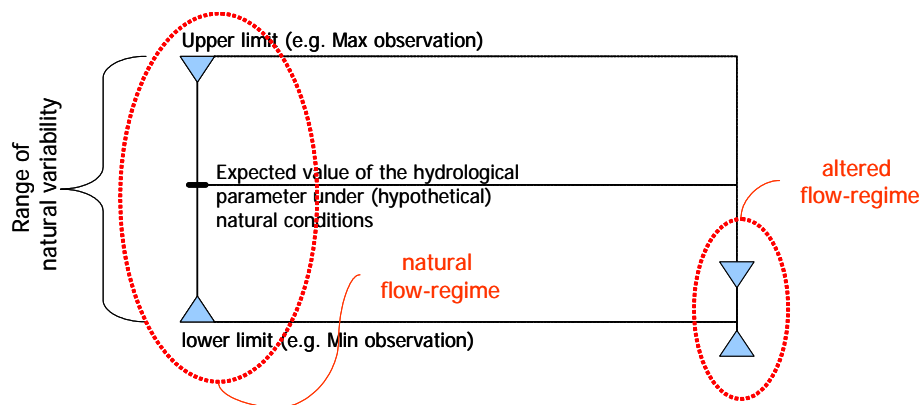


Fig. 3. Rationale of the assessment schemes for classifying a flow regime alteration

The Procedure – step by step until the overall assessment

The methodology consists of a stepwise procedure, culminating in the overall-assessment and classification of the flow-regime status. Schematically this is depicted in figure 4. In the following the individual steps are briefly outlined.

It all starts with the delimitation of the study area. The flow-regime alteration at a certain point along the river network is the result of all interventions upstream (their superposition, mutual aggravation or neutralisation). The “impact area” (that is the area onto which an intervention may lead to an impact) being the hydrologically defined river basin, the latter is the adequate study area.

Next is the definition of the river network that is used as spatial reference (the individual reaches of which being the assessment objects).

It follows the search for information sources in the study area. This comprises for example gauging stations from which the necessary flow regime parameters may be estimated, but also databases that contain information on the interventions (installations and operations) influencing the flow regime.

The next step is about searching those interventions which cause flow regime impacts. That will lead to an inventory of such interventions within the study area. To that end, the method provides a typology of man-made interventions that may serve as a checklist for the application. The same typology will be reused in subsequent steps.

It follows a triage while deselecting minor interventions. Based on the typology of interventions mentioned before, the method provides threshold values for each type which the interventions must exceed in order to be retained as “important” and to be considered for the further analysis. The motivation for this step is to avoid considering innumerable interventions which may have only locally limited impacts and for which it is expected that the necessary data and information for the subsequent analyses are not available. In that sense the motivation is a compromise towards practicability of the method.

