Environmental improvements from alternated gravel mounts in channelized rivers

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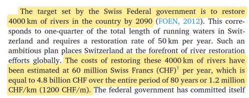
Problem:

- In channelized rivers, water flows fast and homogenous.
- The ecological value is poor and it gets worse during flood stages, when the flow conditions exceed the fishes' swim ability.
- Usually, river restauration projects are very expensive.

Fig. 1: Source: https://wwf.panda.org/wwf_news/?804991/84-collapse-in-Freshwater-species-populations-since-1970



The target set by the Swiss Federal government is to restore 4000 km of rivers in the country by 2090 (FOEN, 2012). This corresponds to one-quarter of the total length of running waters in Switzerland and requires a restoration rate of 50 km per year. Such an ambitious plan places Switzerland at the forefront of river restoration efforts globally. The costs of restoring these 4000 km of rivers have been estimated at 60 million Swiss Francs (CHF)[1] per year, which is equal to 4.8 billion CHF over the entire period of 80 years or 1.2 million CHF/km (1200 CHF/m). The federal government has committed itself

Fig. 2: Source: Logara I., Brouwera R., Paillex A. 2019. Do the societal benefits of river restoration outweigh their costs? A cost-benefit analysis, Journal of Environmental Management 232, p. 1075–1085.

In this research, the ecological improvements thanks to the installation of **alternative gravel mounts** inside channelized rivers are investigated. This simple and cost-efficient method has shown very promising initial results.

Proposal:

Arrowhead-shaped gravel mounts are built on alternative sides of the experimental channel. For stability purposes, each one is reinforced all along its shape with two layers of assembled boulders build like fallen dominoes on top of each others. Two more layers of assembled boulders are built in the same fashion along both sides of the channel with the aim of stabilizing the water surface there.

The mounts are built on alternated sides of the channel to force the flow to meander.

The shape like the head of an arrow also help in forcing the flow to twist and turn around the mounts.

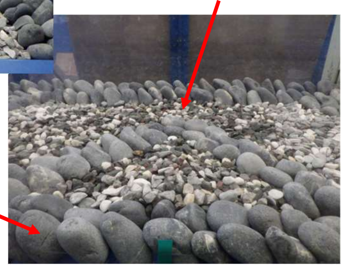


Fig. 3: Here above: The model is viewed from downstream (a). On the right: a gravel mount with stacked boulders is shown from left side wall (b).

Assembled boulders are incredibly stable, not shaking even under the stress of the largest discharges the experimental channel can provide.

Objectives:

This research focuses on **small sized fishes** (body length ≤ 0.1 m) and their habitat requirements. These individuals can fit in the gaps between assembled boulders, but are also at risk of being flushed if the flood discharge is too large. For model simplicity, no distinction between individual swim ability, sex, species and age is made.
Ayu Sweetfishes (*Plecoglossus altivelis*) are the reference species:

Fig. 4: Ayu Sweetfishes. Source: https://www.pechetonton.fr/le-mystere-ayu/

To define the river's habitat healthy, this research looks at the followings attributes:

- Heterogenous flow
- Low flow velocity
- Low turbulence

Curiosity: Ayu Sweetfishes primarily feed on plankton and prefer environments with clean water. They and can grow up to 0.3 m in length and adult males are known to be extremely territorial.

Results:

The water surface is flat and stable. This means that the hydraulic friction caused by the model is low.

Gravel and boulders remain in place. There is no risk of erosion and the model stability is confirmed.

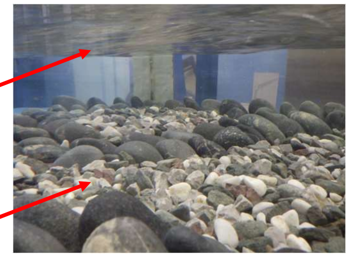


Fig. 5: The model under the channel's capacity discharge Q = 0.155 m³/s (flow from right to left).

The flow meanders like a snake around the triangular shape of each mount. This is a significant change from the usual straight and uniform flow occurring inside channelized rivers.

Behind each gravel mounts there are small areas where the water is flowing much slower than in the rest of the flow. These are exactly the conditions small sized fishes like Ayu Sweetfishes would enjoy!

