# RESERVED FLOW – SHORT CRITICAL REVIEW OF THE METHODS OF CALCULATION

## 1 SCOPE OF THE DOCUMENT

This document has no scientific conceit.

It mainly aims to give a quick and wide overview about the different methods proposed for reserved flow calculation both form the regulatory and research point of view.

The overview itself gives the opportunity for pointing out merits and lacks of the main groups of methods, with the scope not to enter a infinite scientific discussion about the best method, but to stimulate a more general discussion on the role of reserved flow in river protection and on the global consequences of reserved flow on environment and on, more specifically, the chances of surviving to it of small hydroelectric plants.

## 2 FOREWORD

The reserved flow world is a polytheistic world.

Starting from the definition.

We need to clarify what we mean as reserved flow from the early beginning.

Unfortunately each national regulation has its own definition.

Nevertheless all definitions emphasize the protection of the natural life in the river.

"Minimum" or "reserved" flow must be distinguished by "guaranteed" flow, this last being referred to the release of water (from a specific point as a gate or a valve) in order to comply with specific obligations, regardless of the residual flow in the river downstream of the diversion works.

In spite of the lack of simple and unique definitions, the objectives of assuring a minimum flow downstream of hydroelectric installations or other water abstractions is fairly clear.

Anyway we must point out that the problem of a clear definition is important because the definition can greatly affect the value of the reserved flow itself.

We still introduce the auxiliary concept of "dotation" corresponding to the artificially regulated flow rate at a certain time and in a certain cross section to guarantee a required amount of water in a different cross section of the same river.

## 3 MAIN METHODS TO CALCULATE RESERVED FLOW

The formulas for calculation of reserved are dozens and their number tend to increase day by day.

This demonstrates that no one has a good universally valid solution for reserved flow determination.

In the following pages we give a list of some of the formulas subdivided by principle of calculation.

Anyway each formula can only supply a value to be used as a reference for regulatory purposes.

In the following paragraphs the region or country where the method comes from or is applied is put into brackets (-)

### 3.1 METHODS BASED ON HYDROLOGIC OR STATISTIC VALUES

Within these methods, a first group refers to the average flow rate (MQ) of the river at a given cross section.

#### *3.1.1 10% of Q (A)*

Reserved flow must be higher than 10% of the natural flow rate, so the reserved flow is variable in time. The application of this method requires a continuous measurement of the flow rate at the diversion section, not always easy to do.

#### *3.1.2 Lanser (A)*

This method suggest a value varying from 5 to 10 % of the mean flow MQ

#### *3.1.3 CEMAGREF (F)*

This method suggest a value varying from 2,5 to 10 % of the mean flow MQ

#### *3.1.4 Jäger (A)*

In the fishing interest this method suggest as minimum value 15 % of the mean annual flow MQ

#### *3.1.5 Montana (USA)*

This definition refers to the interest of fishing:

- High economic importance of fishery: 40-60% of MQ
- Low importance of fishery 10% of MQ

A second group of methods refers to the minimum mean flow (MNQ) in the river

#### *3.1.6 Steinbach (A)*

Reserved flow must must be at least equal to MNQ measured on a long term basis and eventually divided between winter and summer period. The principle is used by Oberösterreicher Administration as a first indicative value.

#### *3.1.7 Baden-Württemberg (D)*

Reserved flow must correspond to 33% of MNQ

#### *3.1.8 Rheinland-Pfalz (D)*

Minimum flow must be 20-50% of MNQ

#### *3.1.9 Method Hessen (D)*

Minimum flow must be 20-90% of MNQ

A third group of methods refers to the prefixed values on the Flow Duration Curve (FDC)

*3.1.10 Alarm limit value (CH)*

As minimum flow necessary to guarantee the "ecological functioning" of a water course at least 20% of $Q_{300}$ (flow rate exceeding 300 days of duration) must flow in the river.

*3.1.11 Matthey (CH)*

The minimum requirement for fish life should be determined on empirical basis. It is roughly corresponding to the more frequent flow rate in a long series of years, which usually well fits to $Q_{300}$. The evaluation is made according to the following formula:

$RF = 15 \cdot \frac{Q_{300}}{\ln(Q_{300})^2}$ (provided that $Q_{300}$>50 l/s)

*3.1.12 Linearised Matthey (CH)*

The method apply to flow rate between 0,3 and 3,00 $m^3$/s and gives results similar to par. 3.1.11, provided that $Q_{300}$>100 l/s:

$RF = 0{,}25 \cdot Q_{300} + 75$ (l/s).

*3.1.13 Büttinger (CH)*

For the life of Salmonides the minimum flow should be approximately not less than $Q_{347}$.

*3.1.14 Hindley (GB)*

Minimum flow must be approximately equal to $NMQ_7$ that is the lowest mean value of flow rate in the seven months with the higher natural discharges.

*3.1.15 Sawall and Simon (D, former DDR)*

Reserved flow must be 7-100% of $NMQ_{Aug}$ that is the minimum mean flow in August.

*3.1.16 Fitting to FDC (USA)*

Reserved flow must be the mean value between a dry and a rainy year of the discharge which flows for more than 84% of the year.

*3.1.17 Falling below values (A)*

Reserved flow is the value of flow which can't fall below in the normal hydrologic year for 4 days per year ($Q_{361/NHY}$).

*3.1.18 $NNQ_{361/NHY}$ (A)*

Reserved flow can't fall below the monthly maximum low flow of a normal hydrologic year.

*3.1.19 NNQ (A)*

Reserved flow must correspond at least at he NNQ that is to the minimum flow observed in the river.

*3.1.20 Kärtner Institut für Seenforschung (Karinthia Institute for Sea Research) (A)*

As threshold for fishery serviceability monthly mean flows are grouped and then reserved flow falls between 10 to 15% of the minimum value in the group.

## 3.2 METHODS BASED ON PHYSIOGRAPHIC PRINCIPLES

### *3.2.1 Catchment area (CH)*

Reserved flow necessary for conservation of water flora and fauna is described by:

$q = q_{355,NHY} \cdot E \cdot K$

Where E and K are catchment-specific coefficients.