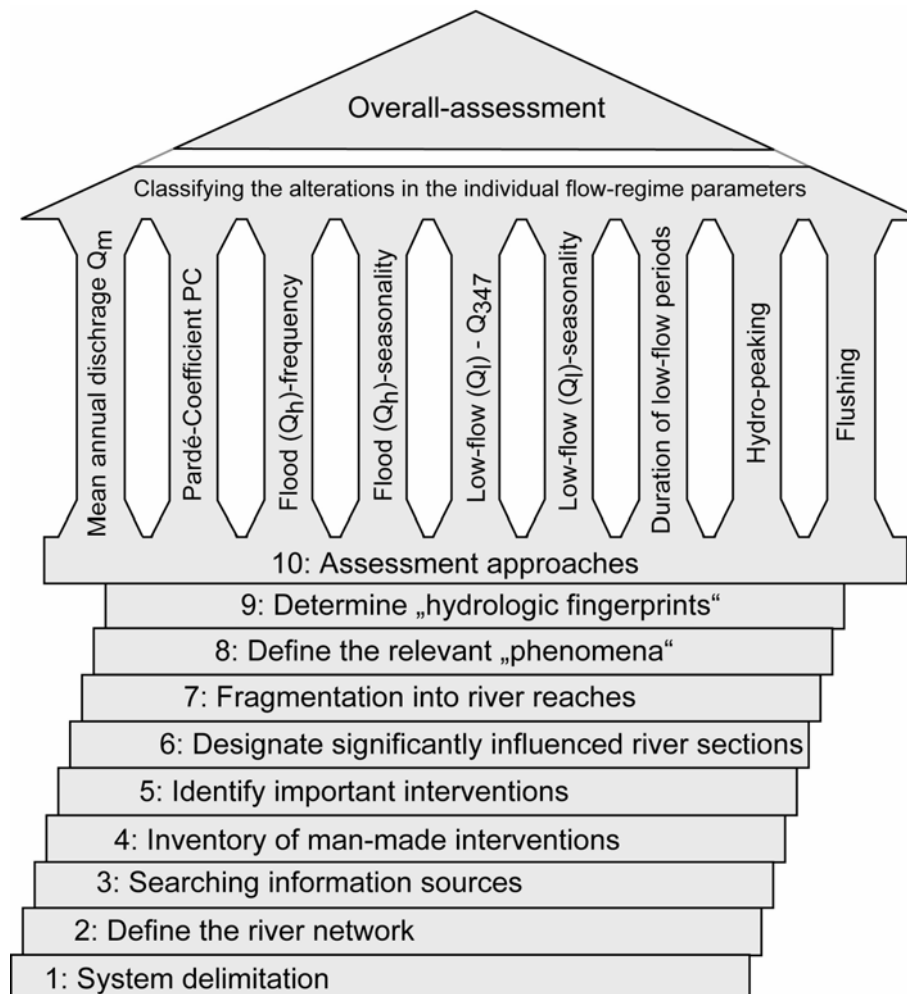


Fig. 4. Schematic overview of the method's step-by-step procedure

The next step is the identification and delimitation of those river sections that are significantly influenced. The same intervention situated along the Rhine-river has a different significance when situated on a small alpine brook. It is therefore suggested to compute a ratio that relates a quantity of the intervention to a flow regime parameter of the affected river. If that ratio exceeds the significance criteria provided by the method then the concerned river section is designated as significantly influenced. The beginning of that designated river section is at the location of the causing intervention. Further downstream the “disturbance-signal” emanating from the intervention is increasingly alleviated as “natural, undisturbed catchment” adds to the basin (e.g. by non-influenced tributaries). The end of the river section designated as significantly influenced is there where the above mentioned ratio falls below the given significance criteria.

As subsequent step follows the fragmentation of the significantly influenced river section into the individual river reaches, the latter being the actual reference-objects that are to be assessed and classified. A new river reach is situated there where a *substantial* change of the flow-regime is expected. Thus a new river reach is caused either by another intervention or when

joining tributaries add substantially “additional runoff” (the method recommends setting a new river reach when the relative increase of catchment area due to tributaries exceeds 15 %).

The next task is to determine which “phenomena” are expected to be caused at the investigated river section by the considered interventions. Depending on the type of intervention all or just few of the flow-regime parameters are effectively altered. The very assessment procedure at a certain river section can therefore be limited to the analyses of those hydrologic parameters which - by the given type of intervention – are expected to be significantly modified. For that purpose the method provides a matrix that shows which of the flow-regime parameters are usually significantly altered by which type of intervention (e.g. water withdrawals have basically impacts on all parameters, whereas flushings do normally not affect the mean flow and the seasonal flow distribution).

Before the actual assessment can be carried out, the required flow regime parameters have to be estimated. More precisely – the assessment’s principle being a comparison between natural and influenced flow regime – the necessary parameters (expected values along with a variability measure) have to be estimated for the actual, influenced and the (hypothetical) natural conditions. Respectively this is denominated as altered and natural hydrologic fingerprint of the river reach under investigation. Depending on the data availability, this can be done on the basis of data (a gauging station is at or close to the site under investigation), with an interpolation/extrapolation approach (gauging stations are available within a suitable distance), or in case no measured data are at disposal via a regionalization approach.

Having determined all necessary parameters eventually the assessment, i.e. the classification of the alterations with respect to the considered flow regime parameters has to be carried out. To that end, the method provides for all selected flow-regime parameters individual assessment schemes. Two of them are presented in the subsequent section.

The tasks of estimating the necessary flow-regime parameters (i.e. the previous step of determining the hydrologic fingerprints) and the application of the suggested assessment schemes have to be carried out only at the location of the interventions causing the significant impact. For the assessment and classification of this “disturbance signal” further downstream a simple approach is suggested that accounts for the increasing “dilution” of the disturbance signal as more uninfluenced catchment adds to the flow-regime. That approach is simply a weighted classification of the sub-basins (altered and unaffected) with the respective basin area (as surrogate for the amount of flow) acting as weight.

