Draft Procedure for
the Control of Water Abstractions
to Ensure Environmental Flow Compliance

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“The procedure for the assessment, monitoring, and control of water abstractions to ensure the continuity of ecological flow in accordance with the standards prescribed by the Water Framework Directive" was prepared by international expert Brian Faulkner within the project *"Protection of Rivers through Establishing Monitoring and Restoration Practices for River Habitats in Protected Areas"*, which is funded by PONT (Prespa Ohrid Nature Trust)* and implemented by Eko-svest.

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ACRONYMS

IBP – International Best Practice

NHMS – National Hydrometeorological Service

RBMP – River Basin Management Plan

WFD – Water Framework Directive (2000/60/EC)

WISE – Water Information System for Europe

1. OVERVIEW OF THE PROCEDURE

1.1 Principal Objectives and Scope of Application

1.1.1 *What This Procedure Does*

This procedure provides a step-by-step methodology for the analysis, regulation and inspection of water abstractions from rivers, so as to ensure that abstraction quantities do not exceed the environmentally sustainable flow limits of the target 'waterbody'. In hydro-ecology this is most usually referred to as 'the environmental flow requirement' (EFR). The environmental flow requirement has both quantity and time-duration components.

Abstractions from rivers are taken by a wide range of activities, including public water supply, hydropower operations, irrigation and aquaculture. This procedure applies equally to any of these activities. Typically, in day-to-day operations, multiple abstractions may occur simultaneously throughout a single river. Upstream abstractions therefore not only deplete water availability for downstream users but also alter the flow regime, so impacting the environmental flow requirement. Similarly, 'return flows' to the river from abstractive operations, or imports from adjacent river basins may also impact negatively on flow regime if these are significantly different from what would be expected under fully natural conditions, either in terms of quantity or timing or both.

The complex interaction of multiple flow abstractions, exports, returns or imports and the timings thereof, may create significant detrimental effects on river ecosystems unless these interactions are *a)* quantified *b)* properly managed.

Many European Water Permit procedures and approvals, including those in the Republic of North Macedonia (RMK) typically do not assess the sequential and accumulative impacts of multiple river operations when evaluating new Permit applications. This invariably leads to excessive abstraction quantities relative to the environmental flow requirements of the river. Rivers that are significantly flow depleted are likely to have highly damaged aquatic ecosystems, thereby endangering vulnerable fauna and flora, depleting natural capital and reducing ecosystem services.

1.1.2 *Who Should Use the Procedure*

The Environmental Flow Requirement Procedure (EFRP) ('the procedure') is intended for a wide variety of applications.
For example:

- It can be used to quantify the natural flow regime of the river, defined as the timing, duration, magnitude and variability of all flows within a river during a representative year. Quantification of the natural flow regime is fundamental to the correct definition of environmental flow. An understanding of flow regime is essential for ecological impact surveys and for the restoration of aquatic ecosystems.
- The procedure should be used by designers of hydropower installations <u>prior to construction</u> to ensure that the quantity and duration of proposed abstractions do not exceed sustainable limits. Public water supply, irrigation and aquaculture operations should undergo similar tests.
- Where river flow is diverted and stored, typically behind dams and barrages, (most usually for hydropower operations), then sudden and large releases of flow over and above the natural in-stream flow may be equally damaging to the aquatic ecosystem. These impacts can be tested with this procedure.
- The procedure should be used by regulatory authorities (e.g. Ministry of Environment, National Park Authorities) as part of the environmental impact assessment (EIA) of proposed abstraction operations to test operational impacts and to set operating flow limits as part of Water Permit conditions.

1.1.3 *Legal Relevance and Compliance*

The approach of this procedure is entirely consistent with the definitions and environmental objectives as set out under the European Union (EU) Water Framework Directive (WFD) 2000/60/EC, the single most important European legislative instrument governing the conservation of the environment. The RMK "Law on Waters xxx/xx" (in draft revision) essentially transposes the majority of the WFD legally binding requirements into national law.

The high relevance and importance of the WFD to environmental flow compliance is technically explained later in this document.

Currently this Procedure has no legal validity within the framework of the Law on Waters. It has been prepared for the Prespa-Ohrid Nature Trust (PONT) as a practical solution to the correct identification and monitoring of environmental flow requirements in ecologically important rivers where hydropower especially is having a detrimental influence.

However, the concepts and methodology outlined in this Report align closely with the investigation and high-level study commissioned by the Ministry of Environment and Physical Planning (MEPP) in 2018, culminating in a draft Ministerial "rule-book" [1]. Due to the enhanced technical content compared to previous methods, and the potentially significant economic implications, the procedure was not taken forward at that time and remains in draft status.

1.2 The Main Steps of the Procedure

Step by step guidance on the data needs and implementation of the procedure is set out in Section 3 of this document. The procedure incorporates both a simplified manual template and a more sophisticated spreadsheet-based model. Technically the alternatives are identical, but the computer model allows a greater range of environmental flow impact scenarios to be tested much more rapidly.

For early orientation for users of the procedure, the main steps only are described below:

1. **RIVER SCHEMATISATION** - the river that is to be evaluated is schematised into a series of equal distance steps. In the manual method there are six equal river steps (called segments), thereby allowing a maximum of 12 abstractions or return flows to be evaluated simultaneously (six on the left bank and six on the right bank). The computerised version expands to a maximum of 20 abstractions and/or returns on each bank (40 total).

   The river can be of any length and can have any user-defined start and end point. It is recommended that the river length should typically not exceed 15-20 km to maintain as much accuracy as possible both in terms of the flow regime data and the modelled abstractions and returns.

2. **PROVIDE FLOW DATA** – the procedure assumes a baseline condition of 'natural flow' in the river. The natural flow will typically increase in the downstream direction at a rate governed by catchment characteristics (precipitation, altitude, geology, land-cover and groundwater discharge). The difference in flow between the upstream (start point) and downstream (end-point) is divided equally to each distance step.

   Natural rivers exhibit a wide range of flows, ranging from winter high flows including riparian flooding and prolonged low flows in summer. The full range of these flows is fundamental to an analysis of environmental flow, and a full range of 'scenario flows' should be tested. Accordingly, the 'flow regime' of the river is most efficiently quantified and presented by means of a "Flow Duration Curve" (FDC). FDCs are a standard method in surface water hydrology, and their application is explained in the procedure. To apply the EFR procedure, it is therefore necessary for a competent hydrologist to provide the matching natural flow FDCs at the start and the end of the assessment river length.

3. **IDENTIFY ABSTRACTION AND RETURN PRESSURES** – along the assessment length, it is assumed that there will be a variety of flow "pressures" exerting influence on the natural flow of the river. Typically, these are abstractions for public water supply, hydropower, irrigation and aquaculture. Some of these installations will return some or all the abstraction to the river at a downstream location (known as 'returns'), others may permanently remove water from the river (known as 'consumption'). Whether returning the flow or not, every abstraction installation exerts potentially damaging influence on the natural flow of the river, either in terms of quantity or time-duration or both.

   All installations should therefore be identified and entered to the river schematisation within the nearest appropriate river segment.

[1] "The methodology and procedure for the identification, maintenance and enforcement of Minimum Acceptable Flows (Surface Waterbodies) or Groundwater Levels (Groundwater Bodies) in the territory of Republic of Macedonia" – Ministry of Environment and Physical Planning Study, 2018. Prepared by the Civil Engineering Institute, Skopje.

4. **DEFINE THE FLOW SCENARIO** – A 'flow scenario' is a snapshot of the river system under specified river and operational flow conditions. Usually it will be used to test if the environmental flow requirement is being met under specified actual or proposed operating conditions. A scenario comprises three elements:

   a) the time-period under investigation *b)* the baseline natural flow in the river in that same time-period *c)* the operational flows (abstractions, returns) appropriate to that same time-period.

   The time-period will usually be a specific month, season, or a full year, depending on the expected influence of the installation under investigation. For example, hydropower operations can significantly impact on receiving waterbodies within days of operation. Therefore, it may be appropriate to apply a monthly time-step to the analysis.

   The baseline flow (also known as the 'reference flow') is assumed to represent the natural flow in the river without artificial influences. The flow to be tested will depend on the objectives of the analysis. Most usually it will be the median average flow of the time-period selected e.g. specific month, 3-month season, annual etc.

5. **PROVIDE OPERATIONAL FLOW DATA FROM INSTALLATIONS** - although the hydromorphological impact is assessed individually at the point of abstraction for each installation, it also takes into account the sequential and accumulated effect of all other flow changes due to abstraction and return flow upstream of each individual abstraction.

   Therefore, the average quantity of the abstraction by the installation (under assumed normal operating conditions) and its time-duration must be provided for every installation for the time-period under evaluation. The scenario time-period is adaptive and could be set for a single day for example, but for practical reasons, it is likely that for most analyses the time-period will be a single month or a 3-month season. Daily or annual operational data is likely to be over-specific or over-generalised respectively to be of any practical use.

   The operational flow data must always match that of the baseline natural flow time-period being analysed.

6. **EVALUATE HYDROLOGICAL IMPACT** - in simple terms, for any given specific flow 'scenario', the procedure evaluates the degree of hydrological impact exerted by each installation on the accumulated residual flow of the river, relative to the original natural flow at each step of the schematisation. The greater the degree of flow regime change relative to the original flow in the river at any specific point, the greater will be the level of hydrological impact.

   According to published European standards, hydrological impact is assigned a score, ranging from 1 (discharge fully natural), to 5 (discharge greatly altered). In the absence of other highly important classifications of 'waterbody status' according to Water Framework Directive criteria (biological, physico-chemical and morphology 'elements'), hydrological impact can be made synonymous with waterbody status utilising the same impact score.[2]

   Waterbodies with an assessed hydrological impact of category 3 or higher ("moderate status") do not achieve the Water Framework Directive legally binding environmental objective of category 2 ("good status"), and will therefore require corrective action to the quantities and time-durations of abstractions within or upstream of the target waterbody to restore environmentally sustainable flows. [3]

   Generally, water abstraction installations (public water supply, hydropower, irrigation and aquaculture) should not be Permitted or operated such that the waterbody fails to achieve 'good status'. The procedure clearly identifies all locations within the schematisation where 'good status' is not achieved.

[2] Water Quality — Guidance standard on determining the degree of modification of river hydromorphology – European Standard EN 15843:2010

[3] European Directive 2000/60/EC – The Water Framework Directive, Recital (25)

The same procedure can then be used iteratively to identify necessary changes to all or some of the abstraction operations such that ‘good status’ is restored. These changes will require either reductions in abstraction quantity, reductions in time-duration of operations or shifting of operations to an entirely different time-period when more flow is available and hydrological impacts are proportionately less.

2. ENVIRONMENTAL FLOW AS DEFINED IN THE WATER FRAMEWORK DIRECTIVE

2.1 Historical Misconceptions Regarding Environmental Flow

2.1.1 *The Discredited 'Biological Minimum Flow' Concept*

The concept of 'environmental flow' has often been widely misunderstood, and incorrectly defined and regulated. For example, it is still common amongst eastern European countries to assume that a sufficient "biological minimum flow" is achieved if a minimum of 1/10 of the river's Mean Annual Flow (MAF) is left in the river throughout the year. Other common terminology includes definitions such as "minimum ecological flow", "in-stream minimum flow". Any terms implying some form of flow minimum or threshold, or 'in-stream needs' without reference to the riparian zone, are outdated, not in line with best practice, and should be discarded.

The most common term now in accepted best practice usage is "environmental flow" (EF), or the "environmental flow requirement" (EFR). This term is preferred because it aligns most closely with the concept of 'environmental objectives', a central pillar of the EU Water Framework Directive (Article 4). "Eflows" mentioned in some documentations are considered synonymous with environmental flows.

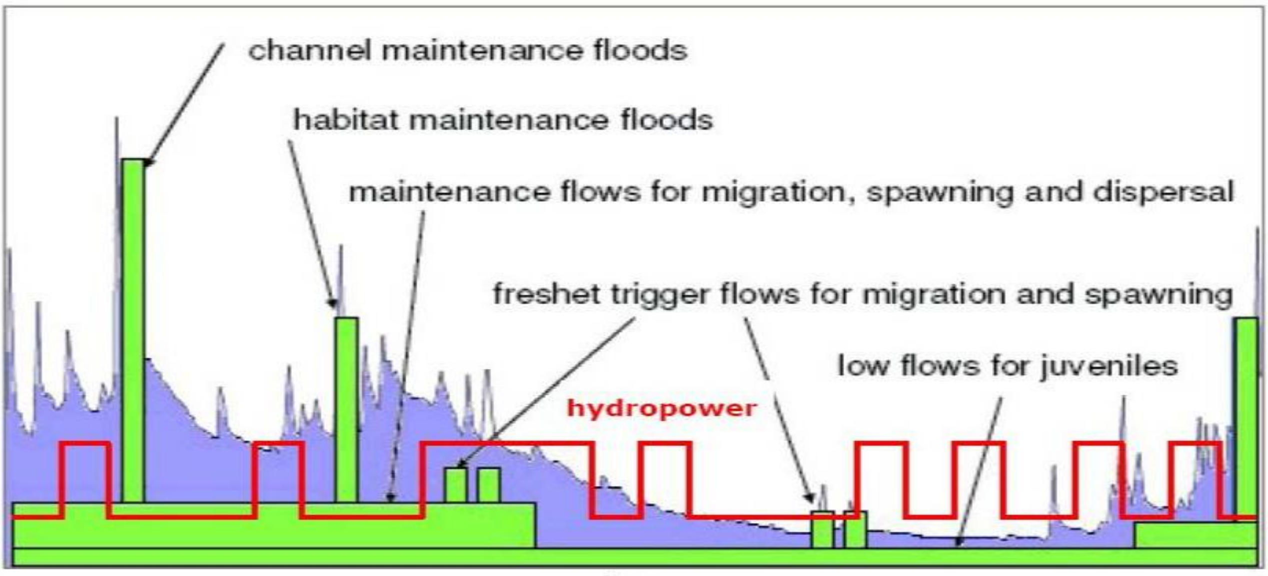
A simplistic threshold rule such as "1/10 Mean Annual Flow" or some reference to a Flow Duration Curve value such as "Q97" (flow in the river equalled or exceeded 97% of the time) completely ignores the highly variable nature of natural flows across a typical hydrological year and is ecologically invalid.