### *3.2.2 Constant specific reserved flow (USA)*

The reserved flow refers to fishery serviceability and has two possible values:

- Excellent abundance of fish $q = 9{,}1$ l/s/km$^2$
- Normal abundance of fish $q = 2{,}6$ l/s/km$^2$

### *3.2.3 Constant specific reserved flow Tirol (A)*

The reserved flow depends on the geological conditions of the catchment area:

- Crystalline $q = 2{,}0$ l/s/km$^2$
- Limestone $q = 3{,}0$ l/s/km$^2$

## 3.3 ADVANTAGES OF METHODS SHORTLY DESCRIBED AT CHAP. 3.1 AND 3.2

- Easily applicable under the presupposition of good basic data
- Natural fluctuation could be eventually taken into account
- Supply of a rough evaluation of the economic energy production
- Methods based on MNQ or NNQ should be preferred
- No recognisable ecologic background

## 3.4 DISADVANTAGES OF METHODS SHORTLY DESCRIBED AT CHAP. 3.1 AND 3.2

- Academic formulas which supply rigid values
- NNQ could be easily underestimated
- No consideration for hydraulic parameters of flow
- Effect of tributaries or abstractions in the diversion section and the diversion length not taken into account
- Economic operation of small hydroelectric plants could be hardly affected
- Methods not suitable for many typology of rivers and doubtful transferability from river to river.

## 3.5 FORMULAS BASED ON VELOCITY AND DEPTH OF WATER

### *3.5.1 Steiermark, Kärnten (A)*

In the stretch of river between weir and tailrace the water velocity in case of reserved flow, or better in case of dotation flow, can't fall under a prefixed threshold value of 0,3-0,5 m/s. The minimum depth of water must be higher than a prefixed value of 10 cm.

### *3.5.2 Oregon (USA)*

In the depleted stretch of river the water velocity in case of reserved flow, or better in case of dotation flow, can't fall under a prefixed threshold value of 1,2-2,4 m/s. The minimum depth of water must be higher than a prefixed value of 12-24 cm.

### *3.5.3 Oberösterreich (A)*

In the depleted stretch of river the minimum water depth must be higher than a prefixed value of 20 cm.

#### *3.5.4 Tirol (A)*

In the depleted stretch of river the minimum water depth must be higher than a prefixed value of 15-20 cm.

#### *3.5.5 Miksch, (A) equivalent to Sawall/Simon (D, former DDR)*

After long studies carried out in Oberösterreich Miksch proposed a diagram with the reserved flow vs. river width where results a value appox. of 30-40 l/s per meter of width.

#### *3.5.6 Standard flow (USA)*

Reserved flow is defined as a function of the wetted perimeter of the natural undisturbed flow. In case of reserved flow the wetted perimeter must be at least 75% of the undisturbed flow.

### 3.6 ADVANTAGES OF METHODS SHORTLY DESCRIBED AT CHAP. 3.5

- Main flow characteristics are maintained
- The shape of profile can be included in the calcoluation
- Individual river approach
- No hydrological data needed
- Only indirect and general relations with ecological parameters
- Suitable to evaluate the consequences on energy production economics

### 3.7 DISADVANTAGES OF METHODS SHORTLY DESCRIBED AT CHAP. 3.5

- Slope and natural water pattern don't enter in the calculation
- Diversion length and effect of tributaries or abstractions stay unconsidered
- Without river re-structuring measures, in wide rivers these methods give very high values of reserved flow.
- Reasonable use only for particular kind of diversion section
- In mountain torrents give unrealistic values of threshold water depth
- Suitable only for particular typologies of rivers, transferability doubtful.

### 3.8 METHODS BASED ON MULTI-OBJECTIVE PLANNING TAKING INTO CONSIDERATION ECOLOGICAL PARAMETERS

#### *3.8.1 MODM [Multi Objective Decision Making] (A)*

The determination of reserved flow results from a model which considers both ecological and economic objectives. The alternative to be chosen must have the best compromise value of both kind of parameters:
The following measured variables are used as parameters.

- Opportunity for regular work (economy)
- Smallest maximum depth (diversity of species and individual size)
- Highest water temperature (change of thermal conditions)
- Smallest oxygen contents (water quality)

#### *3.8.2 Interest consideration (CH)*

If the interest of hydroelectric energy production is taken into account, reserved flow can't completely comply with all river protection interests.

All water demands going beyond the minimum must be decided on the basis of interest considerations.
All additional demands are to be defined clearly and duly justified.
Thus at the moment a provisional value equal to the highest alarm limit value (see par. 3.1.10) is adopted.

### *3.8.3 Dilution ratio(CH)*

The necessary discharge must be at least 10 times of the introduced, biologically cleaned discharge.
The velocity can't fall below 0,5 m/s.

### *3.8.4 Flow parameters (CH)*

The effects of reserved flow are measured with the help of a model.
From this necessary corrections and/or construction measures in the diversion area can be derived.

### *3.8.5 PHABSIM (USA, D)*

The method is based on the knowledge of the combination of the parameters water depth, flow velocity, temperature and sediment preferred by the most part of the fish species. Under this presuppositions, once known the range of preference and defined the desired spectrum of fish species, the reserved flow necessary can be calculated.

### *3.8.6 Habitat Prognose Modell (D) [DVWK, 1999]*

In order to limit the nevertheless expenditure-intensive investigations for the determination of the reserved flow conditions in difficult cases, was developed this model, with which on basis of fewer aggregated-morphologic parameters, the reserved discharge conditions relevant for the biocenosis can be prognosticated computationally.
A "minimum ecological discharge" and an "economic energy" threshold value are determined.
The final residual flow suggested considers both values, whereby the following facts are to be considered:

- It applies for a degradation prohibition with respect of the current condition (when a $Q_{dot}$ regulation is already present)
- The residual flow suggestion may not exceed the minimum ecological discharge.
- Reserved flow is the economic energy threshold value or 4% of the small hydroelectric plant flow rate
- Reserved flow must be 5/12 of MNQ as a maximum.

### *3.8.7 Habitat Quality Index (USA)*

Model based on multiple regression. It links the so called bearing capacity for Salmonides of a river stretch with a set of ecological parameters and requires collection of a great number of different environmental data necessary to calculate the biomass of Salmonides which can live in the river stretch.