The outcome of the latter step is the classification of the individual flow-regime parameters’ alterations for the single river reaches. In order to integrate these detailed assessment results into one overall classification of the flow regime status, the method suggests the following aggregation rule: The worst single parameter assessment gives the overall classification. The reasoning behind that rule is that – as an example – a strong decrease of the low flow cannot be mitigated by a near-natural flood-frequency and seasonality condition. The hypothesis is that there is no compensating and hence weighting of the partial results. Each of the selected hydrologic parameters is deemed to be limiting for the natural status of the flow regime.

The method’s closing step is the representation of the classification results in both a cartographic and a tabular manner (see schematic in figure 5).

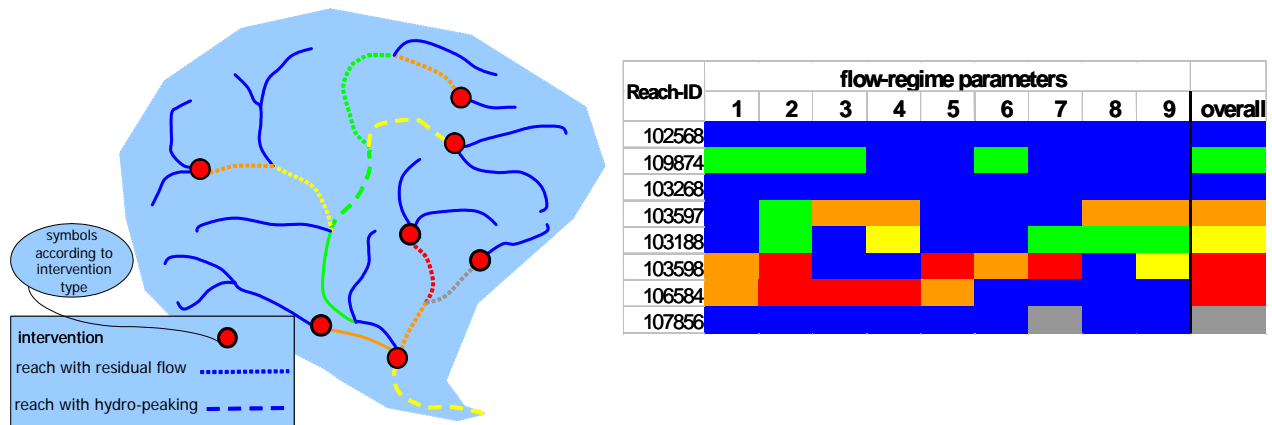


Fig. 5. Schematic of the colour-coded representation of the assessment and classification results for a basin's river reaches; left: cartographic, right: tabular

Assessment approach examples for individual flow regime parameters

The drafts of the assessment approaches for two of the selected flow-regime parameters are presented in the following section.

- **Classifying an alteration in the mean annual discharge and the monthly runoff distribution**

The method suggests one common scheme for classifying alterations in the mean annual discharge, Q_m , and in the seasonal, i.e. monthly runoff-distribution as expressed by the dimensionless Pardé-Coefficients PC_i [3, 4].

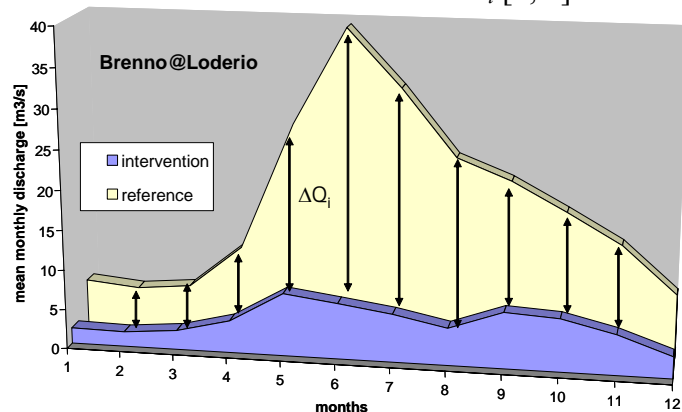


Fig. 6. Natural (reference, period 1904-1958) and influenced (intervention, period 1963-2000) mean monthly runoff along with their differences ΔQ_i for the river Brenno at Loderio (in the Southern Alps of Switzerland)