2.1.2 *The Preferred 'Natural Flow Regime' Concept*

Aquatic ecosystems that depend on the arterial nature of rivers are complex, highly integrated (and frequently) fragile systems. Over many thousands of years, the biota of these ecosystems will have adapted highly to the natural flow regime of the river. The regime includes the timing, magnitude, duration and quality of <u>all</u> flows observed throughout a typical year.

Figure 2-1 illustrates the concept: the natural flow regime (blue hydrograph) across a typical year includes numerous short-duration peaks of higher flows (the highest of which may create out-of-bank flooding in the riparian zone), intermediate peaks of lower magnitude, referred to as 'habitat maintenance flows', (important for channel-floodplain interactions and nutrient cycling), and thirdly, long-duration channel maintenance low flows essential for sediment deposition, predator prevention, juvenile fish development and seasonally emergent flora.

Figure 2-1 – Illustration of the Natural Flow Regime and Its Environmental Significance



The ‘building block methodology’ (BBM) introduced in 2000 [4] shown in Figure 2-1 demonstrates that the natural flow regime can be conceived as a series of flow blocks that represent the main pillars of aquatic ecosystem health. Any significant change in the magnitude, frequency or duration of any of these blocks is likely to reduce the ecosystem sustainability.

As an example, also shown in Figure 2-1, is the typical operation of a run-of-river hydropower plant (with some off-line storage). It can be seen that the significant high flows are typically reduced, natural low flows are typically increased, and there is a continuous effect of on/off flow pulses in the river when the hydropower turbine(s) are operating, known as ‘hydro-peaking’. This complete change of the natural flow regime is intensely damaging to the biota of the aquatic ecosystem.

Whilst it is not possible to replicate entirely the natural flow regime with introduced artificial influences such as abstractions for hydropower, public water supply etc., it IS possible to mimic approximately the natural regime with careful controls on the timings, quantities and durations of authorised abstractions and returns.

This should be the primary requirement of any issued Water Permit, and these limitations should be assessed and stated during the environmental impact assessment phase of any new infrastructure proposal, not afterwards.

2.2 The Relevance of the Water Framework Directive

2.2.1 *Environmental Objectives (Article 4)*

Any study, strategy or environmental management plan, irrespective of the originating Authority, that relates to the natural environment, especially that concerning surface and/or groundwater waterbodies, should comply with the overall objectives of the EU Water Framework Directive (WFD) (EU 2000/60/EC). This includes for example water resources, water supply, flood management, wastewater management and national park management strategies or subsidiary Plans.

At the highest conceptual level, the WFD stipulates that where water resources, water quality and protection of waters generally are the principal objective, national strategies should adopt the mechanism of “River Basin Management Plans” (RBMPs”). The (water) environment, including all its manifestations (ecosystems, water resources, public water supply, wastewater etc.) should be managed in a coherent and holistic manner so as to coordinate and manage all pressures on the aquatic environment.

This coherence should be achieved by the setting out of ‘environmental objectives’. Amongst numerous potential environmental objectives that may be stated within the legally adopted River Basin Management Plan, one of the primary objectives is the achievement of ‘good status’ of all waterbodies (WFD Article 4). This states that:

“Member States shall implement the necessary measures to prevent deterioration of the status of all bodies of surface and groundwater with the aim of achieving good waterbody status within xx years after the date of entry into force of this Directive in accordance with the provisions of Annex V”.

2.2.2 *Waterbodies in the Water Framework Directive – Status, Pressures & Measures*

Waterbodies are the fundamental building blocks of River Basin Management Plans and aquatic protection generally. All surface waters and groundwaters are required to be delineated (i.e. with observable limits or boundaries) into discrete ‘waterbodies’ and characterised according to *a)* a set of physical descriptors such as catchment area, underlying geology and altitude [5] *b)* the significant pressures that are observed/measured for each individual waterbody.

The main purpose of delineating waterbodies is to enable their status to be accurately assessed and compared to environmental objectives i.e. a waterbody must be capable of being assigned to a single ecological status class.

Where the waterbody is assessed at less than ‘good status’, this is invariably due to the damaging effects of artificial influences such as abstraction for public water supply, hydropower and irrigation, destruction of channel habitats due to gravel mining, infrastructure works, or pollution impacts of chemical discharges, nutrient runoff or untreated wastewater. In the language of the WFD, these are known as ‘**pressures**’.

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[4] Water Research Commission, Republic of South Africa – “A Building Block Methodology for Instream Flow Assessments”, 2000

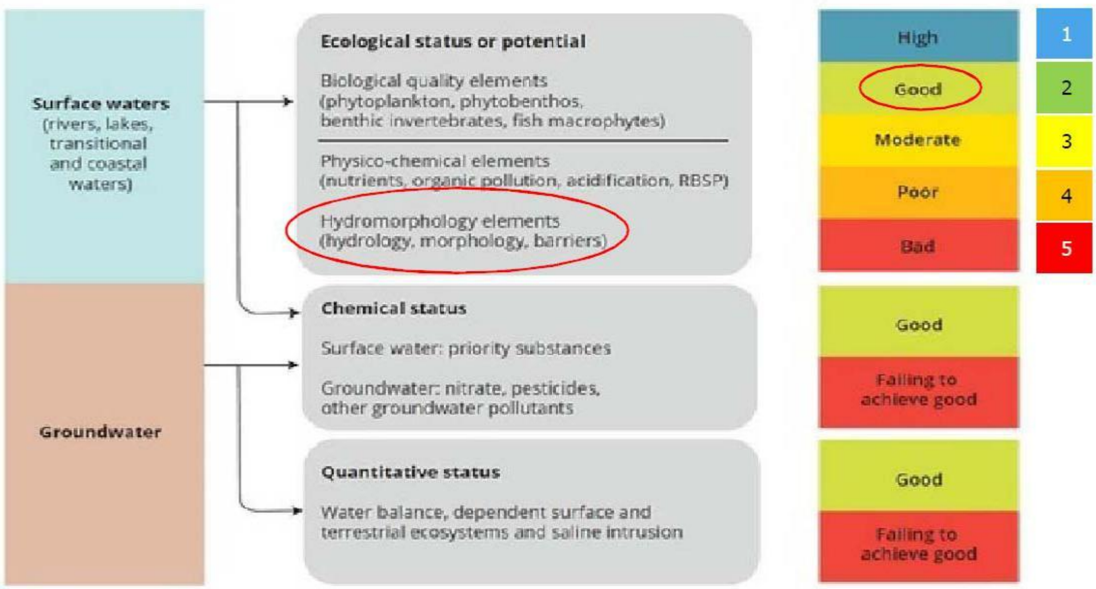
[5] Water Framework Directive 2000/60/EC – Annex II, (1.2)

It is one of the primary deliverables of a River Basin Management Plan (RBMP) to identify and measure the degree of this pressure for each waterbody. Under WFD Article 4, waterbodies that are not in good status require explicitly stated '**measures**' that set out how the River Basin District Authority will rectify the status of the failing waterbodies such that they eventually achieve 'good overall status'.

2.2.3 *'Good Status' of Waterbodies*

The overall status of a waterbody is defined (for surface waters) by the combined influence of 'chemical status' and 'ecological status', and for groundwater waterbodies, by their chemical and quantitative status. Figure 2-2 illustrates the definition.

Figure 2-2 – Illustration of Waterbody Status



Good chemical status is that required to meet the environmental objectives for surface waters established in WFD Article 4(1)(a), that is the chemical status achieved by a waterbody in which concentrations of pollutants do not exceed the '**environmental quality standards**' (EQS) established under WFD Annex IX and other Community legislation.

Ecological status is a complex amalgamation of various '**elements**' which express the quality of the structure and functioning of the aquatic ecosystems associated with each waterbody, relative to its reference (undisturbed) condition (WFD Annex V). The principal elements comprise *biological, physico-chemical and hydromorphological* components.

Figure 2-2 illustrates that waterbody status must be assigned to one of five classes from 1 (High) to 5 (Bad). According to the WFD definition (WFD Annex V) a waterbody is in '**reference**' (high) status when:

"The values of the biological quality elements for the surface waterbody reflect those normally associated with that type under undisturbed conditions. There are no, or only very minor, anthropogenic alterations to the values of the physico- chemical and hydromorphological quality elements for the surface waterbody type from those normally associated with that type under undisturbed conditions".

For waterbodies in '**good status**':

"The values of the biological quality elements for surface waterbody types may show low levels of distortion resulting from human activity but deviate only slightly from those normally associated with the surface waterbody type under undisturbed conditions".

2.3 Abstraction and Return of Flows as a Significant Pressure

2.3.1 *The Concept of the "Pressure-Impact" Test*

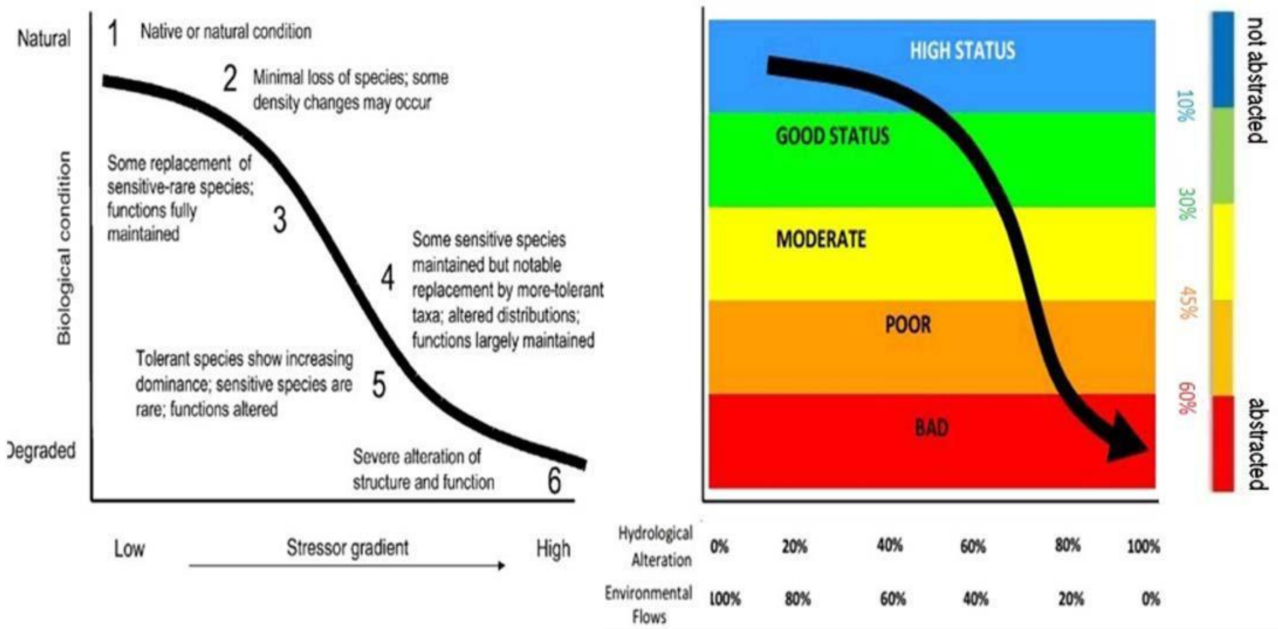
In the context of this Procedure, the abstraction and return of flows, especially for public water supply, hydropower and irrigation operations create significant hydromorphological pressures, frequently leading to a deterioration of waterbody status.

The legal definitions of 'high' and 'good status' defined in 2.2.3 above are highly relevant to the application of an environmental flow methodology. For a waterbody to be in good status (a legal requirement of the WFD River Basin Management Plan) the biological elements may vary only slightly from those seen under undisturbed conditions.

Central to the environmental flow procedure therefore is the test: "*to what extent does the abstraction at Point X influence the biological, hydromorphological and/or physico-chemical elements such that good ecological status is NOT achieved"?*

In simple terms this may be described as the "pressure-impact" test. Essentially, it may be assumed that increasing levels of pressure (by excessive quantity or inappropriately timed abstraction or return flow) leads to an increasing deterioration in waterbody status. This concept is illustrated in Figure 2-3.

Figure 2-3 – Graphical Illustration of Pressure-Impact Concept



Source: CIS Guidance Document 31 – Ecological Flows in the Water Framework Directive, 2014

Figure 2-3 illustrates that an increasing degree of abstraction is likely to have an increasing impact on waterbody status. Whilst the exact biological impacts will vary across eco-regions and waterbody types, it is generally accepted that the environmental flow requirement across a typical year in most rivers is likely to be at least 40% of the mean annual flow to maintain waterbody good status. This is a factor of 4x what is frequently stipulated as a biological minimum flow in many eastern European legislations. This is a simple quantity criterion. The duration of time that flow is abstracted from a waterbody is a parallel constraining criterion.

