Thematic Areas

Evolution of a restored river course and alternative measures to correct unintended effects

Evolución del curso de un río restaurado y medidas alternativas para corregir los efectos no deseados

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Resumen

En los años 1967 a 1970, se llevó a cabo una serie de importantes trabajos de canalización con una fuerte alineación y construcción de escolleras en el río Arbogne, ubicado en el cantón de Friburgo, Suiza. Esta intervención era objetivamente necesaria debido a las inestabilidades del lecho del río, así como a su capacidad hidráulica insuficiente, lo que lleva a frecuentes inundaciones en edificios y tierras de cultivo cercanas. Treinta años más tarde, una revisión

del perfil río del Arbogne mostró una cantidad significativa de depósitos de sedimentos que cubren parcialmente el perfil inicial, reduciendo considerablemente la capacidad hidráulica. Contemporáneamente, las autoridades competentes en la gestión del agua de los cantones de Vaud y Friburgo encargaron un estudio para la construcción de un bypass aguas arriba del pueblo de Corcelles-près-Payerne, dado que también son propensos a inundaciones regulares. El bypass se ha puesto en funcionamiento en el año 2015, lo que lleva a una disminución de la cota de inundación en el tramo aguas abajo de la Arbogne. El caudal en exceso se desvía hacia el cauce principal de La Broye. Previamente, un tramo de río de 0.9 kilómetros situado en Dompierre se ha revitalizado entre los años 2007 y 2008 como parte de las medidas compensatorias obligatorias a raíz de la construcción de la carretera nacional A1 cercana. El objetivo inicial del proyecto era mejorar la función del río como corredor ecológico para la vida silvestre para compensar el efecto de pérdida de conectividad causada por la carretera. Poco después de la finalización de las obras, debido nuevamente a la gran acumulación de sedimentos y el crecimiento de la vegetación, el nivel del lecho del río ha subido y de nuevo se han producido frecuentes inundaciones Para tratar de resolver este problema, el lecho del río se dragó a lo largo de unos 300 m en 2010 y los diques se aumentaron localmente. Los sedimentos continuaron a acumularse y protección contra inundaciones seguía sin estar garantizada. El Cantón de Friburgo en 2015 encargó otro estudio para resolver el problema y garantizar la protección contra inundaciones a largo plazo, así como el valor ecológico del tramo de río. Este estudio propone y evalúa una serie de medidas de regeneración ambiental en relación con los aspectos hidro-morfológicos y ecológicos.

Abstract

In the years 1967 to 1970, important river training works with straight alignment and riprap banks of the Arbogne River, located in the canton of Fribourg, Switzerland, took place. This intervention was objectively necessary because of riverbed instabilities as well as insufficient hydraulic capacity, leading to frequent flooding of nearby buildings and farmland. Thirty years later, a river profile survey of the Arbogne showed a significant amount of sediment deposits partially covering the initial profile reducing considerably the hydraulic capacity. In the meanwhile, the relevant water authorities of the Cantons Fribourg and Vaud commissioned a study for a flood bypass in the upstream village of Corcelles-près-Payerne, also prone to regular flooding. The bypass has been put into operation in 2015, leading to a reduced flood discharge in the downstream reach of the Arbogne. The exceeding discharge is diverted to the valley main watercourse of La Broye. Earlier, a selected 0.9 km long river reach located at Dompierre has been revitalized between 2007 and 2008 as part of legal compensatory measures following the construction of the nearby national highway A1. The initial purpose of the project was to enhance the exchange corridor function for wildlife to compensate for the

highway cutting effect. Soon after completion, again due to large sediment accumulation and abundant vegetation growth, the level of the riverbed has risen and frequent flooding occurred once more. To try to solve this problem, the riverbed was dig out over some 300 m in 2010 and the levees heightened locally. Sediments continued to accumulate and flood protection is still is not ensured. The Canton Fribourg commissioned in 2015 another study to solve the issue and ensure long-term flood protection as well as the ecological value of the river reach. This study proposes and evaluates several re-mediation measures with respect to hydro-morphological and ecological aspects.