Multiplication of Q_m and PC_i yields mean monthly discharges. An alteration of the latter are captured by the statistic R_{impact} being defined as

$$R_{impact} = \sum_{i=1}^{12} |\Delta Q_i| / \sum_{i=1}^{12} Q_i^{natural} \text{ with}$$

$Q_i^{natural}$ mean monthly discharges under natural conditions

ΔQ_idifferences between the natural and the influenced mean monthly discharges

R_{impact} refers the sum of all alterations of the monthly discharges to the sum of the naturally occurring monthly discharges (see sketch in figure 6). Thus, R_{impact} captures both, a shift in the absolute level of runoff (the quantity, with the parameter Q_m) and a change of the relative distribution (the shape of the seasonal cycle, with the parameter PC_i).

In order to translate that into a classification (indicating the degree of naturalness) R_{impact} is related to the natural variability of Q_m and PC_i . The natural variability is determined by calculating how strong the monthly runoffs of individual years vary around the long-term, mean monthly runoffs. To that end, analogous to the formula for R_{impact} , R-values for individual years have been calculated for a number of

uninfluenced gauging stations. The analysis has been carried out in a way that the resulting R-values of representative stations for the 16 Swiss flow-regime-types [4] have been pooled together. This led to flow-regime-type specific distributions of R (see two examples in figure 7), which represent the natural variability of the monthly runoff. In general the alpine regimes show lower variability than the regimes in lowland, pluvially dominated regions.

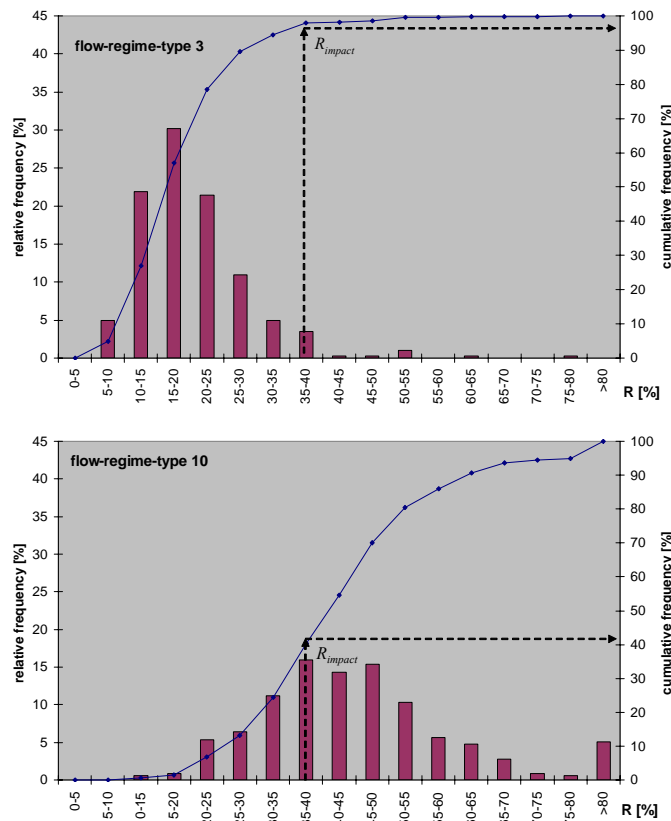


Fig. 7. Examples for two flow-regime-type specific distributions of R-values, representing the natural variability of Q_m and PC_i from year to year;

above: regime-type 3 (a-glacio-nival: highly alpine)

below: regime-type 10 (pluvial inférieur : lowland)

Against the backdrop of the natural variability an example R_{impact} -value of 38% is drawn in the graphs

The classification is now based on the comparison of R_{impact} with the regime-type-specific natural variability, given by the R-value distribution (see table 2 and the example in figure 7).

class	R_{impact}
1	$< R_{50\%}$
2	$< R_{75\%}$
3	$< 60\%$
4	$< 80\%$
5	$\geq 80\%$

Table 2. Classification scheme to translate the alteration of Q_m and PC_i as comprised in the statistic R_{impact} into five classes based on a comparison with the quantiles of the regime-type-specific R-values (for class 1 & 2) and with absolute thresholds of R (for the classes 3-5)

▪ **Classification scheme for shifts in the seasonality (both low-flows and high-flows)**

As to alterations of the flow regime’s seasonal aspects (apart from the Pardé-coefficients as set out above) both, shifts in the low-flow and in the high-flow seasonality are assessed according to the same approach.

