The influence of annual bedload on channel width

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I. Introduction

The morphology of natural flowing waters is determined by the discharge regime, the grain sizes and the bedload. Depending on these three factors, a certain width, morphology and dynamic development that characterize the alluvial habitats. If one or more of these three parameters changes, the morphology of the waterway changes and with it also its habitats.

Many Swiss flowing waters have been channelized, the discharge regime altered by hydroelectric plants and the bedload reduced by sediment storage basins, gravel removal, waterway structures and other facilities. This has led to a deterioration of the habitats, with the consequence that various flora and fauna typical for the waterway are now endangered or extinct.

Swiss Water Protection Act (WPA) decrees that structural measures must preserve or restore the natural water course as far as possible. Furthermore, the bedload regime may not be changed by facilities in such a way that the indigenous flora and fauna and their habitats are significantly compromised. This is the case where facilities adversely affect morphological structures or morphological dynamics.

The Swiss Federal Office for the Environment (FOEN) commissioned a study of the connection between the annual bedload, channel width and morphology. One of the aims of the assignment consisted in developing a method that allows the determination of the annual bedload that is necessary so that the morphology does not change adversely and that ultimately the typical water habitats are not significantly compromised.

The relationship between the annual bedload, channel width and morphology was shown qualitatively by various authors [1, 2, 3]. If, for example, bedload is removed from a braided river, the dominant channels sink into their own alluvion. This increases the discharge in these channel sections and the less dominant channel sections run dry. The morphology of the braided channel changes to become a single channel with bars.

Figure 1 shows the river Simme near Niedermettlisau in the years 1940 and 2004. Following the reduction of the annual bedload from 12,300 m^3/a to 6,000 m^3/a, the channel width decreased from 52 m to 35 m and the morphology changed from a braided river with islands and bars to a meandering channel with bars.

II. Morphology Of The Studied Swiss Waterway Sections

For the study, 34 Swiss waterway sections were assessed, for which there was sufficiently accurate knowledge of the required basic data (morphology, HQ_2, GF, d_m, d_{90}, B, h), collected as part of various projects by Flussbau AG. A common feature of all the studied waterway sections is that the width is and was not restricted by developments.

In Figure 2, 34 waterway sections are presented on a (B/h; h/d) plane. Contrary to Ahmari & Da Silva [8], the morphology "meandering waters with islands and bars" was newly defined (type 3) in the upper area of the region of alternate bars. This morphology can be viewed as a transitional form between the meandering waters with bars and the braided rivers. This results in the following 5 morphological types:

- Type 1: Braided rivers with 3 and more channels
- Type 2: Braided rivers with 2 channels
- Type 3: Meandering waters with islands and bars
- Type 4: Meandering waters with bars
- Type 5: Meandering waters without gravel bars

Elongated waterways with a plane bed are at the bottom left.

III. Comparison Of The Observed Channel Width With The Channel Width According To Parker

Regime theory presents various approaches to estimating the width of a waterway with empirical formulae [4, 5, 6, 7]. The empirical formulae take into account a bankfull discharge and a grain diameter of the bed material, in some cases also the channel slope.

The observed channel widths B_i of the 34 waterway sections were compared with the calculated channel width according to Parker [4] using:

$$B_\mathrm{P} = 4.4\sqrt{\frac{Q}{\sqrt{(s-1)\cdot g\cdot d_{50}}}}. \quad (1)$$

The relationship between the observed channel width B_i and the channel width according to Parker B_P corresponds to:

$$\overline{B} = \frac{B_\mathrm{i}}{B_\mathrm{P}}. \quad (2)$$

To consider the annual bedload, the dimensionless value:

$$\overline{GF} = \frac{GF_\mathrm{i}}{HQ_2} \quad (3)$$

was introduced. This corresponds to the relationship between the annual bedload GF_i and the bankfull discharge HQ_2. If the annual bedload is entered in [m^3/a] and the discharge in [m^3/s], a factor of 31,536,000 results based on the relationship between year and second.