Résumé

Dans les années 1967 à 1970, le tracé du lit de l'Arbogne, située dans le canton de Fribourg, a été corrigé et un aménagement des berges en enrochement a été créé. Ces travaux ont été rendus nécessaires en raison de l'instabilité du lit et du faible gabarit hydraulique, laissant trop souvent déborder les eaux de crues et portant ainsi préjudice aux bâtiments voisins et aux cultures. Trente ans après cette intervention, une campagne de relevé des profils de la rivière a été réalisée, montrant une importante quantité de sédiments recouvrant le profil initial diminuant considérablement la capacité hydraulique. Parallèlement, les services compétents des cantons de Fribourg et Vaud ont demandé une étude en vue de la dérivation des crues de l'Arbogne à l'amont de Corcelles-près-Payerne, également victime d'inondations fréquentes. La dérivation a été mise en service en 2015, diminuant les débits de crue de l'Arbogne à l'aval. L'excédent de débit est dévié vers la Broye, rivière principale de la vallée. Avant ces travaux, un tronçon de l'Arbogne de 0.9 km de long, situé à Dompierre a été revitalisé entre 2007 et 2008 dans le cadre des mesures de compensation écologique suite à la construction de l'autoroute A1. Le but original de la mesure compensatoire était de renforcer la fonction de couloir d'échange de l'Arbogne pour la faune afin de pallier à l'effet de coupure de l'autoroute. Peu après la mise en application de la mesure, du fait d'une large accumulation de sédiments et d'une végétation abondante, le niveau du cours d'eau est remonté et des crues se sont à nouveau produites régulièrement. Pour essayer de palier à ce problème, le lit mineur a été curé sur 300 m en 2010 et les digues ont été surélevées localement. Malgré ces travaux, des sédiments continuent de s'accumuler et la protection contre les crues n'est toujours pas garantie. En 2015, le Canton de Fribourg a mandaté une autre étude visant à la résolution du problème garantissant à long terme la protection contre les crues ainsi que la valeur écologique du tronçon de la rivière. Cette étude propose et évalue plusieurs mesures de remédiation tenant compte des aspects hydro-morphologique et écologique.

1. Introduction

1.1 Project site description

The Arbogne River is a some 30 km long right tributary of the Broye River. It is located mainly in the Swiss canton of Fribourg, but runs on short distances also in the canton of Vaud (*Figure 1*). It is part of the Rhine River basin. The 1.4 km long Arbogne River reach under investigation lies in the fertile and intensively cultivated Broye plane between Corcelles-près-Payerne and Dompierre at an altitude of some 445 m asl. It is located between the CFF railway bridge and a local road bridge. In its lower reach, the Arbogne River flows in the former bed of the Broye River, which has been corrected and straightened between 1853 and 1856 (de Salis 1890)

1.2 Original state and past river training works

Over thousands of years, the Broye plane was filled with thick layers of silty sediment, the main river courses were meandering through the plane at very low slopes. Several exceptional historic floods are mentioned, but every time with large sediment accumulation.

In the years 1967 to 1970, important river training works with straight alignment and riprap banks of the Arbogne River were undertaken. This intervention was objectively necessary because of riverbed instabilities as well as insufficient hydraulic capacity, leading to frequent flooding of nearby buildings and farmland (Parriaux 1981). In the year 2000, a river profile survey showed a significant amount of sediment deposits partially filling the initial profile reducing considerably the hydraulic capacity. The relevant water authorities of the Cantons Fribourg and Vaud commissioned a study for a flood bypass in the upstream village of Corcelles-près-Payerne, also prone to regular flooding. The bypass has been put into operation in 2015, leading to a reduced flood discharge in the downstream reach of the Arbogne. The exceeding discharge is diverted through a tunnel to the Broye River. A selected 0.9 km long river reach located at Dompierre has been revitalized between 2007 and 2009 as part of legal compensatory measures following the construction of the nearby national highway A1. The initial purpose of the project was to enhance the exchange corridor function for wildlife to compensate for the highway cutting effect of the plane. Soon after completion, again due to large sediment accumulation and abundant vegetation growth, the level of the riverbed has risen and frequent flooding occurred once more (Figure 3).