2.3.2 *The Ecological Relevance of Flow Regime*

Whilst the hydromorphological elements of waterbody status (hydrology, morphology and barriers) form only part of the overall status assessment, it is now widely accepted in best practice that:

- Flow regime plays a primary role in the structure and functioning of aquatic ecosystems [6]
- Virtually all rivers, lakes, wetlands and groundwater dependent ecosystems are largely controlled by the hydrological regime [5]
- The changing origin and quantity of water flowing in a river provides habitat and significantly influences water quality, temperature, nutrient cycling, oxygen availability, and the geomorphic processes that shape river channels and floodplains [5]

Significant disturbances or alterations to the flow regime through prolonged and/or excessive abstraction quantities are likely to directly impact on the health and functioning of aquatic ecosystems and thereby fail the legally binding target of good ecological status for each waterbody.

2.3.3 *Full Definition of Water Framework Directive Compliant Environmental Flow*

It should be evident from the explanations above that environmental flow is not a single threshold value. Environmental flow is a regime, mimicking the natural changes, durations and timings of flows throughout a year. Whilst the exact number of e.g. flood peaks and their magnitudes, e.g. the duration and level of low flows etc. cannot be entirely duplicated in an artificially influenced regime compared to the fully natural one, in order to maintain aquatic ecosystem functioning the basic pattern of the flow and a significant proportion of the quantity must be maintained within the river.

Therefore "**environmental flow**" is considered within the context of the WFD as:

"a hydrological regime consistent with the achievement of the environmental objectives of the WFD in natural surface waterbodies as mentioned in Article 4(1)".

In its simplest form, this target can be defined as "Good Ecological Status" (GES) for the waterbody. It should be noted that this is achieved through a regime of flow, never a single threshold value. WFD Annex V (Table 1.2) further clarifies that for GES to be achieved:

"The values of the biological quality elements for the surface waterbody type may show low levels of distortion resulting from human activity but deviate only slightly from those normally associated with the surface waterbody type under undisturbed conditions".

2.4 Quantifying the Natural Flow Regime

The starting point for an assessment of environmental flow and its degree of alteration due to artificial influences is to define the baseline fully natural flow regime. In surface water hydrology, the flow regime of a river incorporates the timings, durations and patterns of all flows throughout a typical year. Seasonality is of course a principal driver of dynamic flow regime, but geology, altitude and land-cover of the contributing catchments are also important static factors.

Based on the data from long-term hydrological gauging stations, river flow is usually monitored only at specific locations nationally. Various hydrological techniques can be used by technical specialists to transfer this data to the local scale on smaller rivers where typically no flow data are routinely measured.

2.4.1 *Natural Flow v. Recent Actual Flow*

It is important to understand that the environmental flow Procedure assumes that the baseline flow being tested for hydromorphological impact is the natural (undisturbed) flow, in compliance with the Water Framework Directive definition of environmental flow.

Problematically, the majority of national flow gauging stations measure what is technically known as '**recent actual flow**'. This is the observed flow in the river at point X, which therefore includes the net result of all artificial abstractions, exports, returns and imports. Unless abstractions and exports are exactly balanced by returns and imports, 'recent actual flow' is very unlikely to be representative of '**natural flow**'.

[6] Water Framework Directive 2000/60/EC - CIS Guidance Document 31 – Ecological Flows in the Water Framework Directive, 2014

For example, assume that the median average natural flow of the river in the season July-August-September at point X is 2.5 m^3/s. Assume that in this period an irrigation system abstracts an average flow of 1.0 m^3/s throughout same the season. Downstream of point X the observed flow will be reduced to 1.5 m^3/s. This is termed the 'recent actual flow' and is what would be measured at a downstream gauging station.

Recent actual flow is usually less than the natural flow, because most abstractions do not return all their flow to the river (referred to as '**consumption**'). However, when water has been abstracted and stored for any significant period in reservoirs, OR imported from an adjacent river basin, the observed (recent actual) flow may be significantly higher than the natural flow during the period when that storage is released.

To arrive at the correct value of the natural flow downstream of any upstream influences, the standard hydrological formulae are useful:

Natural Flow = Observed Flow + (Abstractions + Exports) – (Returns + Imports) [1]

and inversely:

Observed Flow = Natural Flow - (Abstractions + Exports) + (Returns + Imports) [2]

These formulae work at any scale and time-period for any river. The numeric process of converting recent actual flow (observed) to natural flow is termed '**flow naturalisation**'. It is evident that in the operational cases where 100% of the abstracted flow is returned to the river at some point downstream (e.g. frequently the case for run-of-river hydropower), then formula [1] generates a zero-sum i.e. (+ abstraction – return) = 0. Observed flow will be the same as the natural flow at that location.

The observed flow formula [2] can be used in water balance calculations to check that theoretical natural flows match the observed flows +/- the artificial influences.

It can be a challenging and time-consuming exercise to generate long series of naturalised flow data from the historical (observed) record, but such an exercise is the responsibility of the national hydrometric service.

2.4.2 *Annual Flow Regime Described with the Hydrograph and the Flow Duration Curve*

In hydrology the flow regime of a river is described most usually through two related graphical techniques, *a)* the monthly, seasonal or annual hydrograph *b)* the monthly, seasonal or annual flow duration curve (FDC). They both derive from the flow data collected directly at a gauging station or statistically transferred to an ungauged location; they use the same data but present the data in different ways for different purposes.

The hydrograph shows the magnitude and duration of flows at different times. The hydrograph therefore is primarily concerned with the pattern of flow throughout the time-period.

The flow duration curve quantifies the amount of time that a specific flow is equalled or exceeded. The FDC therefore is primarily concerned with the volume of flow throughout the time-period.

Whilst the time-period hydrograph is an important element in understanding in hydro-biological assessments and ecosystem processes, water availability (in terms of its volume and the duration of time that this volume persists) is the most basic component of environmental flow; hence the FDC is the principal tool in determining the environmental flow requirement for any river.

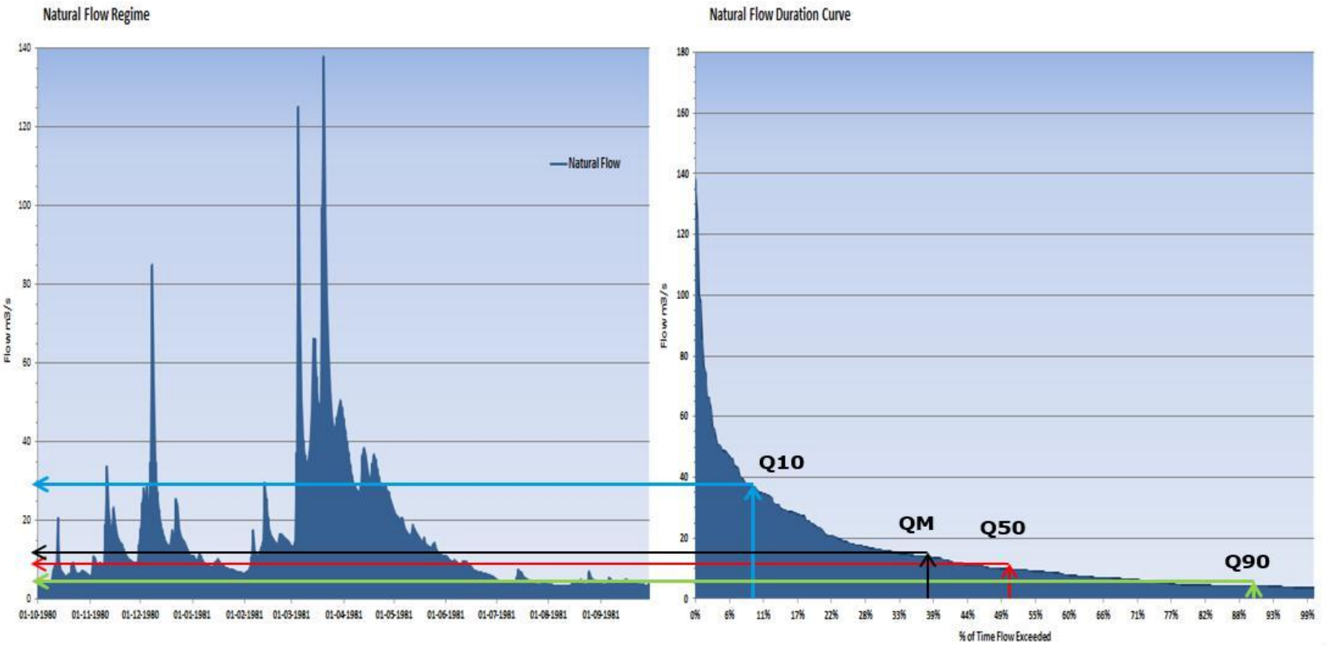
Figure 2-4 illustrates that hydrographs and duration curves simply represent the flow data in different ways. Most usefully, the FDC makes it is easy to determine the median average flow in the river for any given month, season or year. This median flow (**Q50** in FDC terminology) therefore has a 50% probability of being equalled or exceeded in the evaluated time-period, with 50% of flows being less than Q50. Hence the Q50 flow represents the most meaningful statistic for evaluating average availability of water resources. By implication, the Q50 is also the long-term average flow to which the aquatic ecosystem will have adapted over millennia.

Other important index flows on the flow duration curve include the Q10, Q25, Q75 and Q90. Q10 (the flow equalled or exceeded 10% of the time-duration) is a proxy for flood flows which may interact with the riparian floodplain. Q25 and Q75 are the upper and lower limits respectively traditionally used to assess the economic viability of hydropower plants.

The Q90 index value is highly relevant to environmental flow assessment. It is conventionally assumed that this is the point at which all flow derives entirely from groundwater discharge to the river. This may include the influence of large springs. Groundwater discharge has special characteristics with respect to time persistence, temperature and chemistry, and more than any other flow it is the one to which aquatic biota is most likely adapted.

The ratio Q90/Q50 is technically known as the **Baseflow Index (BFI)** and is a very important standardised indicator of how much river water in an average year derives from groundwater discharge. Karstic regions typically have BFI values > 0.5, and because of the stability and reliability of this flow, as well as the high carbonate nature of the physico-chemistry, high BFI rivers frequently support diverse, highly adapted aquatic ecosystems.

Figure 2-4 – Illustration of Flow Regime by Two Methods



2.5 Quantifying the Degree of Hydromorphological Impact

2.5.1 *European Standard on Determining the Degree of Modification of River Hydromorphology*

As set out under 2.3, a waterbody in good ecological status (GES) requires that the biological quality elements should be only slightly different from undisturbed conditions. Central to the environmental flow procedure therefore is the requirement to quantify the degree of hydromorphological alteration created by abstraction or return flows, relative to the fully natural (undisturbed) flow.

In view of the importance of hydromorphological elements with respect to aquatic ecosystems generally, in 2009 the Comité Européen De Normalisation (CEN) published the European Standard on hydromorphological alteration. [7] This Standard should be used in conjunction with the companion Standard on “Assessing the Hydromorphological Features of Rivers” [8].

Both documents set out standardised definitions and terminology of all issues relating to the physical and flow characteristics of rivers. These standards are legally binding for Member States affiliated to the CEN.

[7] European Standard EN 15843:2010 – “Water Quality - Guidance Standard on Determining the Degree of Modification of River Hydromorphology”, Comité Européen De Normalisation, 2009

[8] European Standard EN 14614:2004 – “Water Quality — Guidance Standard for Assessing the Hydromorphological Features of Rivers”, Comité Européen De Normalisation, 2004

The 15843:2020 Standard focuses especially on anthropogenic pressures that affect rivers by indicating the extent to which these pressures might have caused a departure from hydromorphological reference conditions. This quantified level of impact can then be related (indirectly) to the equivalent Water Framework Directive 'status' of the waterbody.

The Standard defines 10 'feature categories', including channel geometry, channel vegetation, longitudinal continuity, and channel-floodplain interactions, amongst others. Of particular importance to this procedure is feature category 5 "flow alteration".

2.5.2 *European Standard EN 15843:2010 – Feature Category 5 – Flow Regime Alteration*

Taking in to account the ecological importance of flow regime as described under 2.3.2, feature category 5 (flow regime alteration) is central to the assessment of environmental flow requirements. Feature category 5 is sub-divided to three elements:

a) 5a - Impacts of artificial in-channel structures within the reach
b) 5b - Effects of catchment-wide modifications to natural flow character
c) 5c - Effects of daily flow alteration (e.g. by hydro-peaking)

Scoring is based on one of two alternative systems:

Score-band A assumes quantitative data and uses a five-point scale, where 1 = little or no flow modification and 5 = very high degree of flow modification.

Score-band B assumes that only qualitative assessment has been applied, and allocates hydrological alteration to only three classes, 1 = low, 3 = medium, and 5 = high.

This environmental flow Procedure assumes that the five-point scoring system will be used, as quantitative data is required for both *a)* the natural flows calculated for the river reach(es) under assessment *b)* the quantities and durations of flows abstracted or returned by all Operators on the river system.

The discontinuity of the river channel due to in-channel artificial structures (weirs, barrages, dams) has a potentially extremely damaging impact on aquatic ecosystems, (feature category 5a) and should be considered in a more comprehensive 'biological status assessment' (see 2.4.3); this Procedure focuses only on flow regime changes (i.e. feature categories 5b and 5c).

The degree of flow regime impact quantified by EN 15843:2020 addresses two basic criteria:

The quantity by which the undisturbed (reference) flow has been altered as a relative percentage, either as a decrease or as an increase

The time-duration that the flow has been altered within the assessment period (day, week, month, season, year) as a relative percentage.