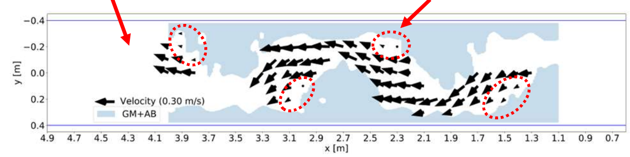


Fig. 6: The flow velocity and direction are given by the black arrows (legend for refence). The measurements are taken 0.01 m above the gravel bed surface and discharge Q = 0.004 m³/s. The surface occupied by the gravel mounts and the assembled boulders is coloured blue (hence the legend "GM+AB").

Conclusions:

The installation of alternative gravel mounts successfully slow the water flow and increase its heterogeneity. The structure has proven strong enough to resist the force of a major flood stage, while maintaining the water surface placid. The water now meanders around the gravel mounts and pockets with slow flowing areas are found behind each construction. All this confirms that alternated gravel mounts have indeed the potential of bringing significant ecological improvements inside channelized rivers.

The future:

The research now need to move from model to prototype. More accurate, thus more complex, definitions of habitat modelling will also be required. Experiments with living aquatic animals and scaled prototypes, as shown in Fig. 7, will remain very important.

Fig. 7: From left: an Ayu Sweetfish uses the spaces between stacked boulders as refuge to escape the force of the flood stage (a); the same behaviour is observed from a school of Japanese eels (*Anguilla japonica*, b); the prototype of a rectangular dike with double-layered stacked boulders is built in Tochigi Pref. (c).

- Beretta Piccoli P., Yasuda Y. 2021. Formation of refuge areas behind alternative gravel dikes for fishes during flood stages, Modern Environmental Science and Engineering Journal, issue 11, 2021, pp. 1021-1031, Academic Star Publishing, USA.
- Beretta Piccoli P., Yasuda Y. 2022a. The stability of alternative gravel dikes with stacked boulders during major flood stages inside channelized rivers, presented at the JSCE Annual Conference of the Japanese Society of Civil Engineers, Japan.
- Beretta Piccoli P., Yasuda Y. 2022b. Experimental analysis on the formation of refuge areas for fishes behind alternative gravel dikes in channelized rivers during flood stages, proceedings of the 39th IAHR World Congress, p. 2290-2299, Spain. Doi://10.3850/IAHR-39WC2521716X2022679
- Bezzola G. R. 2017. Flussbau, lecture script, VAW ETH Zürich, Switzerland. [in German]
- Boes R. 2017. Wasserbau 1, lecture script, VAW ETH Zürich, Switzerland. [in German]
- Gerstner C. L. 1998. Use of substratum ripples for flow refuging by Atlantic cod, Gadus morhua, Environmental Biology of Fishes, volume 51, p. 455-460, Kluwer Academic Publishers, Netherlands.
- Lin J.-Y., Chen Y.-C., Tsao E. H. and Yang H.-C. 2006. Refuge-use strategies of stream fishes in response to extreme low flows, Doboku Gakkai Ronbunshuu B, volume. 62, Nr. 4, p. 320-329, Taiwan.
- Logara I., Brouwera R., Paillex A. 2019. Do the societal benefits of river restoration outweigh their costs? A cost-benefit analysis, Journal of Environmental Management 232, p. 1075–1085, Switzerland.
- Nakamura S., Ishikawa M. et al. 1995. Field Research to Obtain the IFIM's Preference Curves for Japanese Fresh Water Fishes, 第2回河道の水理と河川環境シンポジウム, pp.127-134, Japan. [in Japanese]
- Onitsuka K., Nagaya T. & al. 2005. Study on suitable hydraulic condition for spawning and living of ayu, Collection of academic Theses, volume 4, p. 1471-1476, Online ISSN 1884-9172, Print ISSN 0916-7374 (online platform), Japan. [in Japanese]
- Onitsuka K., Nagaya T. et al. 2009. A Proposal of Preference Curves of Velocity for Ayu, Kyushu Institute of Technology, Japan. [in Japanese]
- Weitbrecht V., Detert M., Koksch M., Weber C. 2018. Revitalisierung von Fliessgewässern, Lecture material, VAW ETH Zürich, Switzerland. [in German]
- Yamamoto R., Honda H. 2005. Numerical prediction for the impact of short-time variations or river flow on the spawning environment of Ayu, 水工学論文集, 2005, 49 巻, p. 1483-1488, 公開日2011/06/27, Online ISSN 1884-9172, Print ISSN 0916-737 (online platform). [in Japanese]

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