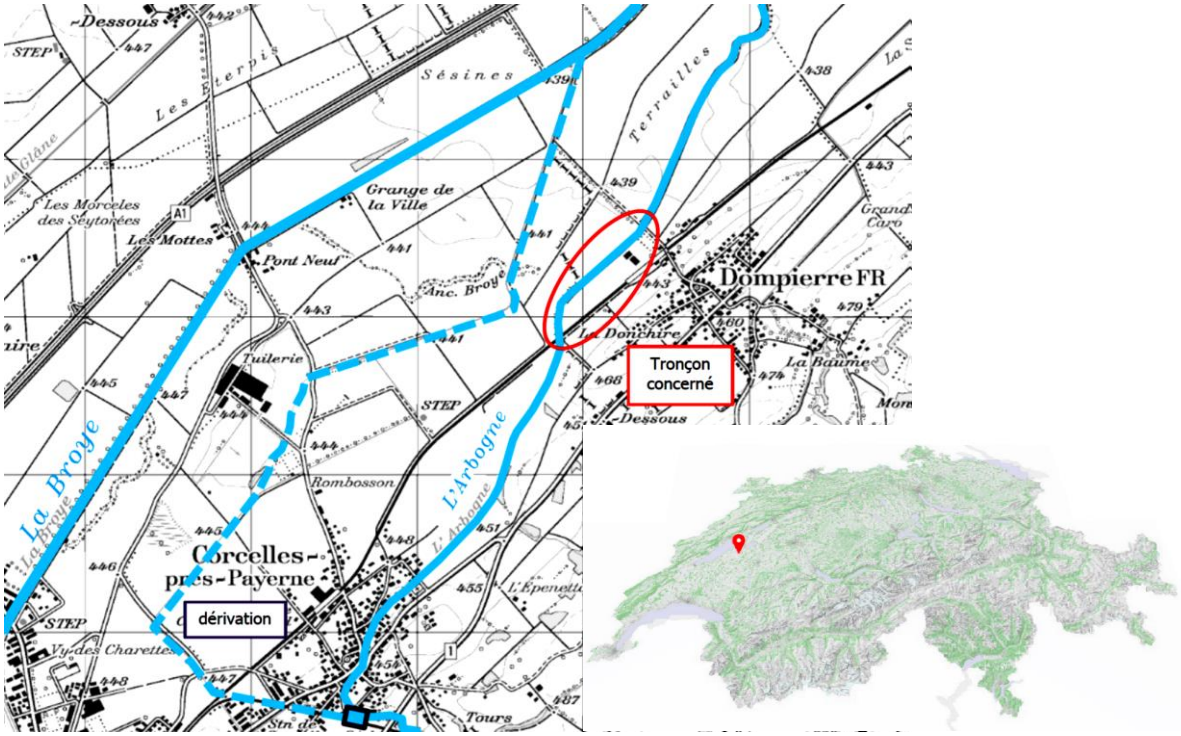

Figure 1 Project site location, the Arbogne River in the canton of Fribourg, the river deviation in Corcelles-près-Payerne is also indicated on the map (with the authorization of Swisstopo JA100120).

To try to solve this problem, the riverbed was dig out over some 300 m in 2010 and the levees heightened locally. Sediments continued to accumulate and flood protection is still is not ensured in 2016. The Canton Fribourg commissioned in 2015 another study to solve the issue and ensure long-term flood protection as well as the ecological value of the river reach.

1.3 Methodology

In order to answer the request formulated by the authorities, the engineering consultant sd ingénierie, together with Bureau A. Maibach Sàrl as ecologist and the Laboratoire de constructions hydrauliques (LCH) of the Ecole polytechnique fédérale de Lausanne (EPFL) regarding hydraulic modelling with sediment transport proposed the following methodology:

1. Analysis of the past and current situation
2. Identification of deficits
3. Establishment of several alternatives to solve the problem
4. Multi-criteria analysis of the alternatives
5. Detailed design of the "best" solution

Currently, steps 1 to 4 have been performed and are presented in this paper. The decision of what alternative to be implemented has not yet been taken.