For example, it is estimated that for a 5% reduction in the natural flow value (for the specific time-period considered), this abstraction could be maintained for up to 60% of the time with minimal hydromorphological impact (flow regime only marginally altered), so the river will remain in reference condition.

A 25% level of abstraction of the natural flow for 50% of the time would however create a category 3 level of impact (flow regime moderately altered).

A 100% increase in flow (due to e.g. hydropower release from storage) for 80% of the time will create a category 5 level of impact (flow regime extremely altered).

Table 2-1 sets out the impact scoring matrix. This impact scoring system applies to any flow scenario being assessed, but for most cases it is likely to be the median average flow (Q50) for the stated period that is being used.

Table 2-1 – Impact Scoring for Degree of Flow Regime Alteration

% days flow different from natural in spring, summer, autumn or winter (worst)	< 20	20 to < 40	40 to < 60	60 to < 80	≥ 80
< 5 % decrease or < 10 % increase in flow	1	1	1	2	2
5 % to < 15 % decrease in flow or 10 % to < 50 % increase in flow	1	2	2	3	3
15 % to < 30 % decrease in flow or 50 % to < 100 % increase in flow	1	2	3	3	4
30 % to < 50 % decrease in flow or 100 % to < 500 % increase in flow	1	2	3	4	5
≥ 50 % decrease in flow or ≥ 500 % increase in flow	2	3	4	5	5

2.5.3 *Relating Hydromorphological Impact to Ecological Status*

Table 2-1 provides a standardised and systematic basis to evaluate hydromorphological impacts of abstractions and returns across any river in an objective way based on the European standard. It is noted that the Standard uses the same 5 classes of impact as for the Water Framework Directive criteria of ecological status.

It should be recognised that hydromorphological impact is not necessarily the same as 'ecological status'. Strictly speaking, waterbody ecological status is only fully and correctly determined through complex biological surveys of the key aquatic determinants of macrophytes, fish populations, phytobenthos and benthic invertebrates. However, such surveys are time-consuming, complex and expensive.

Recent advanced research on the influence of flow regime on aquatic systems has strongly supported the simplifying assumption that although hydromorphological disturbance and ecological functioning are not necessarily linearly related, there is insufficient scientific evidence to justify differential weighting of the scores allocated i.e. it is reasonable to assume that hydromorphological alteration scores can be used as a proxy indicator of 'probable ecological status', as shown in Figure 2-3. [9] [10] [11] [12]

At the minimum, the European standard provides a simple, practical desk-based procedure to provide a risk-based assessment of possible waterbody status because of hydromorphological pressure. Where the implication is that the waterbody may be in less than good status i.e. category 3, 4 or 5, then the onus is on the Permit applicant or the Operator to prove (based on detailed biological assessment) that the waterbody is NOT in the unfavourable status suggested by the risk assessment procedure.

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[9] Poff, N.L. et al. (1997) - The Natural Flow Regime A paradigm for river conservation and restoration, BioScience, Vol.47, No.

11 [10] Richter, B. et al. (1997) - How much water does a river need? Freshwater Biology, Vol. 37, 231-249

[11] World Wildlife Fund (2009) – Keeping Rivers Alive - A Primer on Environmental Flows and Their Assessment

[12] Poff, N.L. et al. (2010) - The ecological limits of hydrologic alteration (ELOHA): a new framework for developing regional environmental flow standards, Freshwater Biology, Vol.55, 147-170

3. WORKED EXAMPLES OF THE ENVIRONMENTAL FLOW METHODOLOGY – MANUAL METHOD

3.1 Overview

The manual method described step-by-step below is a simplified version of the computerised Procedure. It is strongly recommended that first-time users of the method should trial the manual version before using the computerised one. The concepts and general approach are identical to both, but the manual pro-forma is simpler to use and primarily self- trains the user to understand the key steps.

The manual version contains an A4 pro-forma in Annex A, which should be printed out first before commencing the steps below. It is recommended to print out two blank copies of the pro-forma. The first copy can be used as a temporary work-sheet to calculate the natural increase in the reference flow at each segment of the schematisation. The second copy can be used for the final calculations of impact at each segment.

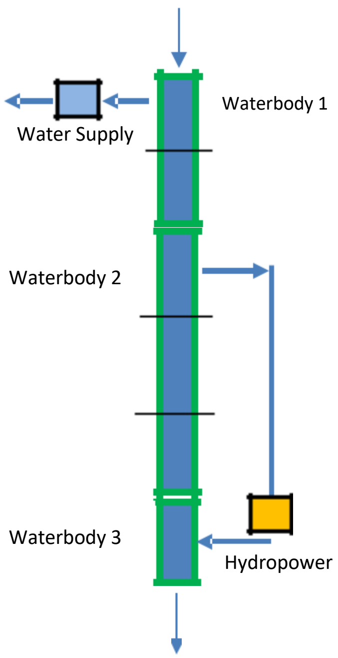
3.2 Manual Procedure

3.2.1 *Step 1 – River schematisation and Waterbody Identification*

The target river has been delineated to three separate waterbodies according to WFD delineation criteria (WFD Annex II, (1.2)). The waterbodies all have the same physical characteristics (e.g. medium altitude, small catchment, with calcareous geology). Therefore they are differentiated only according to the observed pressures applying to each waterbody.

The total length of the system is 1.8km. The schematisation assumes that this distance will be divided to six equal distance intervals i.e. 1800 / 6 = 300m. The waterbody lengths must be approximated to this distance-interval. Waterbody lengths do not have to be geometrically exact. Likewise, the exact location of the pressure within each waterbody is also not critical so long as the pressure is correctly allocated to the relevant waterbody.

Figure 3-1 – Schematisation of River System



Waterbody 1 is the most upstream waterbody. It has an approximate length of 600m i.e. it contains two equal distance intervals (segments). Within this reach a public water supply abstraction takes place for a local town, sited on the right bank. This is measured as a constant flow rate of 0.270 m^3/s for 365 days per year. The abstraction point is in the upper part of the waterbody (first 300m segment). The abstracted water does not return to this part of the river.

Waterbody 2 occupies the middle reach and has a nominal length of 900m (three distance intervals). There is a proposed hydropower abstraction in the first segment on the left bank. A delineation point is made between WB1 and WB2 because this new abstraction will create increased hydromorphological pressure and therefore a change in status between the two waterbodies. It is also very likely that a diversion barrage exists at this location. Therefore they must be analysed and managed as separate entities. The Water Permit operator has proposed that the hydropower will abstract a maximum of 0.900 m^3/s for at least 20 days each month.

Waterbody 3 is the most downstream waterbody. It has a nominal length of 300m i.e. one distance interval. Within this reach, the water taken for hydropower from WB2 is returned. For simplicity it is assumed that there are no losses through the hydropower system, so a full 0.900 m^3/s returns to WB3.

3.2.2 *Step 2 – Obtain and Inspect the Flow Data*

The Procedure always assumes a baseline condition of 'natural flow' in the river. The natural flow will typically increase in the downstream direction at a rate governed by catchment characteristics (precipitation, altitude, geology, land-cover and groundwater discharge). The difference in flow between the upstream (start point) and downstream (end-point) is divided equally to each distance step.

Flow data for the analysis is provided by two Flow Duration Curves (FDCs), and although they are often shown graphically, a tabulation is more useful for analytical purposes. Tables 3-1 and 3-2 show the FDCs for the river system at the upstream (inflow) and the downstream (outflow) points respectively.

To ensure that the environmental flow is being assessed across the full regime, it is essential that a full range of flow scenarios are included in the dataset. At the very least, scenario flows should be provided for each month of the year so the potential impact of any abstraction or return can be analysed in detail. If the variation of average flow across the year is relatively small, it may be acceptable to simplify the analysis to just four seasonal tests or possibly a single annual test.

For the great majority of cases, it is probable that it is the median average flow (Q50) for each month, season or year that will be tested against possible abstraction pressures. The pressures themselves will also usually be represented by median average abstractions or discharges BUT other higher or lower operational flows could be tested, depending on the scenario.

As noted under 2.4.2, the Q90 index flow value is also highly relevant to environmental flow assessment. This is the point at which it is conventionally assumed that all the river flow is comprised entirely of groundwater, technically referred to as **'baseflow'**. Baseflow discharge has special characteristics with respect to time persistence, temperature and chemistry, and more than any other flow it is the one to which aquatic biota are most likely adapted. Therefore a 'Q90' test of the FDC should also always be carried out to demonstrate that Q90 flow itself is not being significantly affected.

In this simplified manual example, only the Q25, Q50 and Q90 flows from each monthly and seasonal FDC are presented and analysed.

Table 3-1 – Flow Duration Curve for the Inflow (m^3/s)

FDC	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	OND	JFM	AMJ	JAS	ANN
Q25	3.86	4.25	4.16	4.07	4.37	4.20	4.48	4.51	3.91	3.35	3.35	3.59	4.09	4.21	4.30	3.43	4.07
Q50	3.47	3.57	3.63	3.67	3.79	3.77	3.99	3.88	3.48	3.09	3.10	3.37	3.56	3.74	3.78	3.19	3.53
Q90	2.82	2.92	2.77	2.35	3.03	2.93	2.82	2.60	2.24	2.00	2.17	2.80	2.84	2.77	2.55	2.32	2.67

Table 3-2 – Flow Duration Curve for the Outflow (m^3/s)

FDC	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	OND	JFM	AMJ	JAS	ANN
Q25	4.83	5.32	5.20	5.08	5.46	5.25	5.60	5.64	4.89	4.19	4.19	4.48	5.11	5.27	5.38	4.29	5.08
Q50	4.34	4.46	4.53	4.58	4.74	4.71	4.99	4.85	4.35	3.86	3.88	4.21	4.45	4.68	4.73	3.98	4.41
Q90	3.53	3.66	3.47	2.93	3.79	3.67	3.53	3.25	2.80	2.50	2.71	3.50	3.55	3.46	3.19	2.90	3.33

Inspection of Table 3-1 shows the median average annual flow (Q50) at the upstream inflow is 3.53 m^3/s. This increases to 4.41 m^3/s at the downstream limit (Table 3-2). The month with the lowest median average flow is July, where the monthly Q50 increases from 3.09 m^3/s to 3.86 m^3/s upstream to downstream. Therefore July is a 'worst case scenario' in terms of abstraction and possible impact.

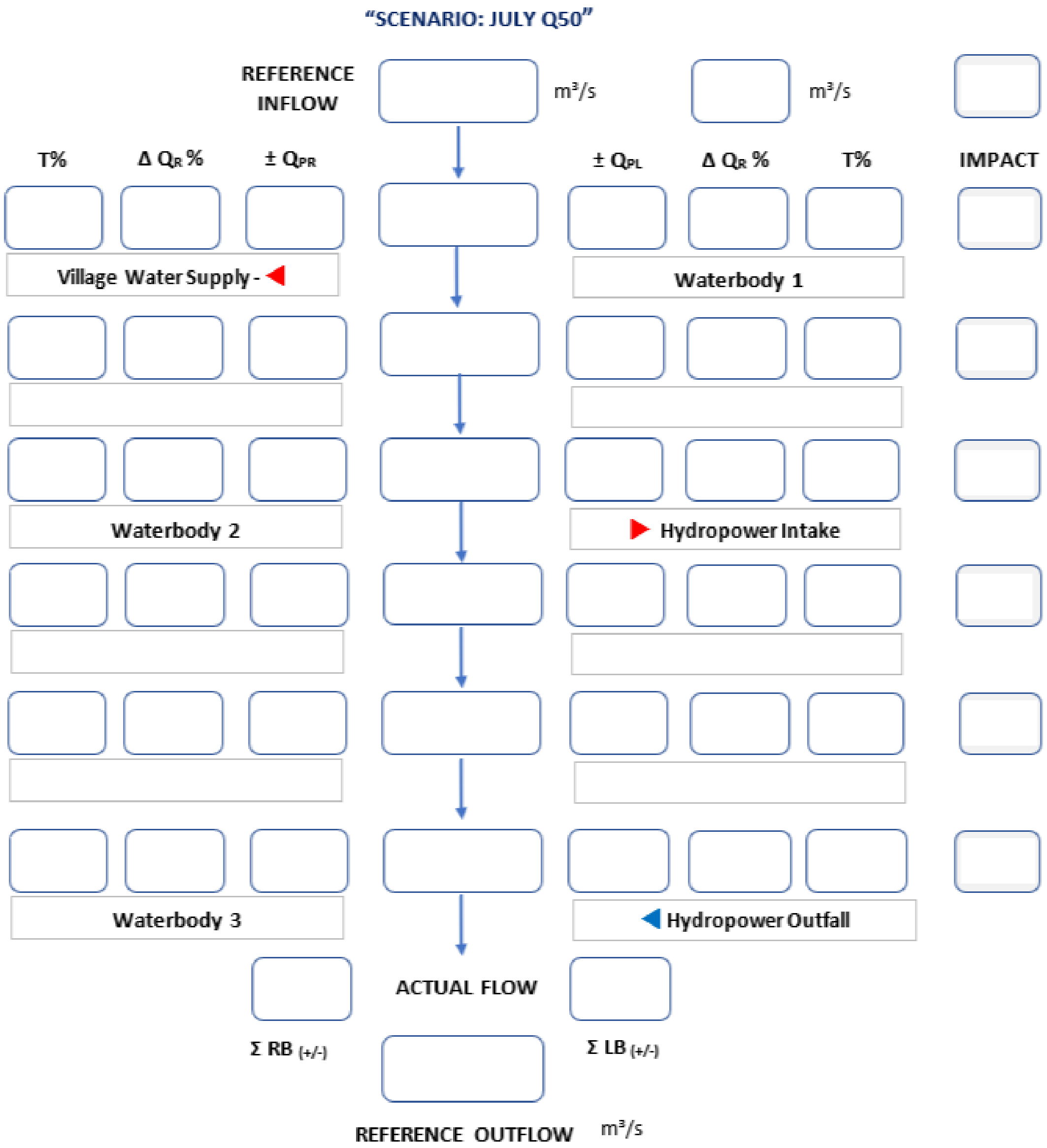
3.2.3 *Step 3 - Identify Abstraction and Return Pressures*

Field-work, Water Permit records, local knowledge and geo-data sources such as Google Earth™ should be used to identify sources of pressure, these being allocated to the appropriate waterbody segment. In an environmental flow assessment, it is essential that all potential pressures are identified and quantified.