### *3.8.8 Pool Quality Index (I)*

Model derived from the HQI method, it's based on the maximisation of the hydraulic diversity: the higher the number of pools in a torrent, the lower the reserved flow is. Depending on the percentage of pools, the method supplies the following values for reserved flow to be compared with values obtained by methods described in chap. 3.1 and 3.2:

- 7 – 9 % of MQ
- 50 – 70 % of $Q_{355}$

- 3,6-4,3 l/s/km$^2$

### *3.8.9 Definition of the dotation water delivery through dotation attempts*

The method is based on the determination of the reserved flow conditions in combination with the simulation of potentially future conditions in the diverted section of the river.

The method represents the connection with ecologically relevant parameters over available realizations concerning to preference ranges and/or preference curves. It is described as rather simple and economical method. It presupposes however the possibility of measuring small discharges in the future diversion section of the river. With existing plants this is simple - in all other cases low-water periods for the measurements must be used and extrapolations at a justifiable extent are inevitable.

## 3.9 ADVANTAGES OF METHODS SHORTLY DESCRIBED AT CHAP. 3.8

- Site specific flow observations
- Taking into account of hydrological, hydraulic, ecological, and meteorological quantities
- Consideration of both ecological and economical parameters

## 3.10 DISADVANTAGES OF METHODS SHORTLY DESCRIBED AT CHAP. 3.8

- Methods expensive in data collecting and mathematical computing
- Suitable only for particular typologies of rivers, transferability doubtful.

# 4 APPLICATION OF SOME DIFFERENT METHODS TO REAL CASES

## 4.1 WIDE LOW SLOPE RIVER

The main data of the river are:

- Catchment area 1.842 km$^2$
- Altitude of the gauging station 185 m.a.s.l.
- Mean altitude of the catchment area 1.429 m.a.s.l.
- Mean annual rainfall on the basin 1.429 mm
- Width in the depleted stretch 40 m
- Slope in the depleted stretch 0.5 %
- Length of the depleted stretch 700 m

Main hydraulic parameters are referred to steady normal flow:

| | Flow rate | Depth | Velocity | Wetted perimeter |
|---|---|---|---|---|
| | m$^3$/s | m | m/s | m |
| MQ | 56.48 | 0.73 | 1.95 | 41.45 |
| MNQ | 28.70 | 0.48 | 1.49 | 40.96 |
| Q355 | 29.59 | 0.49 | 1.51 | 40.98 |
| Q351 | 29.95 | 0.49 | 1.52 | 40.98 |
| Q347 | 30.30 | 0.50 | 1.53 | 40.99 |
| Q84% | 34.10 | 0.53 | 1.60 | 41.07 |
| Q300 | 34.76 | 0.54 | 1.61 | 41.08 |

**Table 1: wide low slope river – main hydrological and hydraulic parameters**

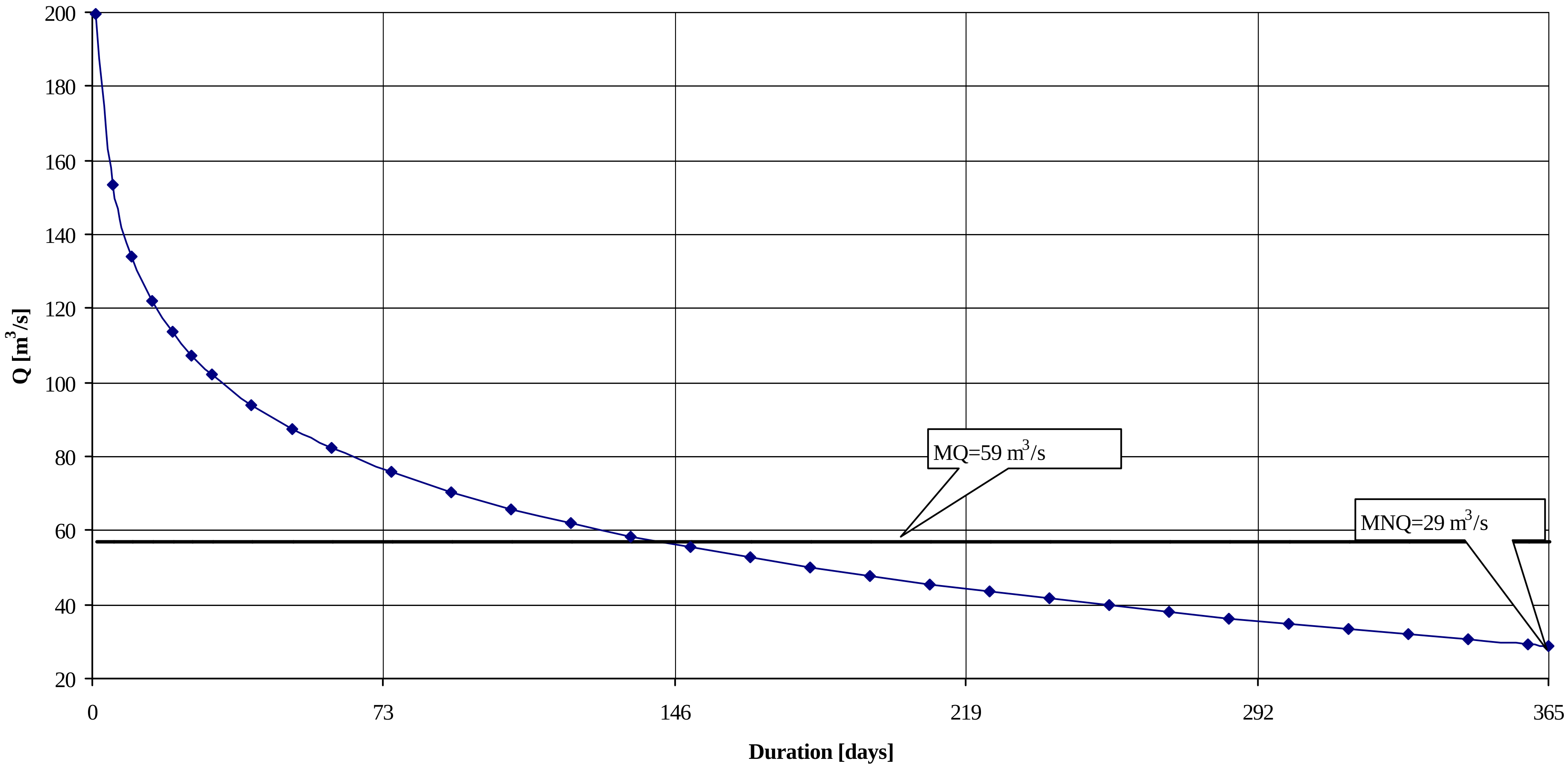



**Fig. 1: wide low slope river – flow duration curve**

Fig. 2 and Table 2 give the values of the reserved flow calculated with some of the different methods and a comparison among them:

| Method | Min | Max |
|---|---|---|
| | $m^3/s$ | $m^3/s$ |
| Lanser | 2.82 | 5.65 |
| Cemagref | 1.41 | 5.65 |
| Jäger | 8.47 | 8.47 |
| Montana | 5.65 | 33.89 |
| Steinbach | 28.70 | 28.70 |
| Baden-Württemberg | 9.57 | 9.57 |
| Rheinland-Pfalz | 5.74 | 14.35 |
| Hessen | 5.74 | 25.83 |
| Alarm limit value | 6.95 | 6.95 |
| Matthey | 4.77 | 4.77 |
| Linearised Matthey | 8.77 | 8.77 |
| Büttinger | 30.30 | 30.30 |
| Fitting to FDC | 34.10 | 34.10 |
| Falling below values | 29.95 | 29.95 |
| Catchment area (CH) | 29.59 | 29.59 |
| Constant specific reserved flow (USA) | 16.76 | 4.79 |
| Constant specific reserved flow Tirol | 5.53 | 3.68 |
| Steiermark, Kärnten (depth) | 2.13 | 2.13 |
| Steiermark, Kärnten (velocity) | 0.50 | 1.80 |
| Oregon (depth) | 2.88 | 9.10 |
| Oregon (velocity) | 16.50 | 96.00 |
| Oberösterreich | 6.73 | 6.73 |
| Tirol | 4.17 | 6.73 |
| Miksch | 1.20 | 1.60 |
| *Minimum value* | *0.50* | |
| *Maximum value* | *96.00* | |
| **Maximum/Minimum** | **192.00** | |

**Table 2: wide low slope river – minimum and maximum values of reserved flow calculated with different methods**

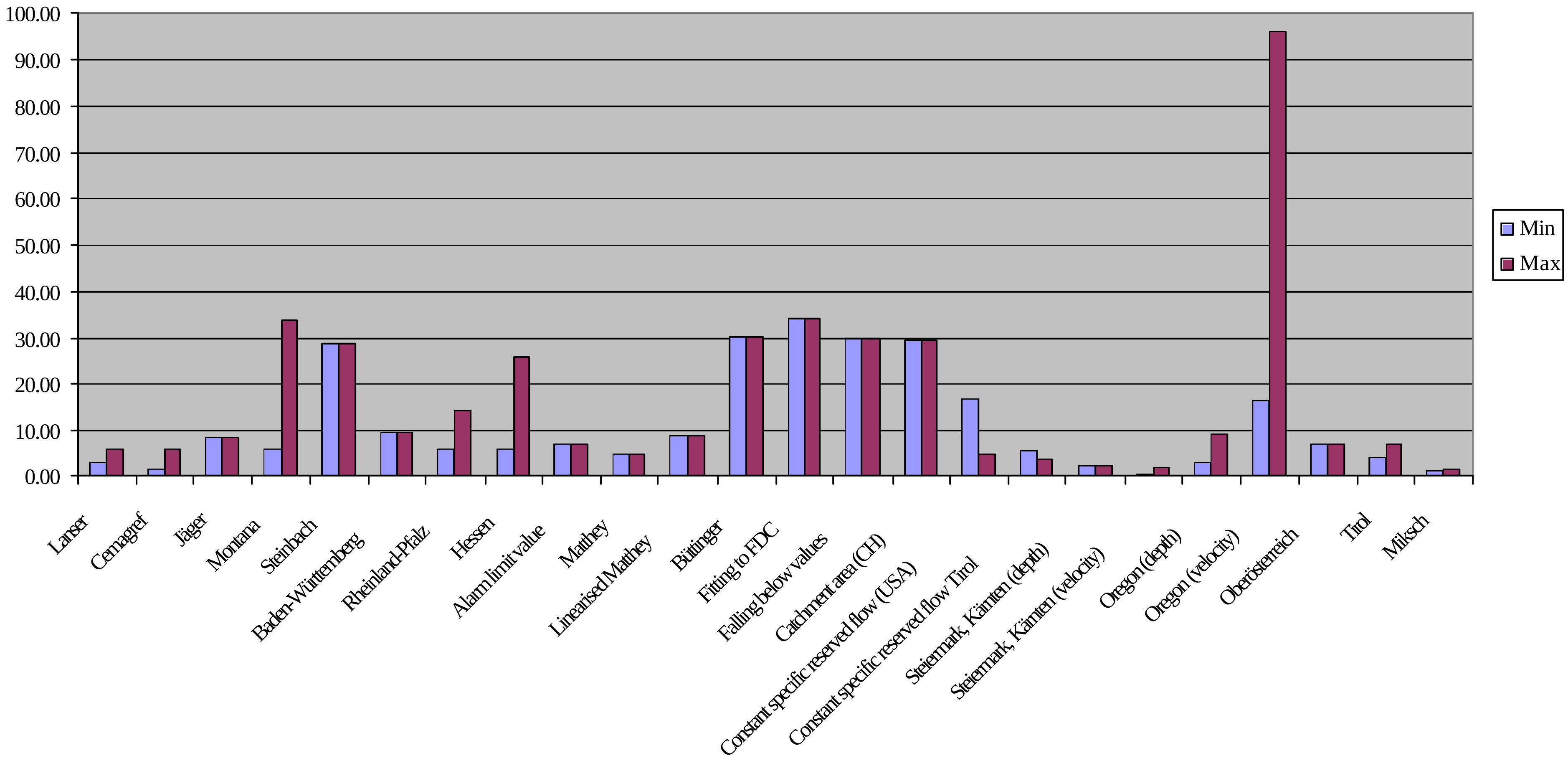



**Fig. 2: wide low slope river – minimum and maximum values of reserved flow calculated with different methods**

As you can easily see the ratio between the maximum and the minimum values obtained by the application of a great number of the methods described is almost 200!!

By the other side it's quite evident that the extreme values (especially the Oregon-velocity one) is not applicable in principle to a low slope river.