For low-flows, the annual maximum low flow periods (defined as periods where flows fall below the Q_{347} -runoff with Q_{347} being the discharge that is on average exceeded on 347 days per year) are considered. For each year the period with the longest duration is considered and the temporal center-point of that period taken for the seasonality calculation.

As to high-flows, the dates of the annual maximum daily discharges are considered.

These dates are used for calculating seasonality parameters according to an approach described in [5, 6], which yields the expected date of occurrence and its variability. This can then be used for plotting the seasonality as a point in the “seasonality space” (see figure 8), where the angle indicates the expected (average) date of occurrence and the position relative to the origin reflects the variability (a point close to the unit circle in the seasonality space indicating a strong seasonality, respectively low temporal variability from year to year).

The position in the seasonality space is also used for the corresponding assessment approach. Two different seasonalities (be it from two different stations, be it from the same station but representing two different periods) are represented as two points in the seasonality space. Their distance is used as indicator for the alteration of the seasonality-behaviour, both capturing a shift in the expected occurrence and the variability (see figure 8). If no measured data are available for calculating the reference seasonality, then the method suggests to estimate that information by means of the corresponding flow-regime-type (which can be estimated solely by geographic criteria). Investigations in that respect showed that the different regime-types as defined for Switzerland [4] discriminate well with regard to their low-flow and high-flow seasonality and can be represented by ellipses in the seasonality space (see figure 8, right hand).

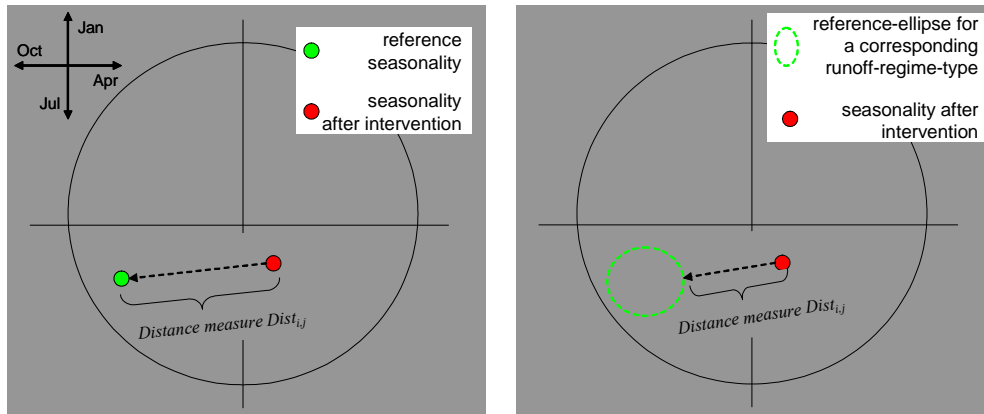


Fig 8. Seasonal behaviour represented as a point in the seasonality space. A shift in the seasonality is indicated by the distance between two points in that space; if data are available the reference seasonality can be represented by a point (left); otherwise the reference seasonality is estimated on the basis of an ellipse representing the corresponding flow-regime type (right)

The distance measure in the seasonality space is used to classify a shift in the seasonality according to the rules shown in table 3.

Distance Measure $Dist_{i,j}$ in the “seasonality space”	class
$Dist_{i,j} \leq 0.3$ (0.25)	1
0.3 (0.25) $\leq Dist_{i,j} \leq 0.6$ (0.5)	2
0.6 (0.5) $\leq Dist_{i,j} \leq 0.9$ (0.75)	3
0.9 (0.75) $\leq Dist_{i,j} \leq 1.2$ (1.0)	4
$Dist_{i,j} \geq 1.2$ (1.0)	5

Table 3. Rules to classify a shift in the seasonal behaviour of low- and high-flows according to the distance measure in the seasonality-space; numbers in brackets apply for the case when regime-type-ellipses (see figure 8) are used as estimates for the reference-seasonality

As an example figure 9 depicts the shift in low- and high-flow seasonality for a river, the flow-regime of which being altered by a reservoir used for hydropower generation.