In Figure 3, the 34 sample waterways are represented on a ($\overline{B}$;$\overline{GF}$) plane. $\overline{B}$ ranges between approx. 0.4 and 7 (values $>$ 3.5 are not represented). The more a waterway is braided, the more its width is underestimated using the Parker

Fig. 1. Orthophotos of the Simme near Niedermettlisau in the years 1940 and 2004.

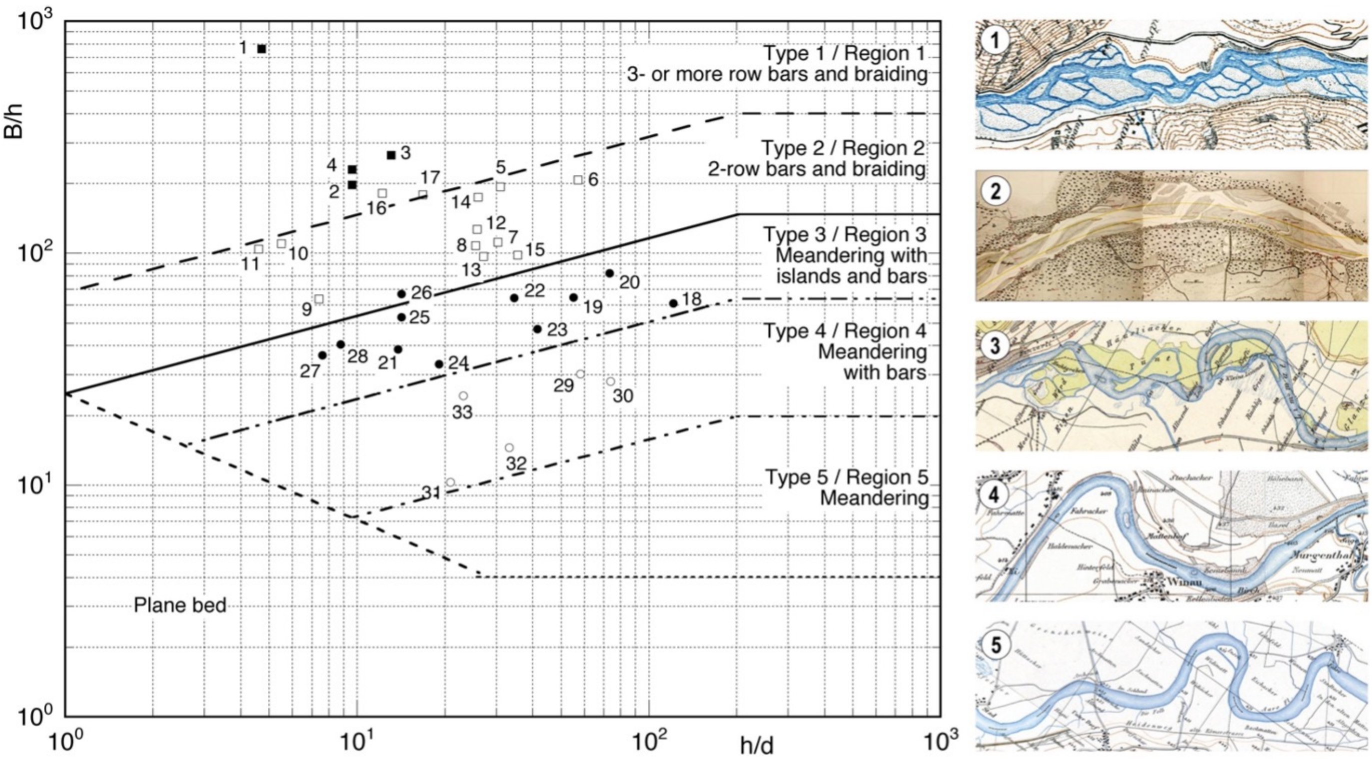

Fig. 2. Modified Ahmari & Da Silva plane with the 5 morphological types and the associated regions.

formula. Vice versa, the width of meandering rivers with bars is overestimated using the Parker formula.