Anyway, even if we don't consider the four highest and the four lowest values the ratio between minimum and maximum is still very high, approx. 14.

The intrinsic difficulty of the said methods to supply values which can be easily agreed upon seems to be rather evident.

## 4.2 SMALL ALPINE TORRENT

The methods have some problems also when they deal with small alpine rivers.

The main data of the river are:

- Catchment area 16.70 $km^2$
- Altitude of the gauging station 1.270 m.a.s.l.
- Mean altitude of the catchment area 2.150 m.a.s.l.
- Mean annual rainfall on the basin 1.600 mm
- Width in the depleted stretch 10 m
- Slope in the depleted stretch 12.2 %
- Length of the depleted stretch 2.100 m

Main hydraulic parameters are referred to steady normal flow.

| | Flow rate l/s | Depth m | Velocity m/s | Wetted perimeter m |
|---|---|---|---|---|
| MQ | 719 | 0.056 | 1.275 | 10.113 |
| MNQ | 0.0 | 0.000 | 0.000 | 0.000 |
| Q355 | 8.3 | 0.004 | 0.219 | 10.008 |
| Q351 | 12.7 | 0.005 | 0.256 | 10.010 |
| Q347 | 17.5 | 0.006 | 0.290 | 10.012 |
| Q84% | 80.6 | 0.015 | 0.533 | 10.030 |
| Q300 | 93.2 | 0.017 | 0.566 | 10.033 |

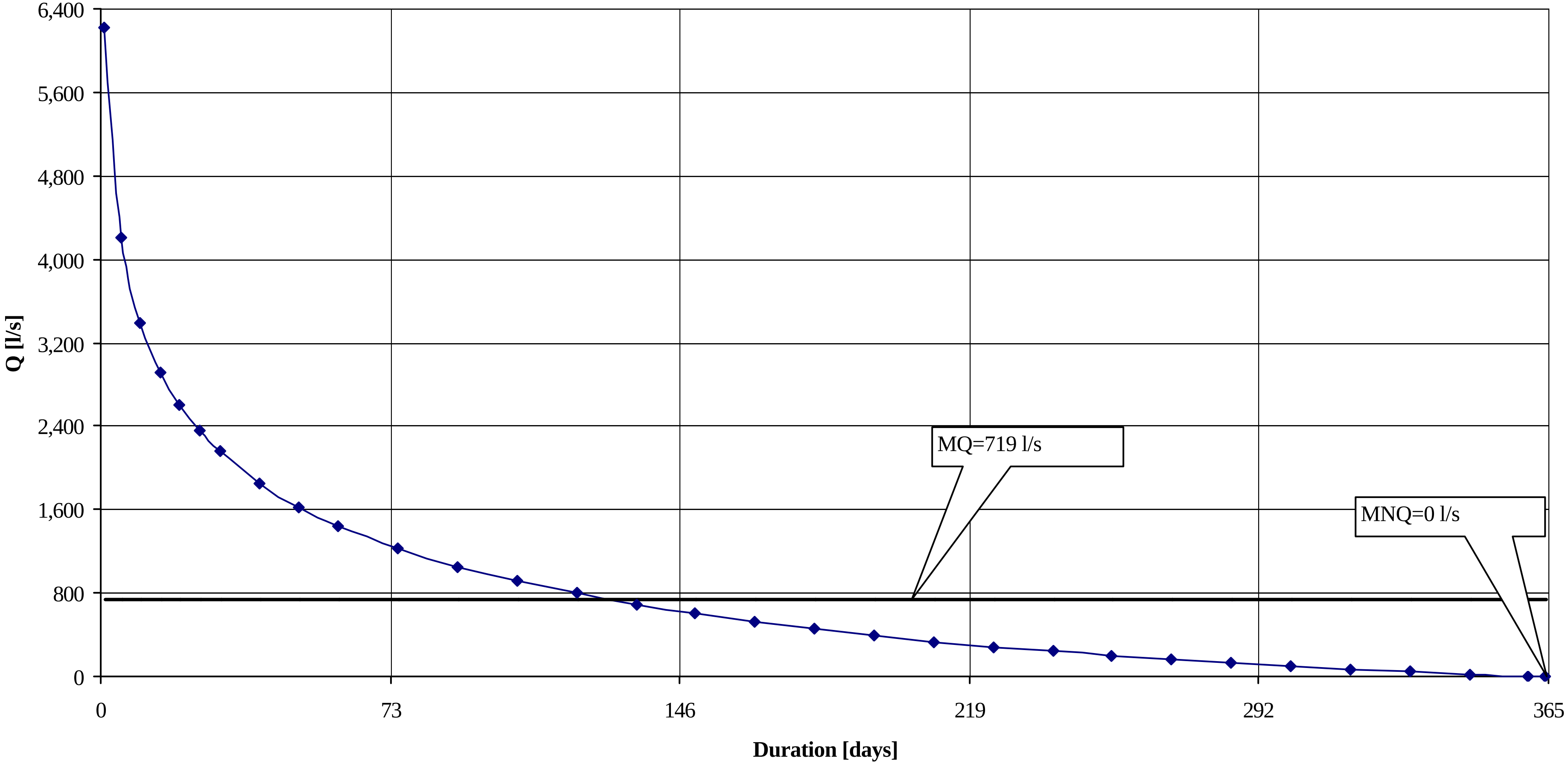



**Fig. 3: small alpine torrent – flow duration curve**

Fig. 2 and Table 2 give the values of the reserved flow calculated with some of the different methods and a comparison among them.
In this case the methods which refers to the minimum yearly flow MNQ should not be applicable because the torrent is subject to dry up (Q ~ 0) in some periods of the year.

| **Method** | **Min** | **Max** |
|---|---|---|
| | l/s | l/s |
| Lanser | 36 | 72 |
| Cemagref | 18 | 72 |
| Jäger | 108 | 108 |
| Montana | 72 | 431 |
| Steinbach | 0 | 0 |
| Baden-Württemberg | 0 | 0 |
| Rheinland-Pfalz | 0 | 0 |
| Hessen | 0 | 0 |
| Alarm limit value | 19 | 19 |
| Matthey | 11 | 11 |
| Linearised Matthey | 23 | 23 |
| Büttinger | 17 | 17 |
| Fitting to FDC | 81 | 81 |
| Falling below values | 13 | 13 |
| Catchment area (CH) | 8 | 8 |
| Constant specific reserved flow (USA) | 41 | 143 |
| Constant specific reserved flow Tirol | 31 | 47 |
| Steiermark, Kärnten (depth) | 1860 | 1860 |
| Steiermark, Kärnten (velocity) | 20 | 70 |
| Oregon (velocity) | 620 | 3550 |
| Oregon (depth) | 2510 | 7840 |
| Oberösterreich | 5820 | 5820 |
| Tirol | 2630 | 5820 |
| Miksch | 300 | 400 |