A best-practice procedure must not only assess the isolated impact of an operation on the waterbody, but also the accumulated impact considering all upstream abstractions and returns. An individual minor abstraction may have negligible influence at a single point, but the accumulated impact of numerous such abstractions may become significant.

In this manual example, the pressures have been identified and located as shown in Figure 3-1 and are added to the pro-forma worksheet (Figure 3-2). Although it is not essential, it may be useful to also enter the names and delineation points of the waterbodies. Waterbody 1 extends across two river segments; Waterbody 2 extends across three segments and Waterbody 3 extends for one segment.

Figure 3-2 – Initial Setup and Base Data



3.2.4 *Step 4 – Define the Flow Scenario*

Numerous alternative scenarios and operational permutations are possible when considering the environmental flow requirement, incorporating alterations to the natural flow being tested (e.g. Q25, Q50, Q90), abstracted flows, changes in operating time-duration etc. For complex assessments where many flows and/or operations are being tested, the manual calculation process is laborious, and the computer-based version is to be preferred once the analyst is familiar with the procedure.

A 'flow scenario' comprises three elements:

a) the time-period under investigation *b)* the river design flow in that same time-period *c)* the operational flows (abstractions, returns) appropriate to that same time-period.

a) The time-period will usually be a specific month, season, or a full year, depending on the expected influence of the installation under investigation. For example, hydropower operations can significantly impact on receiving waterbodies within days of operation. Therefore, it may be appropriate to apply a monthly time-step to the analysis. This means that 12 individual monthly analyses would have to be examined. The average performance of the hydropower installation in each month (average running time and average flow abstraction) is used in each case. Conversely, if public water supply is being tested (which tends to be of lower quantity and more consistent across time), it may be appropriate to use a seasonal time-step.

b) The river design flow is selected from the range of flows that have been prepared for the flow duration curve (FDC). The baseline flow data in the FDC is assumed to represent the natural flow in the river without artificial influences. The FDC may contain a wide range of design flows that can be tested, collectively known as the 'flow regime'. For example, in FDC terminology, the median average flow in any time-period is referred to as the "Q50" flow. This is the most likely and frequent design flow to be tested, since 'average operational conditions' will be the most usual scenario of interest for regulatory purposes.

But other flows e.g. the "Q10" (which is the flow equalled or exceeded for only 10% of the time-period i.e. probable flood conditions), or e.g. the "Q90" (which is the flow equalled or exceeded 90% of the time and is typical of when the river flow is entirely derived from groundwater discharge) may be of relevance to the analysis.

c) Once the time-period and the associated baseline natural flow have been selected, the operational flows matching that time-period must be quantified. If a different time-period (month, season) is selected or a different river flow is tested, then this is an entirely new scenario, and the operational flows for that scenario may also change.

In the worked example of Figure 3-2, we will test operational conditions against the lowest average monthly flow which (from Table 3-2) is seen to be in July, so the flow scenario is defined as "JULY Q50". In this case Q50 = 3.09 m^3/s for the inflow and the Q50 outflow is 3.86 m^3/s.

3.2.5 *Step 5 – Enter Baseline River Flow and Flow Data from the Operations*

In the first pass of the pro-forma, it may be helpful to enter the calculations of the baseline natural flow progression i.e. before the effect of the operations is added. The natural flow for the July Q50 scenario increases from 3.09 m^3/s upstream to 3.86 m^3/s, and this flow increases linearly across six river segments.

Therefore the natural flow increment at each segment = (3.86 – 3.09) / 6.00 = 0.128 m^3/s. The natural flow increment at each segment should be calculated and added to pro- forma (see Figure 3-3). This value will be recalculated for each segment once the operational flow data are added.

The next step is to enter the existing and/or proposed abstractions, exports, returns and imports to the schematisation.

The flow data from the operations must match the time-period being assumed for the flow scenario. For example, if an annual river flow is being tested, then the average annual abstraction (or return) flow must be used for all the operations. Similarly, if the month of e.g. July is being tested, then it is the operational data for July that must be used.

In this simplified example, it is assumed that the abstractions being tested are constant throughout the year so there is no specific data for July, the month with the lowest natural flow.

It is established from 3.2.1 that there are two operational pressures in this analysis:

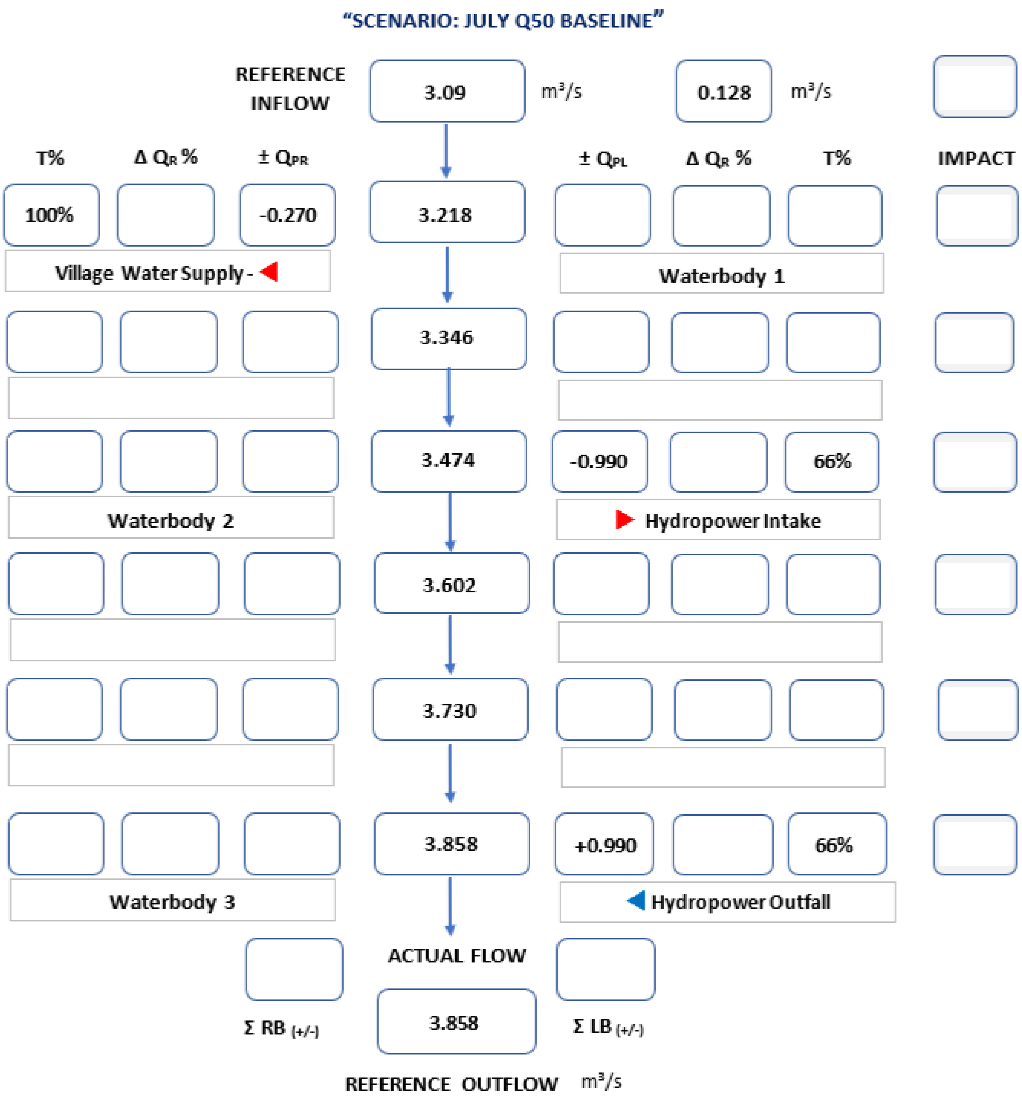
a) Public water supply abstraction in Waterbody 1 on the right-bank comprising an abstraction rate of 0.270 m^3/s for 365 days per year, 100% of the time. (This quantity amounts to the equivalent of supplying a population of 66,000 inhabitants (e.g. Tetovo) with 350 l/c/d, typical of Balkan abstraction quantities). Also likely, at least 50% of this abstraction is not likely to reach consumers, being lost to the leakage of the supply network, and is therefore a wasted abstraction.

b) A proposed hydropower operation on the left-bank in Waterbody 2, comprising an abstraction rate of 0.900 m^3/s for two turbines with an installed capacity of 0.450 m^3/s each. The Operator plans to operate both turbines throughout the year for an estimated 20 days every month i.e. 66% of the time.

These data are added to the pro-forma (see Figure 3-3). On the pro-forma, the notation $\pm Q_{PL}$ and $\pm Q_{PR}$ denote the average actual flow rate of the operation (-ve for an abstraction, +ve for a return) from the left and right banks respectively. T% is the time-duration of the operation within the time-period being assessed (annual, seasonal, month etc.).

Figure 3-3 shows that it is possible to have two pressures entered for each segment, one on each bank. Both may be negative (abstraction), positive (returns) or one of each, in which case it is the net result that will be tested. Note that the T% value may be different for two separate operations on each side of the river.

Figure 3-3 – Interim Stage of Baseline River Flow + Artificial Influences



3.2.6 *Step 6 – Evaluate the Modified Flow Regime and Hydromorphological Impact*

The next stage is to compute the modified ('recent actual') river flow in each segment of the schematisation, considering *a)* the increase in natural flow moving downstream *b)* the hydrological change on the flow regime (i.e. pressure) exerted by each individual operation for each river segment.

For every segment of the schematisation, the 'recent actual flow' formula is always the same:

Recent Actual Flow = Modified Outflow from Upstream + Natural Flow Increment + Left Bank Q_{PL} + Right Bank Q_{PR} [3]

where Left Bank Q_{PL} or Right Bank Q_{PR} represents the quantity of the abstraction or return flow by any operation within that segment. The arithmetic sign is important and should always be shown in the pro-forma. Abstractions and exports are always regarded as negative ($-Q_P$) and returns and imports are always positive ($+Q_p$).

Experienced users will do the full 'recent actual flow' calculation for each segment with a single arithmetic pass of formula [3], but for clarity, the screenshot of Figure 3-3 shows the <u>interim stage</u> of the assessment, including the calculated progression of the natural flow sequence and the allocation of the operational flows at each segment.

Figure 3-4 – Final Stage of Recent Actual Flow Calculation + Impact

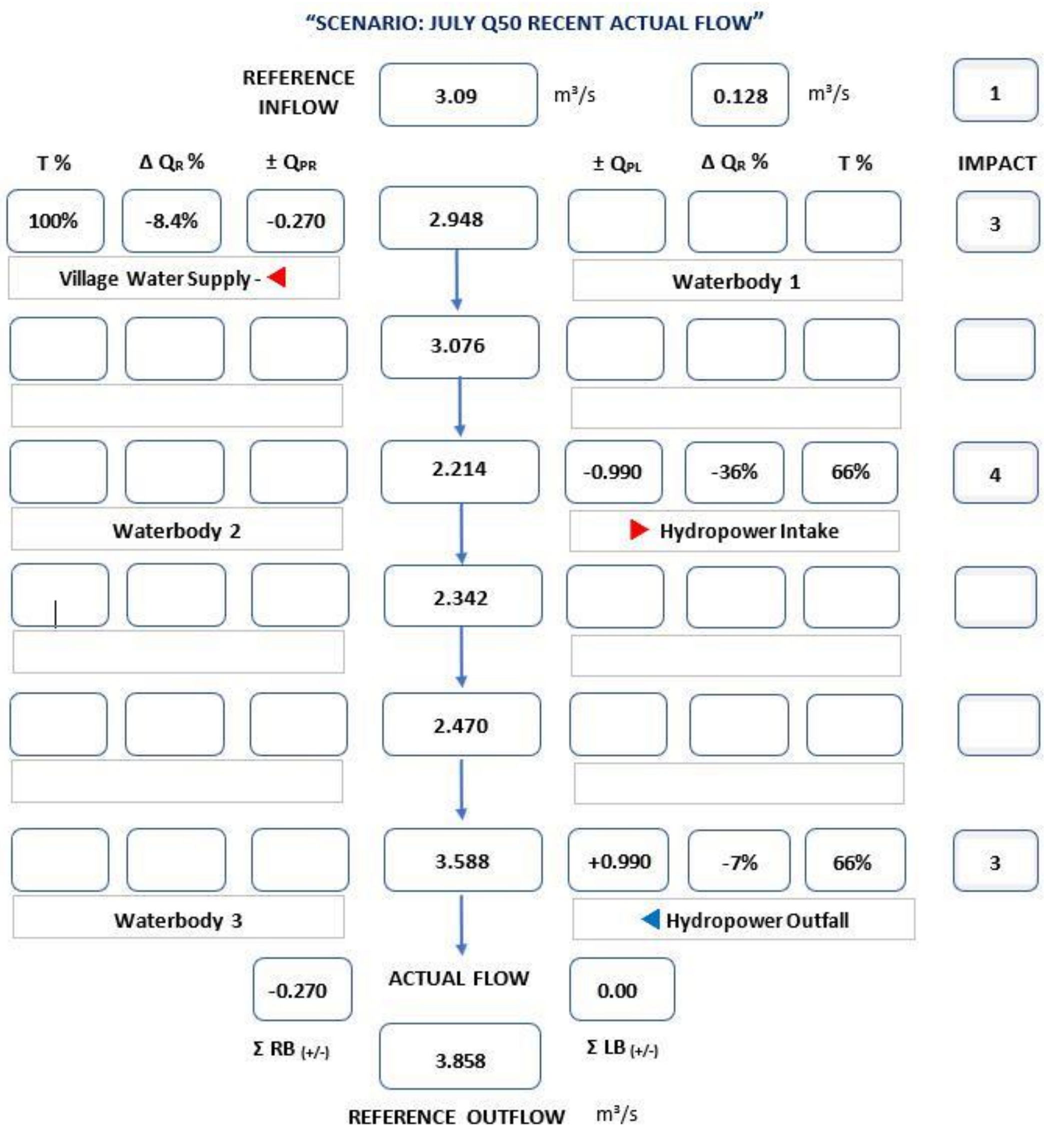


Figure 3-4 shows the final set of calculations, including an assessment of the two artificial influences (water supply and hydropower) on the hydromorphological impact on the relevant segments of the waterbody according to the 'pressure- matrix' of Table 2-1.