2. Site survey and characteristic figures

2.1 Hydrology

The hydrological situation of Arbogne River has been investigated many times in the past, especially for the flood bypass structure. Therefore no new hydrologic study was required. The flow in the Arbogne River and other rivers in the Broye plane is fluvial (subcritical), even during flood events. According to field observations reported by Consuegra (1990 and 1991) the flow pattern is induced by relatively gentle slopes and the corresponding flow velocities vary between 1 and 2 m/s even during flood events. Table 1 indicates the flood discharges as a function of return period. As already mentioned, discharges higher than 21 m^3/s will not transit any more the river reach, as the exceeding discharge is diverted into the Broye River. The maximum flood return period is slightly below a 5-year flood event that is still considered to have morphologic effects on the river course.

Table 1 Project discharges and corresponding return periods

Type or return period [year]	average	1	2	5	10	20	30	50	100
Discharge [m^3/s]	0.5	12	19	25*	29*	32*	35*	38*	41*

*Discharges higher than 21 m^3/s will not transit any more the river reach

2.2 Geometry

The Arbogne River reach has a slight S-bend in the plane view. In the length profile, the slope is higher in the first part of the river reach with some 0.3%, while the lower part has a slope of some 0.2%. The cross sections have an average width of some 15 m between the levees, with a permanent water width between 2 and 4 m. Some 15 cross sections characterize the river course with an equidistance of about 60 m, the considered section is about 900 m long between the two bridges.

A river survey was conducted in March 2015, on the same cross sections than in 2008. A comparison of cross sections allowed estimating the sediment deposits on the stretch for a period of six years and a half. The analysis of 885 meters between the two boundary profiles gives a total sediment deposit 6'165 m^3, therefore on average 960 m^3/year. The linear deposited volume vary by a factor of two (4.7 to 10.1 m^3/m) between the cross sections.