**Table 3: small alpine torrent – minimum and maximum values of reserved flow calculated with different methods**

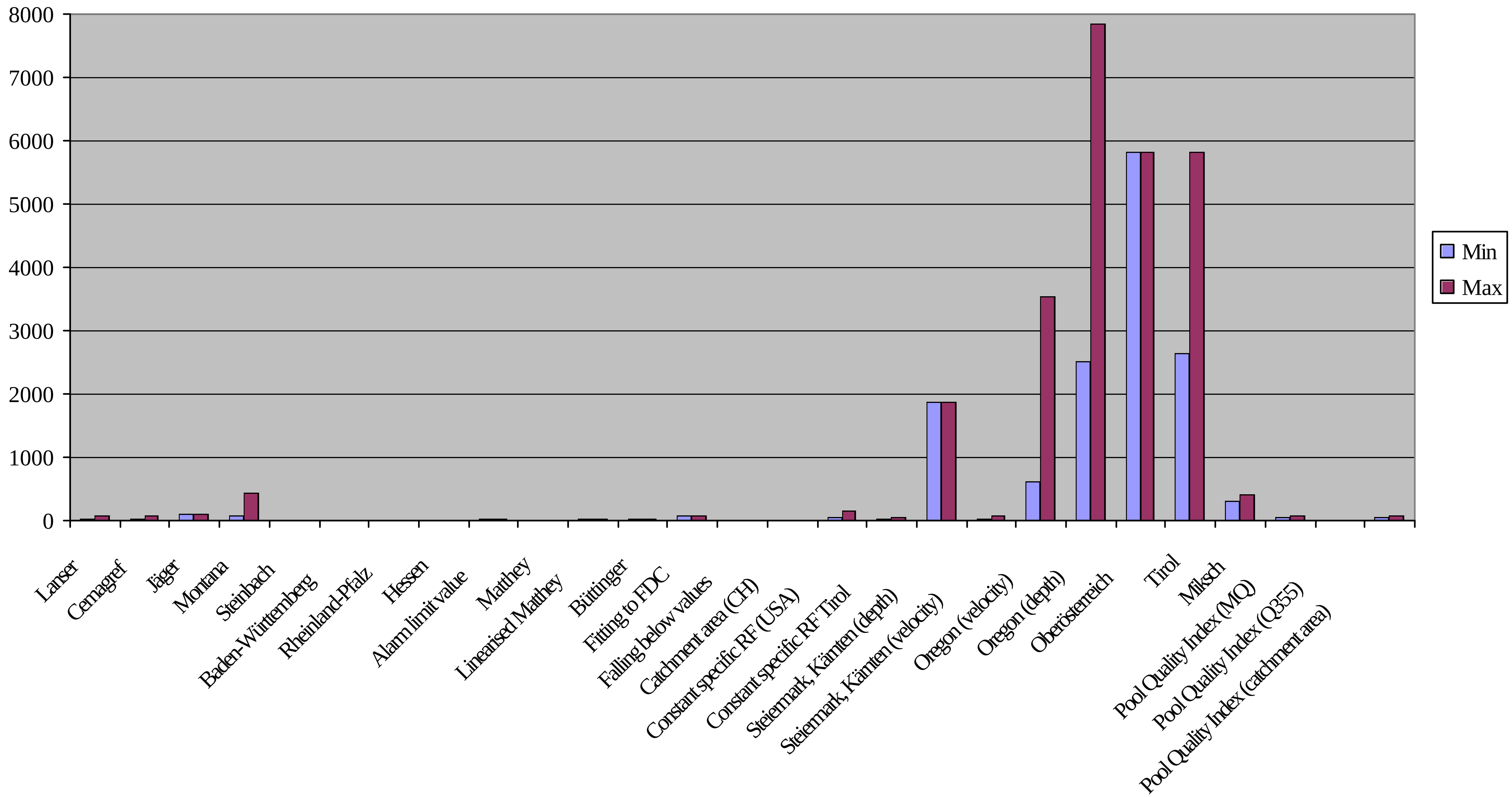



**Fig. 4: small alpine torrent – minimum and maximum values of reserved flow calculated with different methods**

The application of the above described methods put into evidence all their limits:

- Methods based on velocity or depth lead to disproportionately high values of reserved flow and the reason is quite evident: from a geometric point of view a torrent is highly irregular so that if you want to apply this methods, you must refer to a specific and geometrically well defined section.
- Methods based on NMQ or on the low part of the flow duration curve ($Q_{355}$ ….) give very low or null values of the reserved flow. If you calculate the values of depth, velocity, wetted perimeter referred to the reserved flow you find very low and inadequate values even if in principle that flow could be enough to guarantee the ecological function of the river.

# 5 NATIONAL REGULATION

## 5.1 FOREWORD

The survey on national regulations is necessarily not complete because in many countries the reserved flow is changing and will probably change in the future due to the entering in force of the Water Framework Directive 60/2000 within the end of this year in all Member States.

So, in the following paragraphs only a partial survey will be made in order to give an idea about the different methods applied.

## 5.2 FRANCE

According to Article L432-5 of the Code Rural, any work to be built in the bed of a river must comprise devices maintaining in this bed a minimal flow permanently guaranteeing the life, the circulation and the reproduction of the species which populate water at the time of the installation of the work like, if necessary, devices preventing the penetration of fish in the headrace and tailrace canals. This minimal flow should not be lower than:

- 1/10 of the module of the river corresponding to the inter-annual medium flow, evaluated starting from information available relating to a five years minimum period, or with the flow with the immediate upstream of the work, if this one is lower.
- However, for the rivers or part of rivers whose module is higher than 80 $m^3/s$, a decree of Council of State can, for each one of them, to fix at this minimal flow a lower limit which should not be below 1/20 of the module.