3.2.7 *Summary of the Manual Method*

Referencing Figure 3-4, for each segment, the recent actual flow from the upstream segment is increased by the natural flow increment, in this case 0.128 m³/s. At each segment, if there is an abstraction, this will deplete the flow; if there is a return, the flow will increase. Proceeding downstream, the changes in flow (both negative and positive) are accumulated, and therefore the impact of any new artificial influence correctly considers the pressures from upstream.

It is important to understand that the flow change calculated for each operation in each segment (expressed as a % i.e. ΔQ_R %) is the amount by which the original (reference) flow in the river has been reduced or increased by the operation(s) at each segment.

For example, for the village water supply in segment 1, the flow impact is calculated as follows:

1. Upstream inflow (3.09) + natural flow increase (+0.128) – right-bank abstraction (-0.270) = 2.948m³/s
2. The reference outflow from segment 1 was originally 3.218 m³/s
3. Therefore the abstraction results in a river flow reduction of (2.948 / 3.218) -1 = - 8.4%
4. The time-duration of this public water supply is constant at 100%
5. Therefore, by reference to EN 15843:2010 (Table 2-1), the impact is quantified as category 3.

This illustrates that <u>time</u> is a key factor in hydromorphological impact. Although the abstraction quantity is small (-8.4%), it persists for a long % of the time. Hence the impact is significant.

Figure 3-4 shows that an abstraction may return to a downstream waterbody much further down the system, as for the hydropower example. The abstraction of -0.990 m³/s from segment 3 does not return to the system until segment 6. In this simple example it is assumed that there are no flow losses through the hydropower system, so a full +0.990 m³/s is returned at segment 6. In river management terminology this interval gap is referred to as a '**depleted reach**'.

In the hydropower example, the calculation proceeds as follows:

1. Upstream inflow (3.076) + natural flow increase (+0.128) – left-bank abstraction (-0.990) = 2.214 m³/s
2. The reference outflow from segment 3 was originally 3.474 m³/s
3. Therefore the abstraction results in a river flow reduction of (2.214 / 3.474) -1 = - 36%
4. The time-duration of this hydropower abstraction is 66% of the time-period.
5. Therefore, by reference to EN 15843:2010 (Table 2-1), the impact is quantified as category 4.

It should be obvious that the impact of the hydropower abstraction is worse than it would otherwise be because flow has already been abstracted upstream from the river by the public water supply in segment 1, and this impact persists for the full length of the system. This is why it is critical that a hydromorphological impact assessment <u>must</u> consider all the artificial influences operating on any river system under investigation.

Finally, it is important to carry out a water balance check on the entire calculation set. Figure 3-4 shows two summary cells at the bottom of the pro-forma, ΣRB (+/-) and ΣLB (+/-). These are the summed net quantities abstracted or returned on the right and left banks respectively. A negative sum indicates that water has been permanently lost from the river (i.e. consumption); a positive sum indicates that additional water has been imported to the system from an external source. A zero balance indicates either that there were no abstractions or returns, OR they cancel out, as in the case of the hydropower operation.

In the example of Figure 3-4, the only change in the overall water balance is therefore the -0.270 m³/s reduction on the right-bank operations due to the village water supply. And in this case Formula [2] from 2.4.1 can be used at the downstream limit of the system to check that the system correctly balances:

Observed Flow = Natural Flow - (Abstractions + Exports) + (Returns + Imports) [2]

i.e. **3.588** = 3.858 – (0.270 + 0.990) + (0.990) = **3.588** ☑

3.3 Computerised Procedure

3.3.1 *Overview*

It will be evident that although the environmental flow requirement procedure is simple in application, the segment computations are time-consuming and laborious. A single change of input flow scenario, for example from Q50 to Q90, requires all the segment calculations to be repeated.

This project has developed a sophisticated and powerful computerised version of the procedure, which is nevertheless very easy to use with some basic training. The software is EXCEL based and is referred to as **QUASIMO+EF** (**QU**antitative **SIM**ulation of **E**nvironmental **F**low.

The computerised version uses the same calculation steps and the look-up Table of European Standard EN 15843:2010 (Table 2-1) but automates all the calculations. The computer model assumes 20 separate segments, so a total of 40 installations can be simulated. Flow Duration Curve data must be provided in separate data Tables as set out in the format of Table 3-1 and Table 3-2.

3.3.2 *Commentary on Key Features*

A screen-shot of a typical setup for a river analysis is shown in Figure 3-5. Users will require basic training in the use of the model, but there is sufficient data and explanation of the methodology in this Report for users to follow for themselves how the output has been derived for any individual segment. Users are encouraged to replicate some of the calculations to ensure that they are confident of the methodology.

Some of the key features and advantages of the computerised version will be highlighted below.

River Schematisation - The central columns (N+O) represent the river from upstream to downstream. Various key parameters are shown at the head of the model (project title, flow scenario, study length etc.). The computed flow values in the central column always represent the 'recent actual flow' of the river, comprising *a)* the natural flow in the river, incremented by segment *b)* changes to the natural flow depending on the accumulated abstractions, exports, returns and imports in all upstream segments.

The river model is automatically divided to 20 segments. There can be one operation on each bank in each segment (abstraction or return flow). The natural flow progression (controlled by the FDC) is automatically divided across the 20 segments.

In each case the flow value shown is the computed recent actual flow leaving the segment after all natural increases and artificial influences have been calculated. For reference, the original natural flow inflow and outflow values are shown in cells N7 and N50 respectively. As in the manual method, the net result of all abstractions and returns is shown at the bottom of the analysis for each bank separately.

It should be noted that the waterbody delineations in this example are generally aligned with changes in significant pressure. For example, the change from Waterbody 1 to Waterbody 2 occurs at S6 where an abstraction takes place for the Hydropower 1 intake. The change from Waterbody 5 to Waterbody 6 takes place at S15 where there is a significant wastewater discharge. This discharge, although not large in flow terms, will nevertheless significantly change the physico-chemical quality of the river i.e. a different type of pressure thereby requiring a different type of measure.

Flow Scenarios – In cells C5 and C7, any flow scenario can be selected with 2 mouse-clicks, providing those data are in the Flow Duration Curve (FDC) data Tables. In this example it is the median average flow (Q50) for the month of July that is being analysed. Without any artificial influences, the baseline natural flows are shown automatically at each segment. In this case the study length is 4.00 km (Y5), the natural upstream inflow is 3.085 m^3/s (N7) and the outflow is 3.856 m^3/s (N50). Hence the distance step for each segment is 200m (Q7), and the natural flow increment is 0.039 m^3/s (K7).

Operational Data – As for the manual method, two items of data are required to set up an operational pressure:
a) the average expected abstraction OR return flow during the time-period under investigation *b)* the expected duration of time that the abstraction/return will operate for the time-period. Flow is entered in units of m^3/s, Time as a percentage of the time-duration unit (days, months, season, year).

Because **QUASIMO+EF** is primarily a decision tool, evaluating many possible permutations of the impacts of numerous individual operations in combination, a powerful feature of the model is that the operational flow value does not activate until the Time % is also entered.

Typically, most water infrastructure abstracts or returns near-constant values, due to fixed hydraulic constraints. Whereas the time-duration for which the operation is active may be very variable and is one of the key variables that can be changed to see what impacts result from a different operational schedule.

Therefore the model makes it very easy to set up a 'hydraulic scenario' i.e. with fixed operational flow values throughout the model that do not become effective until the flow value is switched 'on' or 'off' by the time-duration cell. This means that the operational flows usually need only be entered once.

In the example of Figure 3-5, the existing public water supply abstracted at S2 (-0.270 m^3/s, left-bank) is operational for 80% of the time (July) and exerts a -9% change in flow (pressure) at S2. (Note that this pressure persists down through all segments to the downstream end of the river)! Conversely, the proposed water supply abstraction at S4 (-0.200 m^3/s, right-bank) is not currently active and does not therefore exert any pressure until it is 'switched on' by the time- duration value.

Most flow operations shown in Figure 3-5 mirror the procedures of the manual example and are self-explanatory.

Assessing River Performance and Impact - One of the most useful and powerful features of **QUASIMO$^+$EF** is the "power column" (AB). This shows a range of segment related independent or accumulated values depending on the variable selected in the **UNITS** cell (Y7). There are six variables that can be examined, each profiling the segment (and by implication the related waterbody) in a different way:

"km" – this will show the incremental distance from the start of the schematisation. This allows the user to align the schematisation with real-world data regarding the positioning of *a)* waterbody delineations *b)* operational installations for example.

"SEGMENT" – this simply replicates the nominal identifier that is the default identification shown in column (A). S1, S2 to S20.

"QREF" – this shows the natural (reference) flow as a baseline scenario i.e. without artificial influences. Once artificial influences are added, column (N+O) (recent actual flow) can be compared with column (AB) (reference flow) to visualise the degree of flow change.

"PPRS" – this is the point pressure (i.e. segment specific net abstraction and/or return flow) exerted by both operations on left and right banks, expressed as a percentage of the natural (unmodified) flow e.g. a value of -22% means that the operation(s) at this segment are abstracting 22% of the natural flow (assuming that flow is available). This value can therefore be used to identify the operations throughout the system that are exerting the largest individual pressure(s).

"QPRS" – this is the accumulated flow pressure at each segment, considering all upstream abstractions and/or returns. It therefore shows at each segment increment how much water has been taken (or added) down to that point. For example, a value of -39% means that 39% of the original reference flow at that point has been removed. It can be seen in Figure 3-5 that accumulated pressure varies depending on the net value of upstream operations. In the example, the worst point of pressure is at S12 (-57%) due to the exported flow on the left-bank. The negative pressure reduces at S14 (-36%) due to the flow returned by Hydropower 2.

"ΣTM%" – It is essential to understand that at each segment, the impact value is based on the accumulated flow change due to all upstream influences (QPRS). Accumulated flow is straightforward, being the net sum of the natural flow increments +/- operational flow changes. However the time factor is infinitely more complex, depending on the model scenario. EN 15843:2010 (Table 2-1) assumes a fixed single change of flow and a fixed single time- duration. But in **QUASIMO$^+$EF** multiple accumulative changes are being assessed, and each installation may operate for different time-durations within a single scenario, resulting in thousands of different dynamic outcomes depending on which representative time-duration is used.

There is no single 'correct' time-duration solution for an accumulated assessment. However, because EN 15843:2010 (Table 2-1) requires a single time-duration to approximate the hydromorphological impact, **QUASIMO$^+$EF** calculates the "flow-weighted average time" value of all upstream operations:

Average Impact Time (ΣTM%) = $\Sigma(Q_{S1} \times T_{S1} + Q_{SN} \times T_{SN}) / \Sigma Q_{S1-SN}$)

(where Q_{S1-N} and T_{S1-N} are the sector specific flow and time pressures respectively at S1, S2, S3 etc. to the downstream limit of the assessment at Q_{SN}.

i.e. higher abstraction or return flow values have more influence on the time-duration average than lower ones. The resultant single value therefore is the most representative time-duration element of the scenario considering all the upstream conditions.

"IMPACT" – one of the primary uses of the EF methodology is to ascertain the risk that a particular waterbody will not achieve good ecological status because of excessive change in flow-regime. This risk is quantified through the application of the hydromorphological impact look-up Table of EN 15843:2010 (Table 2-1), using the combined values of "QPRS" and "ΣTM%" for every segment in the schematisation. Note that a single change to any variable in the scenario (design flow, design time-period, altered abstraction or return in any one of 40 possible operations) constitutes a new 'scenario', and the impact at all downstream segments may change as a result.

Confirmation of Water Balance – As for the manual method, **QUASIMO^{+}EF** provides the net balance of operations of both left and right banks. A negative balance indicates that flow has been permanently abstracted from the river (consumption), a positive balance indicates imports of water.

Note that this balance assumes that only active operations are in function. Applying Formula 2 (2.4.1):

Observed Flow = Natural Flow - (Abstractions + Exports) + (Returns + Imports) [2]

For the example of Figure 3-5, at the final downstream outflow:

2.74 = 3.856 – (*Σ abstractions* = 2.320) + (*Σ returns* = 1.201) = **2.74** ☑.

