Chapter 4

Overview Instream Flow methods

Instream flows are those which are retained in their natural setting, as opposed to those waters which are diverted for off-stream users such as industry, agriculture etc. [25]. Instream waters can support economically important uses such as transportation, production of hydroelectricity and waste disposal. Instream flows are valuable for maintaining fish and wildlife habitat. This concern has led to the provision of instream flows specifically for environmental purposes, also sometimes called environmental flows. These are designed to enhance or maintain the habitat for riparian or aquatic life. They may be provided for preserving native species of flora and fauna and to protect features of scientific and or cultural interest. For indigenous species, the best model is one which mimics nature, since the biota have evolved in accordance with the historical patterns of high, low and zero flows. The minimum flow is normally specified as an instantaneous flow rather than a daily average, meaning that the flow should never drop below the minimum at any time [23]. Instream flow recommendations may also include artificial floods or flushing flow, which are e.g. designed to remove fine material from the stream-bed. In establishing instream flow requirements the difficulty lies in deciding how much modification of the natural flow regime is acceptable and a great deal of scientific uncertainty persists. One of the main difficulties in determining an instream flow requirement is lack of quantitative data. This becomes especially critical, when the preservation of aquatic habitat conflicts with other water uses. To assist in the development of instream flow recommendations, a number of numerical techniques have been developed over the past few decades. Most of the efforts have been centered around the preservation of trout or salmon habitat in cold-water streams. Over time, increasingly sophisticated techniques have been derived which consider the changes in stream hydraulics at varying flow levels and the habitat requirements of species at different life stages and seasons. According to [25], techniques may be broken down into the three categories

- Historical discharge
- Threshold
- Instream habitat simulation

The following chapter wants to give an introduction to several methods existent. It is attempted to describe the motivation for development comprising the area of interest, explain the methodology and functional dependencies.

4.1 Determining Instream Flow: Historic methods

Historical discharge techniques utilize stream-flow records only, setting instream flow recommendations into proportions. In the simplest form a single static minimum flow is computed, as for example the 7-day, 1-in-10-year flow, which represents the weekly maximum flow during a time-range of 10 years. More sophisticated methods vary the proportions of flow retained at different times of the year, thus generating a more dynamic minimum flow. Thus for example higher proportions may be allocated during fish migration periods.

4.1.1 Tennant Method

The Tennant method [10] was developed for 11 streams in Montana, Wyoming and Nebraska / USA in order to find satisfactory discharge levels for fish-passing, since fish were crowded into smaller pool-riffle structures. A flow of 30% of the annual average flow was found to maintain satisfactory width, depths and velocities, based on site observation. The method comprises different percentages for winter and summer months (see further details in table 4.1). This method requires stream morphology to be similar to those stream targeted. Requirement criteria are not given by Tennant, hence making it difficult to transfer this technique to other streams. Also it does not account for daily, seasonal or yearly flow variations. [9] argue though that simple methods requiring little or no field work are indispensable for river wide planning purposes.

	Recommended base flow regimes	
Description of flows	October-March	April-September
Flushing or maximum	200%	
Optimum range	60-100%	
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair or degrading	10%	30%
Poor or minimum	10%	10%
Severe degradation	0-10%	

Table 4.1: *Instream flow recommendations by Tennant method. All flows are defined as a percentage fraction of the average flow*

4.2 Determining Instream Flow: Current models

4.2.1 Range of Variability Approach (RVA)

[11] developed a new assessment approach based only on hydrologic data. The idea was to utilize long-term hydrologic observations and to exploit the variability of discharges in order to find meaningful results, thus Range of Variability Approach (RVA). Hence the applicant ought to dispose over gauging records originating for pre- as well

as post-dam construction. 33 ecologically relevant parameters are employed in his examples to indicate natural discharge variability, e.g. monthly discharge, magnitude, duration and point in time of high and low waters throughout the year. Also parameters describing the frequency and duration of discharge fluctuations are used. For each RVA parameter a reference spectrum is defined, which is based on respective percentile or standard deviation, e.g. 25^{th} and $75i^{th}$ percentile, separating into upper, middle and lower bands. In order to determine a state of hydrologically influenced waters, RVA parameter fluctuations are defined on a percent basis as follows:

$$HydrologicAlteration = \frac{(Frequency_{Observed} - Frequency_{Expected})}{Frequency_{Expected}} * 100$$

Observed is defined here as the period where the RVA parameter is supposed to fall into the reference range (i.e. post-dam period), whereas reference is defined as the period where the discharge is assumed to represent the reference spectrum (i.e. pre-dam period). If RVA parameters fall into the reference spectrum the hydrologic alteration is zero. If more parameters fall into the reference spectrum the alteration value is positive, whereas less parameters matching the reference spectrum cause negative alteration values. [12] differentiate in their work on the Colorado river between three categories of hydrologic alteration.

- 0-33% = none to very small hydrologic alteration
- 34-67% = moderate alteration
- 68-100% = strong alteration

Calculated values may subsequently be illustrated using GIS systems for various river reaches in order to utilize the RVA technique for basin management purposes.