The owner of the work is held to ensure the operation and the maintenance of the devices guaranteeing in the riverbed the minimal flow

The provisions above envisaged are extended to the works existing at June 30, 1984 must be applied gradually within three years after 1984.. These provisions apply completely to the renewal of the concessions or authorizations of these works. As from June 30, 1987, their minimal flow, except technical impossibility inherent in their design, cannot be lower than the quarter of the values above fixed (that is 1/40 or 1/80 of th module).

## 5.3 GREECE

Reserved flow must be at least 1/3 of the average summer flow rate of the river.

## 5.4 ITALY

The reserved flow rules are fixed by River Basin Authorities or by Regional Governments. The regulation is still ongoing. We report only some examples because the regulations are decades. Anyway the general tendency is for physiographic methods with correction factors.

- <u>Po river basin</u>: until now there is a regional regulation. A new river basin regulation was issued in 2002. According to it, the reserved flow is calculated as follows:

  $RF = k * q_m * S * M * Z * A * T$ (l/s)

  where:

  k = experimental parameter function of each hydrographic area (approx. 0,08-0,12)

  $q_m$,= specific average inter-annual flow rate (l/s $km^2$)

S = catchment area ($km^2$ )

M = morphological parameter (0,7-1,3)

Z = maximum value among the three parameters N, F, Q, where:

- N = naturalistic parameter (=1, the higher the naturality of the river is, the higher the value of the parameter)
- F = fruition parameter (=1, the higher the fruition of the river for use different from the diversion, e.g. tourism, fishery, is, the higher the value of the parameter)
- Q = water quality parameter (=1, the higher the pollution of the river is, the higher the value of the parameter)

A = parameter related to the interaction between surface and underground water (0,5-1,5; lower value if water table contributes to reserved flow, higher value otherwise)

T = parameter related to the time modulation of reserved flow, due to particular exigencies during the time of the year (fish spawning, tourism, etc.).

- Tagliamento river basin: 4-6 $l/s/km^2$ ·A (catchment area, $km^2$).

### 5.5 LITHUANIA

A regulation issued by the Ministry of Environment (LAND 22-97 of 4 November 1997) provides with the methodology of determination of reserved flow necessary for overall river engineering, including hydropower operation. The Lithuanian territory is split up into two different hydrological regions in which different reserved flow values are to be imposed. For the first hydrological region, which rivers have irregular flow pattern, reserved flow is equivalent to the low flow warm season (from April to October) of 30 days duration value corresponding to the 5-years return period (probability - 0.80). For the second hydrological region, characterized by more regular river flow pattern reserved flow value is less and it is calculated using above methodology, but low flow return period is fixed at 20-years (probability - 0.95). In the diversion schemes, independently of the type of hydrological region, the minimum reserved flow in channel for diverted water is fixed at 10% of the long term average seasonal flow.

Most SHPs in Lithuania are not diversion type, consequently the losses in electricity production resulting from provision of reserved flow are minimum.

The value of low flow of 30 days duration is equal to about 1.2 to that of monthly minimum discharge. Instead of Flow duration Curves there is established the low flow probability (frequency) distribution curve. A theoretical distribution (for example Gumbel) is applied to low flow plotted points.

### 5.6 NORWAY

Reserved flow must be equal or higher than $Q_{350}$.

### 5.7 PORTUGAL

Reserved flow must be equal or higher than 1/10 of the average inter-annual flow rate.

### 5.8 SCOTLAND

Reserved flow must be equal or higher than 45% of the average inter-annual flow rate.

### 5.9 SPAIN

In the 1985 Spanish Water Act the residual flow was established at 10% of the inter-annual average flow. This was considered by the different autonomic and local institutions as a minimum value, and in every new project a higher and often arbitrary value has been fixed.
In the new Water Act of July 2001 the reserved flow must be established in the "River basin management plans" to be made by the corresponding river authorities (in Spain there are 14). In fact, up to now, only one river authority (the Basque) have elaborated a computer programme to fix it. Many others have subcontrated, with private consulting firms, the elaboration of their evaluating systems. Most of them are based on the IFIM method that requires long studies on the different reaches of the river. It must be said that the different climatologies in Spain make impossible to issue a common rule.

In rivers rich in trouts the maximum value among: $0{,}35 \cdot Q_{347}$, $0{,}25_{347}+75$, $0{,}15 \cdot \frac{Q_{347}}{\ln Q_{347}}$ must be used.

In case of rivers rich in salmonides the previous values must be increased by 4 l/s/km$^2$.
In case of spawning areas the previous values must be increased of further 2 l/s/km$^2$.

## 5.10 UNITED KINGDOM

The UK has no standard method. The main river authority (Environment Agency) looks at each site on an individual basis before granting a license. The starting point for negotiations is usually Q95 (that is the discharge which flows for more than 95% of the year), but it can be more or less than this in reality.