The morphological types 1 to 4 can each be attributed their own range of $\overline{B}$:

- Type 1: Braided river with 3 or more channels $\overline{B} > 2.6$
- Type 2: Braided river with 2 channels $1.5 < \overline{B} < 2.6$
- Type 3: Meandering waters with islands and bars $0.9 < \overline{B} < 1.5$
- Type 4: Meandering waters with bars $0.45 < \overline{B} < 0.9$

With these classifications, the regime width of currently narrowed waters can be estimated more precisely, with knowledge of the channel form in its natural state and without knowledge of the annual bedload.

IV. Empirical Equation For Calculating The Channel Width In Relation To The Annual Bedload

For the derivation of an empirical equation for calculating the channel width in relation to the annual bedload, those of the 34 Swiss waterway sections were taken into consideration for which the channel width decreased due to a reduced annual bedload alone or that transport no or only very little bedload.

The channel width $\overline{B}_2$ of a waterway with the annual bedload $\overline{GF}_2$ can be calculated as follows, with knowledge of the channel width $\overline{B}_1$ and the annual bedload $\overline{GF}_2$ of a known state

$$B_2 = \frac{GF_2}{GF_1}(B_1 - 0.45 \cdot B_{\mathrm{P}}) + 0.45 \cdot B_{\mathrm{P}} \tag{4}$$

with B_{P} according to equation 1. The natural state (= reference state) or another state with a known bedload and unrestricted width can be referred to as a known state. Vice versa, an annual bedload GF_2 can be determined, which is

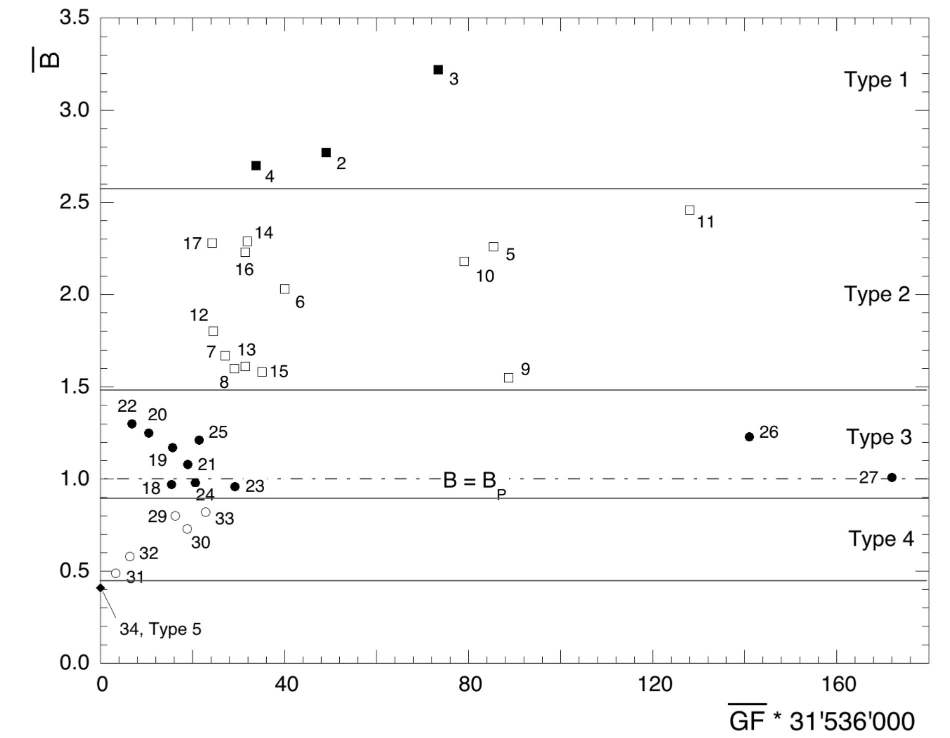

Fig. 3. Relationship between the dimensionless width $\overline{B}$ in relation to the dimensionless annual bedload $\overline{GF}$ for the 34 waterway sections. Values > 3.5 are not represented.