Users should check for themselves the basis of this calculation to familiarise with the procedure. Note that the proposed water abstraction at Segment 4 is not included in the water balance because it is not specified as active i.e. time-duration = 0%.

Figure 3-5 – Screen-shot Example of Computerised Method

Waterbody Compliance Tool QUASIMO+ EF

Training Inflow | **INFLOW** | **OUTFLOW** | Training Outflow

JUL PERIC | *Example Output for Training - JULY Q50 Scenario* | STANCE **4.00** km

Q(50) FLOW | RUNOFF 0.039 ↓ 3.085 ↓ 0.200 Δ km | UNITS ΣPRS +/-(%

	Right-bank Object	% Time	m³/s		m³/s		m³/s	% Time	Left-bank Object	ΣPRS
S1	*Waterbody 1*			-	3.12	-				
S2	*Existing water supply*	80%	-0.270	<	2.89	-				-9%
S3				-	2.93	-				-8%
S4				-	2.97	>	-0.200		*Proposed water supply*	-8%
S5				-	3.01	-				-8%
S6	*Hydropower 1 intake*	75%	-0.300	<	2.75	-			*Waterbody 2*	-17%
S7				-	2.78	-				-17%
S8				-	2.07	>	-0.750	50%	*Hydropower 2 intake*	-39%
S9	*Hydropower 1 discharge*	75%	0.300	>	2.41	-			*Waterbody 3*	-30%
S10				-	2.45	-				-29%
S11				-	2.49	-				-29%
S12	*Export to upper Vardar*	50%	-1.000	<	1.53	-			*Waterbody 4*	-57%
S13				-	1.57	-				-56%
S14	*Waterbody 5*			-	2.33	<	0.725	50%	*Hydropower 2 discharge*	-36%
S15	*Urban wastewater*	80%	0.176	>	2.54	-			*Waterbody 6*	-31%
S16				-	2.58	-				-30%
S17				-	2.62	-				-30%
S18				-	2.66	-				-30%
S19				-	2.70	-				-29%
S20				-	2.74	-				-29%
TIME PERIOD	JUL	Σ_R	-1.094		3.856		-0.025	Σ_L	Q(50) FLOW	

EFERENC

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4. PRACTICAL IMPLICATIONS OF THE ENVIRONMENTAL FLOW METHODOLOGY

4.1 Overview

Previous sections have set out the legal and theoretical basis for the environmental flow methodology. However, the methodology is intended for 'real-world' situations, seeking to ensure that water infrastructure operations comply with the EU Directive 2000/60/EC such that 'good ecological status' is being achieved for all waterbodies supplying that infrastructure.

There are two real-world considerations in applying the method:

a) The theoretical flow data of the Flow Duration Curve(s) should be verified by direct river flow measurement
b) Operational flows set out in the Water Permits or historical 'custom and practice' infrastructure must be checked, inspected and enforced.

4.2 Validating the Flow Duration Curve Data

Various standard hydrological procedures will have been used to prepare the localised flow duration curves (FDCs). Usually the source data is derived from gauging stations sited on main rivers far from the minor tributaries that are typically used for hydropower operations. The transfer and scaling of regional flow data to local level is beset by many assumptions and approximations and is frequently notoriously inaccurate.

Correct input flow data is of course critical to the validity of the impact assessment. If the FDC flow values are say only +/- 25% accurate, evaluating flow regime changes of e.g. +/- 15% makes the environmental flow assessment somewhat pointless because the impacts lie within the margin of error of the reference flow data.

4.2.1 *Local Flow Calibration with Continuous Monitoring*

It is therefore essential that local flow monitoring is carried out on the target river(s) to cross-check the validity of the flow duration curve data. This work needs to be carried out by hydrometric specialists.

The most valid method of calibrating the theoretical FDC is to install continuous monitoring of the river at a temporary gauging location with appropriate sensors and data-loggers, for a period of at least 1 year, preferably 2. Continuous monitoring typically will typically check water level and/or flow at 15 – 30-minute intervals. The local data yields useful calibration statistics such as e.g. the mean annual flow, median monthly flows for each month, Q90 baseflow etc. If the FDC is valid, the theoretical values should be within say +/- 15% of the measured values.

Providing that the actual flow monitoring is considered representative of the average flows in any time-period, then the theoretical FDC data should be scaled accordingly to match the observed data. It is the observed data that is assumed to be the most valid!

4.2.2 *Local Flow Calibration Using the Q90 as the Base Value*

Recognising that continuous monitoring is technically complex, resource demanding and expensive, an alternative and hydrologically sound alternative is to make only sporadic manual measurements in the field when hydrometric experts consider that the river is in "full baseflow" condition. This flow rate will typically be approximated by the measured flow following a dry period of at least 18-20 days. At this point most surface runoff contribution from precipitation will have ceased, and river flow will be 90%+ dominated by groundwater discharge to the river.

This flow condition therefore equates to Q90 on the flow duration curve and can be considered an 'anchor' value for the remainder of the curve. Important research carried out by the Civil Engineering Institute, Skopje [13] demonstrated that most flow duration curves in North Macedonia rivers follow approximately a standard mathematical 'growth curve' with reproducible coefficients. Quoting the source [12] (Figure 4-1):

[13] "The methodology and procedure for the identification, maintenance and enforcement of Minimum Acceptable Flows (Surface Waterbodies) or Groundwater Levels (Groundwater Bodies) in the territory of Republic of North Macedonia", Civil Engineering Institute of North Macedonia, Skopje, 2018.

Figure 4-1 – Calibration of FDC Data Based on Observed Q90 Values

Calibration of the Method

12. a) It can be shown mathematically that for any river in Macedonia, provided the anchor value is set equivalent to the Q_{90} of the river, the exponential growth function gives a good general approximation of the long-term flow for any selected flow index $Q_{(QX)}$ (m^3/s) in the flow regime range Q_{10} to Q_{90} :

$$\mathbf{Q_{(QX)} = Q_{90}} * e^{[k * t]}$$

where Q_{90} is the flow of the target river at the assessment point exceeded 90% of the time (the baseflow), derived from a naturalised flow duration curve; where e is the base constant of natural logarithms (2.71828); where k is the exponential curve shape or growth factor; where t is the number of 5% intervals on the X-axis distant from the anchor value Q_{90} (i.e. at Q_{85}, $t = 1$, Q_{50}, $t = 8$ etc.).

It has been established through calibration tests of long-term gauged data provided by the National Hydrometeorological Service (NHMS) that setting the curve 'shape factor' $k = 0.125$ gives a close approximation of the natural flow growth curve for most rivers in Macedonia (± 15%). If Q_{90} is the naturalised Q_{90}, the growth curve will represent natural flow values.

The typical prediction error of this method was 15% at the Q50 index flow, and 19% at the Q25 index flow. This error margin is probably at least equivalent to similar values that would be estimated from long-term continuous monitoring, but at a fraction of the cost and complexity. Error margins of 10% - 15% are considered acceptable for environmental flow approximations.

4.3 Direct Monitoring of Hydropower Installations

4.3.1 *Overview*

Preparation and use of flow duration curve data and the EF methodology of this Report provides the theoretical basis for the setting and regulation of permissible operations through the mechanism of the Water Permit, issued by the regulatory authority, in this case the Ministry of Physical and Environmental Planning (MEPP).

A correctly implemented Environmental Impact Assessment (EIA) and the associated Water Permit conditions should have identified precisely the maximum permissible abstraction flow AND the time-duration of that abstraction (or return), based on the premise that hydropower (or any other abstraction) should not deteriorate the waterbody below 'good ecological status'.

Irrespective of the Water Permit conditions however, without appropriate and regular inspection and enforcement, many hydropower installations typically abstract well beyond permissible limits, either in terms of flow quantity or time- duration or both.

Quantity and time-duration aside, there are also potential absolute minimum flows below which hydropower installations should not be allowed to operate at all. This minimum value will be a function of the ecological sensitivity of the river system, and typically would require intensive biological surveys to identify the minimum threshold.

Extensive research and international best practice suggest, as explained in 2.3.2, that the baseflow condition (Q90) has an extremely important eco-hydrological influence on in-channel species diversity and sustainability.

Consequently, it is pragmatic to assume, (and monitoring should check and enforce) that residual flow in the river system as a general rule should not be allowed to reduce below the Q90 natural flow value for any extended period. EN 15843:2010 (Table 2-1) gives useful guidance on this issue.

For example, if the river system is subjected to abstraction such that it is the Q90 flow value that remains in the river, this can be read from Table 2-1 as a > 50% decrease in flow. To maintain good ecological status (impact level 2), this artificially induced flow condition can only be allowed to persist for less than 20% of the time.

4.3.2 *Monitoring Installation Options*

To enforce Water Permit conditions generally, hydropower Operators should be legally obliged to self-monitor and report to the Regulator on their flow abstraction performance. This is already a requirement of the Water Law of North Macedonia.

Ref xxx? <text needed>

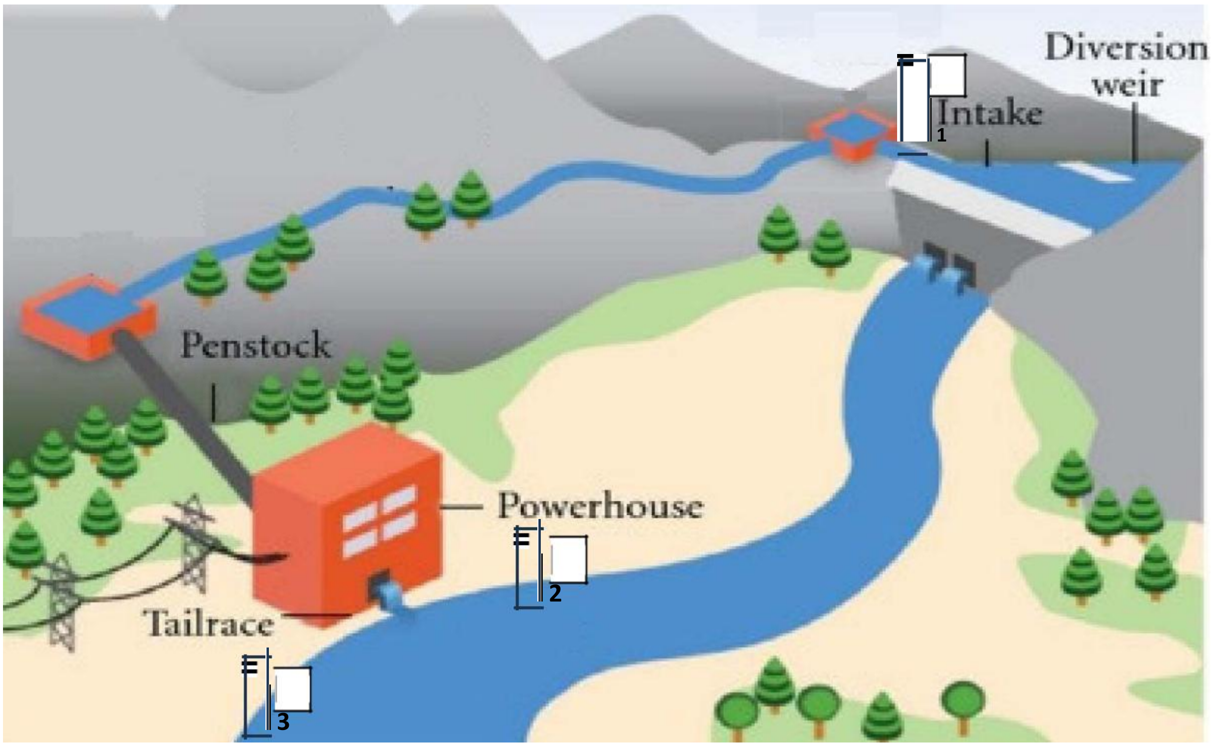
Additionally, flow regime checks should also be carried out by the regulatory or enforcement authorities themselves to *a)* enforce Water Permit conditions of the Operator(s) *b)* monitor residual flow conditions in the river to ensure that the waterbody remains in good ecological status.

Monitoring is resource demanding and costly. It follows that both Operators and regulatory authorities should plan their monitoring activities such that maximum information is obtained at minimum possible cost. The key questions that must be addressed via monitoring are:

1. Is the Operator complying with its Water Permit conditions – specifically, for the time-period in question (month and/or season), is the abstraction quantity AND its time-duration within the permissible limits?
2. Secondly, concerning the river channel directly, is the residual flow in the river at acceptable levels such that where possible *a)* the Q90 baseflow value is being maintained for at least 80% of the time *b)* the Q50 flow value (or greater) is being maintained for at least 60% of the time. (Both constraints (which are needed to achieve good ecological status) can be determined from Table 2-1).

Figure 4-2 illustrates a classical arrangement of a hydropower abstraction system. Also shown are the ideal locations for either continuous automatic monitoring and/or manual monitoring, indicated by a **staff gauge** that shows the depth of the water at the monitoring location relative to the stream bed. Permanent staff gauges are essential in at least locations 2 and 3 so that a **rating curve** can be prepared and the graphical relation between river stage (level) and flow can be quantified.

Figure 4-2 – Idealised Monitoring Arrangements



Considering each monitoring location in turn:

Staff Gauge 1 – (at the hydropower intake position) – strictly speaking this location is not required to monitor the environmental flow regime. However virtually all modern hydropower installations provide this measurement of water level and flow (with SCADA automatic continuous monitoring) because it is required to control the operations of the turbine(s). Therefore all hydropower Operators know their quantity of flow abstraction on a continuous basis.