4.2.2 Instream Flow Incremental Methodology (IFIM)

The IFIM methodology has been developed by the US Fish and Wildlife Service Cooperative Instream Flow Service Group (Aquatic System Branch of the National Ecology Research Center) and can be thought of a flexible set of guidelines to solve problem involving disturbance of riverine ecosystems. It is made up of a collection of analytical procedures and computer models and allows the development of different approaches adapting to the ecosystem in focus. The IFIM has been described using the sequence of seven steps as follows:

1. Description of status quo of the ecosystem using key variables (e.g. water quality, channel form or flow regime).
2. Development of functions or mathematical expressions describing the habitat preferences of evaluation species including humans.
3. Development of functions or mathematical expressions integrating the macro- and micro-habitat availability of the present system.

4. Incrementally change one or more variables to reflect a particular management option, determining habitat availability for fictive system employing relationships developed in 2 and 3.

5. Determination of potential alternatives of remedial actions to correct adverse impacts found in 4.

6. Repetition of 3 and 4 in order to evaluate impacts of a range of management alternatives.

7. Evaluation of alternatives under the strategic management objectives and preparation of recommendations for the project.

Curves are developed by combining population-habitat data with the availability of habitat type and subsequently normalized to obtain suitability index from 0 to 1. Ideally, criteria should be developed at different times of the year.

4.2.3 PHysical HABitat SIMulation System (PHABSIM)

PHABSIM forms a major component of IFIM following the assumption that aquatic species will react to changes in the hydraulic environment. Programs are available for modeling changes in water surface and velocity patterns with discharge and combining these with habitat-suitability curves to produce habitat-discharge relationships. Results obtained display the change in a composite factor, the weighted usable area (WUA) in relation to discharge. WUA is an indicator of the net suitability of use of a given reach by a certain life stage of a certain species. WUAs are determined as functions of depth, velocity, cover and substrate for specific discharges, so that the physical habitat is redefined at each discharge to obtain a functional relationship. These factors are weighted and the WUA for each cell is calculated by multiplying the cell area by its weighted preference factor. There are three alternative weighting methods [31] available.

- Multiplication: f(d)*f(v)*f(s)

- Geometric mean: $(f(d)*f(v)*f(s))^{0,333}$

- Minimum: Minimum of f(d), f(v) or f(s) respectively

Chosen is the most conservative index of suitability area. In addition to velocity, depth and substrate, temperature may be considered as an additional factor. The temperature factor is multiplied by the WUA for the whole reach. Simulation is carried out either by using average conditions in stream channel or by dividing the reach into rectangular cells of smaller areas to describe the distribution of physical habitats in more detail. The latter approach sums individual WUA cells for the reach in focus. Also weighted usable volumes (WUV) and weighted usable bed area or wetted perimeter (WUBA) are available as weighting methods. For most applications, calibration requires a set of water-surface elevations and velocities taken at several transects for at least one discharge. These may be calculated within PHABSIM using a backwater curve program and/or Manning's respectively stage-discharge relations.

4.2.4 Discussion

Having reviewed a few models in this chapter the input requirements for their functionality can be illustrated as seen in table 4.2. The data availability for the reach in focus allows for the application of the purely hydrologically-based models (Tennant and RVA). Other models require data input that is sparely available and only in coarse resolution and thus can only be calibrated and applied roughly. It has thus be kept in mind that the application of the Phabsim model as seen in the next chapter can only be an approximation.

A fairly recent alternative shall be mentioned with works by [24]. As part of a European research project they model potential impacts and scenarios for plans to reconstructing large parts of the river Rhine's former floodplains. For the Gamerensche Waad floodplain along the Dutch Nederrijn and the river Waal they couple a numerical 3D hydrodynamic FE model (Delft3D) in order to simulate the river's morphological changes with a fuzzy-logic based fish habitat model (CASIMIR). Advantages of this approach are on the one hand, that sediment transport is included from the hydraulic side and that the fuzzy-based approach of the habitat model takes into account that physical habitat parameters cannot be considered isolated from one another and allows for more flexibility in the generation of habitat suitability indexes. This is done via analyzing the degree of fullfilment (DOF) for each fuzzy rule generated. While hydraulic calculations are undertaken over a range of 30 years, life-stages are calculated using an input with time-steps of 5 years. Applying similar techniques might be of great interest especially for the Ebro Delta for potential morphological changes, which could serve as an input for an enlarged fish habitat model defined by the salt-wedge development. Once application is under way, this model could be extended to its adjacent eco-regions like e.g. the upstream reach between the salt-wedge and the Flix dam.

Also other models like the HARPHA (Austria), FISU (Finland), 5M7 (France), Rhyahabsim (New Zealand), HEP (Holland), River-2D (Canada) and others have not been considered in its application.

Model	Q	T	d	v	Fish	Macroinvertebrae
Tennant	X					
PHABSIM	X	Optional	X	X	Either	Or
RVA	X					

Table 4.2: *Overview of model input requirements or dependencies respectively. All data require discharge input (Q). The physical habitat model Phabsim furtheron requires depth (d) and velocity input (v). Habitat curves are being defined in relation to fish and/or macroinvertebrae habitat curves. Optionally a temperature input dependancy can be defined (T).*

4.2.5 Conclusion

Several models have been developed in order to determine instream flow requirements. Their fundamentals differ in complexity and aim. The most widely used model is without doubt the Phabsim. Data availability in the section in focus limits the credibility of the applicability and the output. All hydrologically-based models can be applied to the reach undoubtedly, whereas hydraulically and biologically-based models like the Phabsim have to be considered with care. This situation may though be improved considerably by extending the data basis available. Several specific measurement campaigns could improve the applicability of the de facto standard Phabsim model. Recently developed semi-empirical and empiric models will hence become accessible for consideration. This requires though a clear administrative statement.