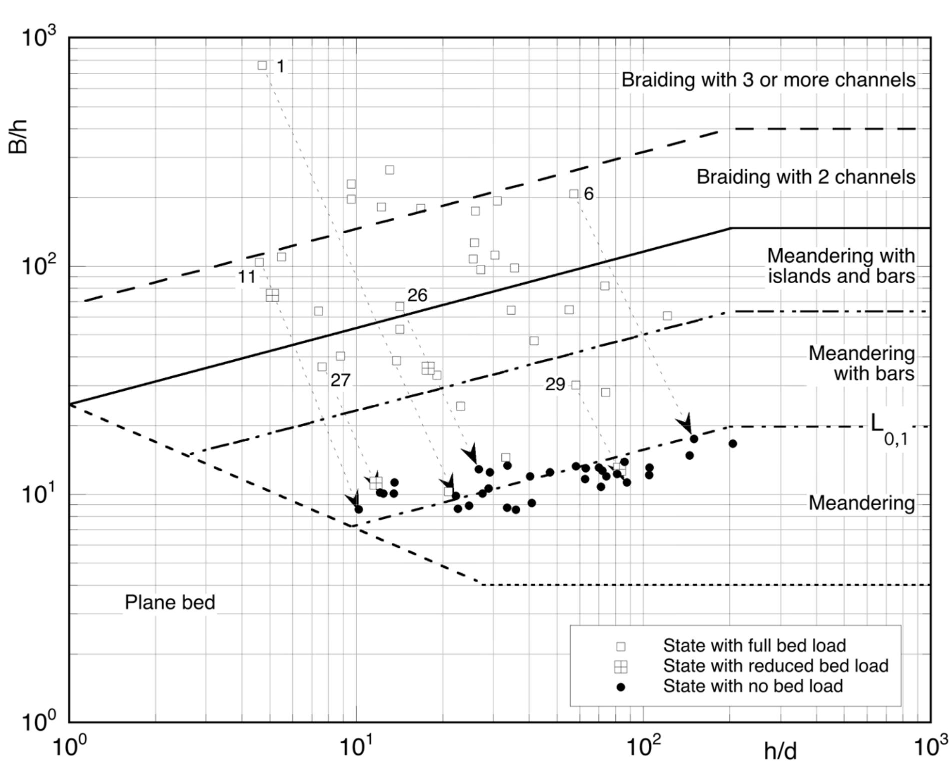

Fig. 4. $(B/h;h/d)$ plane with the Swiss waterway sections in the condition of a full bedload and without a bedload, as well as for selected waterways with a reduced bedload.

necessary so that the waterway takes on a width B_2. The following applies

$$GF_2 = GF_1 \frac{B_2 - 0.45 \cdot B_{\mathrm{P}}}{B_1 - 0.45 \cdot B_{\mathrm{P}}} \quad (5)$$

if bedload is removed from a waterway, its width decreases and the value pair (B/h;h/d) ranges within the double logarithmic Ahmari & Da Silva plane on a straight path with the inclination -3.03 and in case of absent bedload reaches the line $\mathrm{L}_{0,1}$ (Figure 4). Beginning at the starting point, it goes through the morphological types in between.

V. Required Annual Bedload For Fulfilling Legal Requirements

The legal requirements in Switzerland for the bedload regime of a waterway can be deemed fulfilled if the morphology of the waterway is similar to the reference state. In consultation with the Swiss Federal Office for the Environment, this qualitative target was regarded as fulfilled if the relative width B/h is reduced by a maximum of 25 %. Under consideration of this specification, the value pair (B/h;h/d) in the morphological types 2-4 is shifted by somewhat less than half of the width of the morphological type. For waterways with a small relative annual bedload (GF/HQ_2), so that the annual bedload does not become negative, a second condition not mentioned here was defined.