Importantly, the time-duration of the abstraction flow is also recorded with SCADA systems, and therefore the two necessary data items for **QUASIMO+EF** (flow quantity and time-duration) should be easily available. There is no reason why these data should not be reported to the regulatory authorities as part of routine monitoring.

Staff Gauge 2 – (in the river immediately upstream of the hydropower tailrace) – this location is directly relevant to the monitoring of the residual flow left in the river in the depleted reach downstream of the hydropower intake. It should be as near to the powerhouse as possible for reasons of security and access, and 'flow relevance'.

It is essential to note that Gauge [2] is reporting 'recent actual flow' at that location i.e. it is the net sum of the original (reference) flow – abstractions + returns of all upstream segments. This obviously includes the impact of the one hydropower location but may also include numerous other upstream abstractions and returns.

Staff Gauge 3 - (in the river immediately downstream of the tailrace) - this is the point at which the abstracted flow returns to the river. The flow at [3] represents the restored river flow without the influence of the hydropower installation if there are no transmission losses from the intake at 1. Transmission losses may be significant however, so it is important to have measurements of flows at both 1 and 3.

The ratio of (flow [2]) / (flow [3]) is the most important measurement, as it represents the relative impact of the hydropower installation on the river flow. It should be noted that the impact of the abstraction will be proportionately higher at Gauge [1] than at Gauge [2] because natural flow will be increasing between these two points. **QUASIMO+EF** should be used to determine the impact level of these abstractions and returns at every segment.

5. POLICY IMPLICATIONS OF THE ENVIRONMENTAL FLOW METHODOLOGY

5.1 Overview

Previous sections of this Report have set out the legal, technical and operational implications of implementing a more sophisticated environmental flow procedure that complies with *a)* The EU Water Framework Directive 2000/60/EC *b)* international best practice.

There are significant policy and economic implications arising from applying an improved best practice environmental flow requirement procedure (EFRP). The economic implications of the method set out in this Report are expected to be assessed in follow-on studies under the PONT project. This final section highlights only some principal regulatory and enforcement issues that should be addressed as part of administrative policies.

There are two principal policy areas:

1. Compliance with national and EU legislation concerning the protection of the environment, especially the EU Water Framework Directive (2000/60/EC) where the aquatic environment is the focus
2. Ensuring the long-term sustainability and availability of national water resources for all stakeholders in the face of increasing water scarcity due to *a)* excessive demand in relation to supply *b)* decreasing availability and increasing unpredictability of resources due to climate change.

5.2 Policy Implication 1 – EU Water Framework Directive (Article 4)

5.2.1 *Waterbodies in Good Ecological Status (GES)*

As already summarised in Section 2.2, the EU Water Framework Directive (WFD) is a central pillar of European environmental management. North Macedonia Water law largely transposes the Directive into national legislation.

Article 4 of the WFD sets out the fundamental requirement that environmental objectives must be set out by the competent Authority (in North Macedonia - the Ministry of Environment and Physical Planning) to ensure that all waterbodies are in good overall status.

Methodologies and decision tools are required especially to identify and quantify the ecological status of waterbodies. Where waterbodies are not in good status, the causes of this failure should be identified and rectified through the 'Programme of Measures' of the relevant River Basin Management Plan (RBMP).

Hydromorphological pressures in the form of excessive abstraction by public water supply and hydropower installations are considered a significant cause of non-compliance of 'good status' of many rivers.

The EF procedure set out in this Report provides a clear, objective statement of the sustainable limits of abstraction and return flows to maintain waterbodies in the required status. The procedure can and should be used: *a)* to identify where existing installations are placing excessive flow pressure on the aquatic environment and therefore require corrective action *b)* as a risk-assessment tool for proposed installations to ensure that operating limits are correctly defined as part of Water Permit conditions.

5.2.2 *Derogation for Waterbodies Not Achieving Good Ecological Status*

The foregoing procedure of this Report makes clear that with respect to hydrological pressures (a key element of ecological status) sustainable abstraction has narrow limits. For example, inspection of Table 2-1 shows clearly that for a waterbody to remain in GES, the total of all abstractions in a specific waterbody should not exceed 15% of the normal average flow for at least 60% of the time. Alternatively, a 50% decrease in flow should not be allowed to persist for more than 20% of the time.

These are challenging targets, and in heavily exploited rivers may prove to be difficult to achieve such that, realistically, the waterbody may at best achieve only 'moderate ecological status' (category 3) for example. The challenging target of GES still does not exempt the River Basin District Authority (MEPP) from its obligations under WFD Article 4.

Under WFD Article 4 (5) it is permissible to allow a waterbody to achieve a status of 'less than good' only under these criteria:

a) *the environmental and socio-economic needs served by such human activity cannot be achieved by other means, which are a significantly better environmental option not entailing disproportionate costs* - Article 4 (5) (a)

b) *no further deterioration occurs in the status of the affected body of water* - Article 4 (5) (c)

c) *the establishment of less stringent environmental objectives, and the reasons for it, are specifically mentioned in the river basin management plan required under Article 13* - Article 4 (5) (d)

In plain language, this means that where a waterbody will not achieve GES (demonstrably shown by a quantitative procedure such as **QUASIMO^{+}EF** for example), the regulatory authority must assess and show that the benefits of the installation (i.e. water supply, hydropower energy, irrigation etc.) could not otherwise be provided either in an alternative location (or more efficiently at the current location) which would be ecologically less damaging.

5.3 Policy Implication 2 – Water Resources Management

5.3.1 *Significant Documents under EU Policy*

The EF procedure of this Report explicitly shows how affected water balances impact on the ecological status of the waterbodies assessed. The general sustainability of water resources, defined in terms of *a)* preservation of ecosystems *b)* equitable allocation of water between stakeholders *c)* efficiency and productivity of water as a commodity is of high- level policy concern in Europe.

Various recent EU policy documents emphasise increasing concerns about water quantity management generally.

Water resources across Europe — confronting water scarcity and drought (2009) [14]

The balance between water abstraction and availability has now reached a critical level in many areas of Europe. Of critical importance is the timing of abstraction. Peak abstraction for both agriculture and tourism (mainly via the public water supply) typically occurs in the summer months when water availability is generally at a minimum. As a result, the potential for detrimental impacts upon freshwater ecology is maximised.

A Water Blueprint for Europe (2013) [15]

Europe's water is under significant pressure, especially from economic activities, presenting serious challenges to water security, now and in the future. As such, Europe urgently needs to improve its resilience and ensure sustainable freshwater supplies for people and the environment.

If not sustainably managed, water use may exceed the carrying capacity of the environment, thereby damaging or destroying aquatic ecosystems, while having negative impacts on human health. It is essential therefore that all sectors that use water resources, such as industry, agriculture, tourism, urban development and energy production, are sustainably managed.

Europe's state of water 2024 - The need for improved water resilience (2024) [16]

Urgent action is required to improve Europe's water resilience. Climate change is disrupting weather patterns and further increasing pressures on our water resources and ecosystems. Europe's water management practices are poorly adapted to cope with such rapid and large-scale change, which will compromise water security.

This report presents the state of Europe's water. It outlines three overarching challenges facing future European water management:

1. Protecting and restoring aquatic ecosystems
2. Achieving the zero-pollution ambition
3. Adapting to water scarcity, drought and flood risks.

[14] "Water resources across Europe — confronting water scarcity and drought" - European Environment Agency EEA Report 02/2009, 2024.

[15] "A Water Blueprint for Europe" European Commission: Directorate-General for Environment, 2013, https://data.europa.eu/doi/10.2779/12145

[16] "Europe's state of water 2024 - The need for improved water resilience" – European Environment Agency EEA Report 07/2024, 2024.

All the above policy documents highlight the high degree of relevance and inter-connection between water resource quantities and aquatic ecosystems.

5.3.2 *Water Efficiency and the Water Exploitation Index (WEI^+)*

Water resource is a valuable and finite commodity with significant value. It therefore beholds users of the resource to operate their installations in the most efficient way(s) possible. Reducing water use and improving water efficiency are key to tackling water stress. Reducing leakage, using water-efficient devices and processes and increasing water reuse are all measures that improve water use efficiency.

One of the key European indicators used to quantify water use efficiency is the "Water Exploitation Index". The index (WEI^+) quantifies water consumption as a percentage of the renewable freshwater resource. Although it is normally used at national and river basin scales, it is applicable at any scale, including for example a discrete river system.

It is defined as:

$$WEI^+ (\%) = \frac{(\text{Abstractions} + \text{Exports}) - (\text{Returns} + \text{Imports})}{\text{Annual Renewable Resource}}$$

At river-scale, the annual renewable resource is simply the naturalised mean annual flow of the river system at point X.

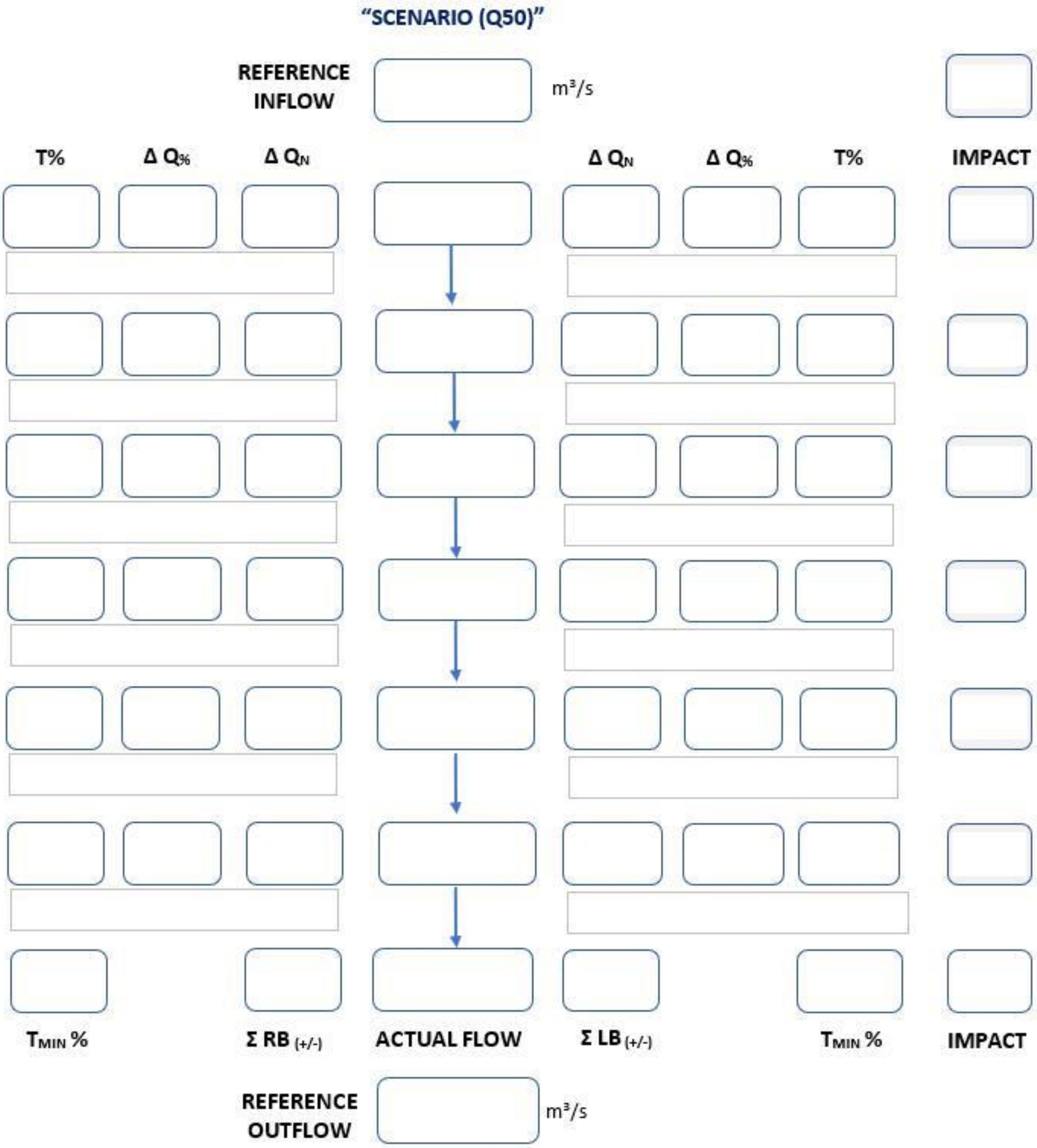
The water units may either be in flow rate (m^3/s) or volumetric terms (Mm^3) for a representative year.

It is evident that WEI^+ is a measure of "consumption" i.e. where water is abstracted from a source and not returned. WEI^+ values above 20% indicate that water resources are under stress and therefore water scarcity conditions may prevail; values above 40% indicate that stress is severe and freshwater use is unsustainable.

As explained throughout this Report, increasing levels of water exploitation i.e. consumption result in increasing (and detrimental) flow pressures on the aquatic ecosystem and hence reduced ecological status. It will be evident that the water balance concepts explained in this Report align exactly with the definition of the index, and as such the WEI^+ is a simple arithmetic calculation based on the data being used in the environmental flow procedure.

The environmental flow requirement procedure of this Report explicitly considers the quantitative aspects of the economic uses of water by quantifying the hydrological impacts of water use on the natural flow regime. It is therefore an important step forward in contributing to improved operational practices and legislative compliance generally.

6. ANNEX 1 – ENVIRONMENTAL FLOW PRO-FORMA – MANUAL METHOD



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