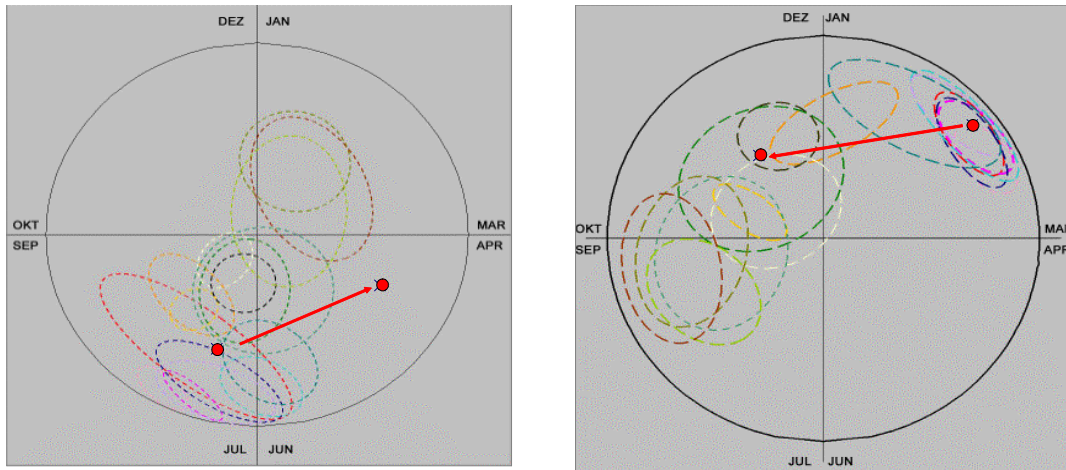


Fig. 9. River Julia at Tiefencastel: comparison of the time periods before (1919-1948) and after (1976-2002) the construction of the Marmorera reservoir (in operation since 1954); left: shift of the high-flow (Q_h)-seasonality / right: shift of the low-flow (Q_l)-seasonality (colored ellipses represent the natural seasonality of the Swiss flow-regime types)

Conclusion

A draft outline of a method to assess and classify the impacts of man-made interventions on the flow regime has been presented. Being designed for wide application it is somewhat in the area of conflict between practicability on the one hand (limited effort in terms of time, model and data requirements in the implementation), and scientific soundness on the other. Its purpose is to give regional overviews of the flow regime's natural status (respectively the degree of naturalness) via a classification approach. A set of pertinent hydrologic parameters that are also deemed to be ecologically relevant have been selected to characterise the flow-regime and its anthropogenic alterations.

Due to the fact that alterations in the flow regime can normally be well attributed to single interventions, the latter are quite in the center of the method (they are inventoried, a typology has been established, assessment is limited to river sections significantly affected by interventions, which hydrologic parameters to assess depends on the intervention-type etc.). Thus the proposed procedure might be referred to as an intervention-driven approach.

A drawback in a certain sense may be the introduction of "importance thresholds" that an intervention must exceed in order to be retained for the further analysis and assessment. That concession to the method's practicability may lead to an underestimation or even disregard of the impact for small rivers.

Finally it is noteworthy that the assessment method described in this paper goes along with estimation approaches for the required hydrologic parameters. This is in response to the varying data availability, ranging from – on the one hand - a situation with measured data before and after the intervention took place at the study site, to – on the other hand – places without any utilisable data: For the latter case alternative estimation approaches like regionalisation methods have to be provided, if wanted that the presented assessment method can effectively be realized.

References

- [1] SAEFL/FOWG (Eds.), 2003: Guiding Principles for Swiss watercourses. Promoting sustainable watercourse management. Swiss Agency for the Environment, Forests and Landscapes (SAEFL) and Federal Office for Water and Geology (FOWG), Bern, 12 pp.
- [2] BUWAL, 1998: Modul-Stufen-Konzept. Mitteilungen zum Gewässerschutz Nr. 26. Bundesamt für Umwelt, Wald und Landschaft, Bern. [www.modulstufenkonzept.ch]
- [3] Pardé, M., 1920: Le régime des cours d'eau en Suisse. *Revue de géographie alpine*, VIII, 359-457.
- [4] Aschwanden, H. und Weingartner, R., 1985: Die Abflussregimes der Schweiz. Geographisches Institut der Universität Bern. Publikation Gewässerkunde Nr. 65.
- [5] Bayliss A.C. and Jones, R.C., 1993: Peaks-over-threshold flood database: summary statistics and seasonality. Report 121, Institute of Hydrology, Wallingford, UK.
- [6] Burn, D.H., 1997: Catchment similarity for regional flood frequency analysis. *J. Hydrol.*, 100, 269-290.