Under consideration of these specifications, the required annual bedload GF_{erf} for the 34 Swiss waterway sections was established and evaluated. It emerged that for the morphological types 1-4 at least the following percentages of the annual bedload must be reached in the reference condition GF_{RZ}:

- Type 1: Braided rivers with 3 or more channels $GF_{\mathrm{erf}}/GF_{\mathrm{RZ}} \geq 80$
- Type 2: Braided rivers with 2 channels $GF_{\mathrm{erf}}/GF_{\mathrm{RZ}} \geq 75$
- Type 3: Meandering waters with islands and bars $GF_{\mathrm{erf}}/GF_{\mathrm{RZ}} \geq 70$
- Type 4: Meandering waters with bars $GF_{\mathrm{erf}}/GF_{\mathrm{RZ}} \geq 65$

Accordingly, the braided rivers react the more sensitively to a change in the annual bedload, which may only be reduced by a maximum of 20-25 %. For meandering waters, the annual bedload may be reduced by a maximum of 30-35 %.

The relationship between the normalized B_{n}/B_1 and GF_{n}/GF_1 is outlined in Figure 5, in which the natural state of the waterway (B_1/GF_1) refers to the reference condition. For a given reduction of the annual bedload, the expected width reduction can be estimated along the sloping path of the respective morphological type. As long as the resulting width does not drop below B_3, one can state that the morphology is expected to remain similar to the reference condition.

A similar approach shall be applied vice versa. The required annual bedload within a compromised waterway condition B_2 is to be increased until the resulting width reaches or exceeds the width of B_3. If these requirements are fulfilled or exceeded, for waterways with an unrestricted width a morphology and habitats can develop that are similar to a natural state.

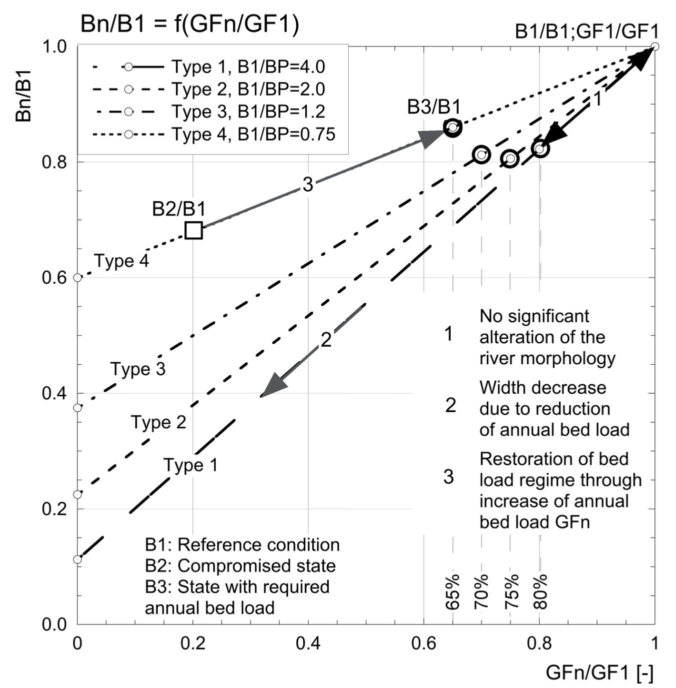

Fig. 5. Alteration of the normalized width B_{n}/B_1 in relation to the normalized annual bedload GF_{n}/GF_1 for morphological types 1 to 4.

VI. Notation

- B = Channel width and water level width at discharge HQ_2 [m]
- BP = Channel width according to Parker [m]
- d = Typical grain diameter [m]
- g = Earth acceleration [9.81 m/s^2]
- GF = Annual bedload [m^3/a]
- h = Discharge depth [m]
- HQ_2 = Flood discharge, which from a statistical point of view is reached or exceeded once every 2 years [m^3/s]
- Q = Discharge [m^3/s]

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