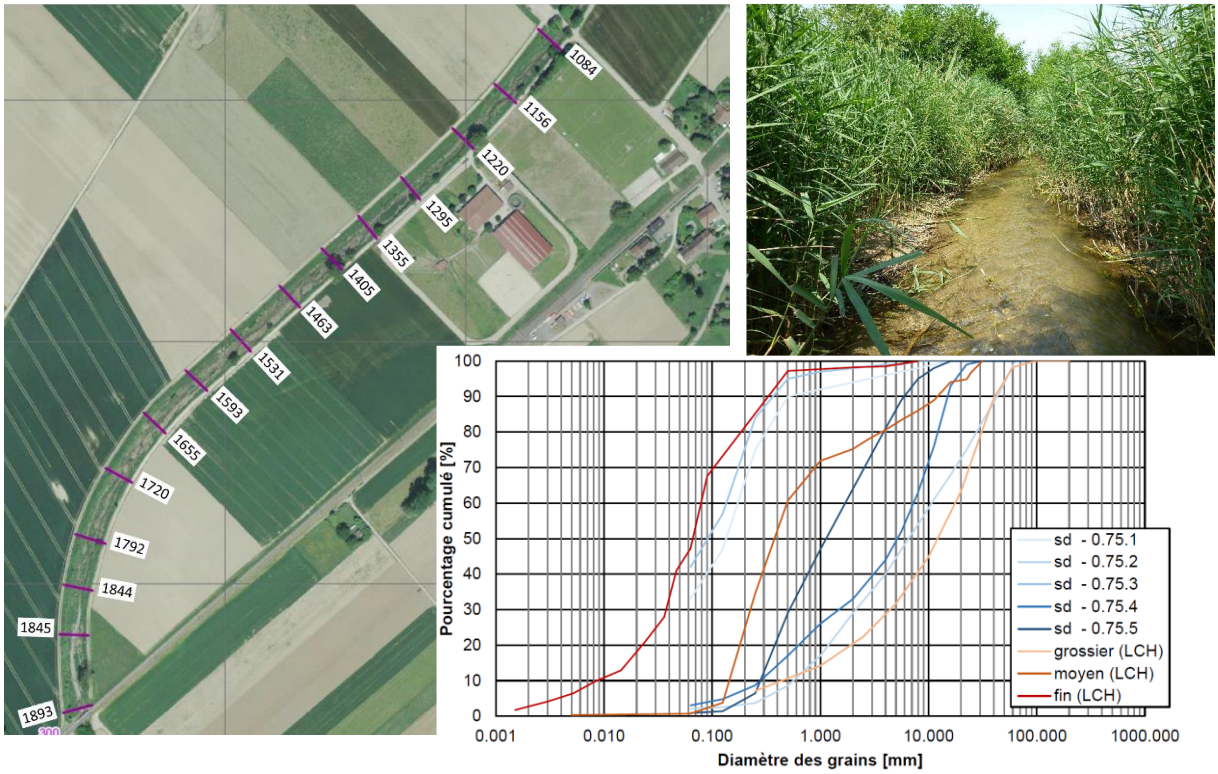

Figure 2 Aerial photo of the Arbogne River reach. Cross sections used for evaluation, photograph of the water course seen from upstream as well as the bed grain size distributions

2.3 Bed load and suspended sediment

The sediment transport calculations require to know the characteristics of the deposited materials. Several samples in the bed of the Arbogne River, as well as in the flood plain between the lateral levees were taken. Three different types of deposits were encountered, which can be described by a fine, medium and coarse grain size distribution, respectively (Figure 2). The finest grains are situated on the vegetated flood plain and the largest grains can be found in the main channel bed of the upstream "steeper" section. Within this context, the samples taken have as well been analyzed regarding pollutants. Fortunately, the sediment deposits do not present any and can therefore be evacuated and potentially used for agricultural dispersal in the surroundings.

2.4 Environment

It is found that the flood plain between the levees is disconnected from the low flow river section dynamics. By definition, it is mainly used during flood events and functions as powerful silt

deposit area. In the meanwhile, minor floods created a rather deep and narrow low flow river bed with great diversity of the main channel and flood plain morphology.

The disconnection of the flood plain terraces results in alluvial surfaces in generally dry conditions, and consequently biodiversity similar to fat hay meadow and related communities of reed canary-grass beds. Several field surveys were conducted during summer 2015 to map the vegetation and wildlife on site, especially with regard to birds and dragonflies. These field data were enriched by the national biodiversity database. It shows that the Arbogne River reach currently houses a remarkable biodiversity compared to the rest of the Broye plain with large surfaces of terrestrial reed beds getting denser while approaching the permanent water course.

The entire reach has a natural environment worth of protection according to Swiss Federal Act on the Protection of Nature. A conflict of interest between flood protection and nature preservation can be foreseen. The reed bed gets regularly flooded, and the fine sediments together with the plants create very strong, naturally reinforced deposits, that can be hardly eroded. Therefore regular new deposits reduce considerably the flow section.

3. Current situation and encountered deficits

In this chapter, the current situation regarding flood protection, sediment transport and eco-morphology is presented.

3.1 Flood protection

As presented in the previous chapter, the flood plain discharge capacity has been considerably reduced due to the filling up of the river cross section with fine material. Flood events occurred in 2012 and 2013 that exceeded the capacity of the river reach and lead to the flooding of the neighboring terrain.

The hydraulic capacity of the river reach is currently reduced to 14 m^3/s (slightly higher than a one-year return period) from the original design discharge of 21 m^3/s.

Figure 3 Flooding in 2013 along the project site

3.2 Sediment transport

The sediment transport capacity has been analyzed taking into account hydraulic data (energy grade line, velocity, cross section, etc.) using HEC-RAS, and Python program calculations with the formula proposed by Ackers & White (1973), Meyer-Peter & Müller (1948) as well as Recking (2013) on four characteristic cross sections. The calculations have been separated into main channel and flood plain, as well as overall transport capacity.

Theoretically, fine sediment can be eroded by any flood discharge, but due to the vegetation armoring, the deposits remain. To initiate bed load, at least a 1-year flood is needed for medium size grains (d_{50} ≈0.4 mm). For the mobilization of coarse grains (d_{50} ≈10 mm), a 4 times higher discharge is needed, however that will not occur due to the upstream flood diversion tunnel.

Between 2009 and 2015, in the critical section (section 700) and for a 1-year flood event, transport capacity has decreased by some 30%, which means that for the same upstream sediment supply, more material will deposit.