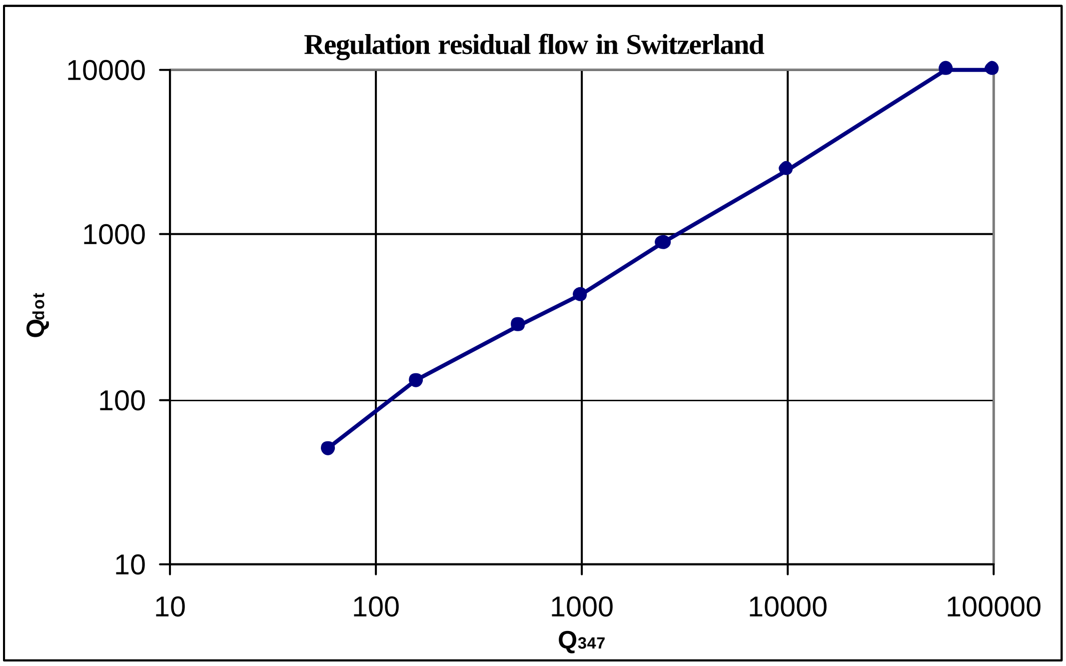
## 5.11 AUSTRIA

Austria has no general formula to be applied but some approaches to obtain a “correct” value. Usually the decision is taken by an official expert, included in the granting procedure. So the variability and the expertise of different people lead to different results.
A first approximation is usually done with hydrological parameters, using the range between “annual mean minimum flow” (MNQ) and “annual minimum flow” (NNQ).
A useful but sometimes expensive tool to avoid a rather high fixation is the presentation of a specific expertise based on dotation testing. Governmental experts will in most cases except the result.

## 5.12 SWITZERLAND

Although Switzerland is not part of the EU their regulations concerning reserved flow are worth mentioned.
A certain act dealing with the protection of water bodies regulates the questions of reserved flow. A short overview of a rather complex regulation is given below:

The fixation is based upon the so-called $Q_{347}$, means the discharge appearing more than 95% of the year – obviously a kind of low flow. The graph shows the dependencies:




At very little discharge the function starts with 80% of Q 347, at 10.000l/s the percentage has been reduced to 25%. Starting from 60.000l/s there is a fixed value of 10.000l/s which is about 17%.
For some reasons like ground water, water quality, fish passing, and others an increase of the values mentioned is foreseen. On the other hand a decrease under special conditions is allowed due to the independence of the "Kantone", a certain governmental structure in Switzerland.
The regulation is applied within new plants. Still existing plants are somehow protected and the maximum demand is less than 5% of the rated flow. In case of a higher value it is said to be a dispossession and connected with some compensation payment.

### 5.13 GERMANY

There is no regulation valid for the whole country. The so-called "Länder" have their specific regulation. A very common approach depends on the "mean minimum flow" (MNQ). Usually 1/3 to 1/6 is the amount of residual flow. More often the 1/3 is chosen.
The final decision within the frame described is taken during the granting procedure by the governmental reprresentatives.

## 6 CONCLUSIONS

The quick overview of the previous pages put into evidence that many gods fight in the reserved flow Olympus.
When so many solutions to the same problem are given, it's quite clear that no one is the best one, both in absolute terms and from a scientific point of view.
Far from us the thought that the results summarised in the formulas didn't come from serious scientific work, but anyway all these solutions, exception made for the highly site-specific methods of chap. 3.8, try to find simple formulas to a complex problem. This approach results in rigid systems, without any degree of freedom and consequently, sometimes, in inappropriate values of reserved flow both from the strictly ecological and from the hydroelectric energy producer point of view.

By the other side simple formulas has many advantages:

- Simplify work for river basin planners
- Supply to hydroelectric investors a clear idea of the water resource exploitable for energy production (although in many cases reserved flow is so high to make the plant realisation unfeasible)

The conclusion isn't that site-specific methods are the good ones, because - as honestly pointed out in many studies - they are too much site-specific even within the same river stretch and consequently you can fall into great errors again.

### 6.1 A PROPOSAL

A dead point seems to be reached, but we must be positive.

A possible tentative solution, without any presumption, could lay in a pragmatic approach.

Water depth and velocities, much more than the flow rate value itself, seem to be the main abiotic parameters affecting riverine life.

In case of reserved flow minimum values must be assured. In a completely natural river stretch this goal can't be achieved because of continuously changing river cross section shapes, so that a fixed value of velocity or depth can be not suitable for a cross section or largely exceeding the minimum in another section.

In many case the problem could be solved by creating a low water riverbed, e.g. by means of bioengineering techniques or by river restoration methods, where water velocities and depths are good for riverine life.

This possible solution doesn't solve all the problems and it has pros and cons which we'd like will be discussed within the Thematic Network, out of which:

- reserved flow is always consistent with demands of riverine life because suitable velocities and depths are assured all along the river stretch;
- reserved flow can be set at minimum values with consequent possibility of increasing energy production from small hydroelectric plants, so that a sort of environmental optimisation can be achieved;
- if the river stretch is long the works necessary for creating low water riverbed and river restoration can be very expensive and subject to be partially remade after important flood events;
- who pays for restoration works in case of existing plants subject to the reserved flow release obligation?

### 6.2 THE STONE THROWN IN THE POOL

In the frame of the Thematic Network on Small Hydroelectric Plants, as we said in the chap. 1, we have no scientific conceit, because we think that the reserved flow problem is not a scientific problem.

We can fight for months or years around the best method for calculating reserved flow and no one will be the winner: all of us knows that this battle is on going since years and the results are self-evident.

The reserved flow problem is a problem of priorities and setting priorities is a political matter.

So here we want to provoke not a scientific discussion, but a more general discussion about the role of reserved flow in the environment protection where environment must be intended in the widest possible sense.

When reserved flow problems are concerned, sometimes we have the feeling that the forest is forgotten through talking so much of the leaf. Every l/s left in the river is lost for renew able energy production.

Which is the priority?

Finally, to further provoke discussion, we want to mention a word banned in the environmental world: economics.

Each l/s left for reserved flow can’t produce renewable energy from small hydroelectric plants. This energy has an economic value that is, this energy is recognised as a resource, something not sufficient.
It’s quite clear that if a higher price for energy from small hydroelectric plants is granted to producer, the reserved flow problem is immediately solved: plant owners and investors will be available to release theoretically any amount of water provided that the incomes from energy selling is not diminished.
But this approach can solve the local environmental problem of the amount of water in the river, the problem of the decreasing income from energy selling due to reserved flow release, but it can’t solve the global environmental problem connected with the recognised necessity of increasing energy production from Renewable Energy Sources.