3.3 Ecomorphology

As described in §2.4, the ecology in the considered river reach is currently in a good state. The surroundings of the section of the Arbogne River involved in this project belong to the ecological network Belmont-Broye which was initiated in 2013. This network targets several endangered species such as stonechat (Saxicola rubicola), wryneck (Jynx torquilla), the corn

bunting (Emberiza calandra), the sand lizard (Lacerta agilis) and brown hare (Lepus europaeus).

The river morphology is rather poor, as no more major flood event can occur, that creates active river structures. As this did not happen in the past since the first river training works, no major morphological evolution of the river will occur.

4. Alternatives to solve the problem

Some 10 alternatives have been considered, from the alternative 0 "do nothing" to alternative 10 with strong river correction. A selection is shortly presented here below.

Alternative 0: "Do nothing" variant, let's keep people complain, and nature develop, and say why live in a dangerous area and by the way, flooding has always occurred.

Alternatives 1: Basically the same as #0, but that compensate for losses linked to flooding. It is a reference case for which a compensation cost estimate will have to be performed. A weakness of this approach is who will pay compensation and on the long term how a compensation fund can be created (Figure 4).

Alternatives 2 to 7: These alternatives all try to manage and control flooding. First points are to define where the overflow from the rivers course should take place by lowering the levee, then designate areas to flood, delimited them, assure the return flow to the river or deviate water to a neighboring drainage canal that has to be adapted (Figure 5). Some of this set of alternatives foresee raising the downstream bridge and adding an apron to reduce backwater curve.

Alternative 8 to 10: Assure flood and sediment transit by straightening the river course, heightening the levees, raise the downstream bridge and adding an apron to reduce backwater curve that favor sediment deposits.

The alternatives have been predesigned and a cost estimate was made. The following chapter analyses the different alternatives with a multi-criteria approach.

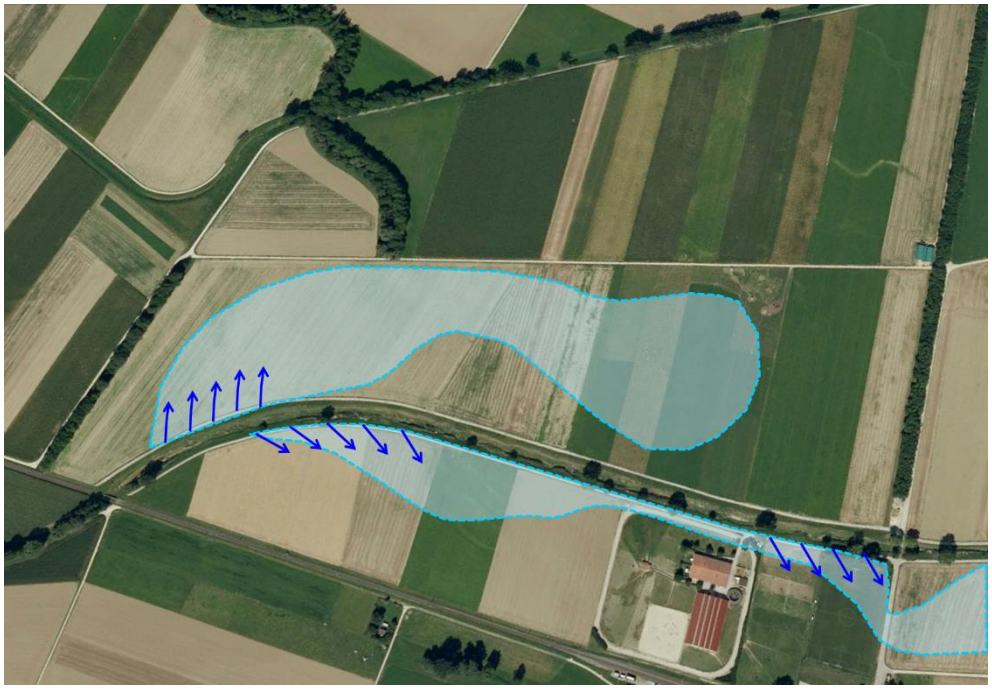

Figure 4 Alternative 0 and 1 "Do nothing" and in case financing is available, compensate for the occurred losses.

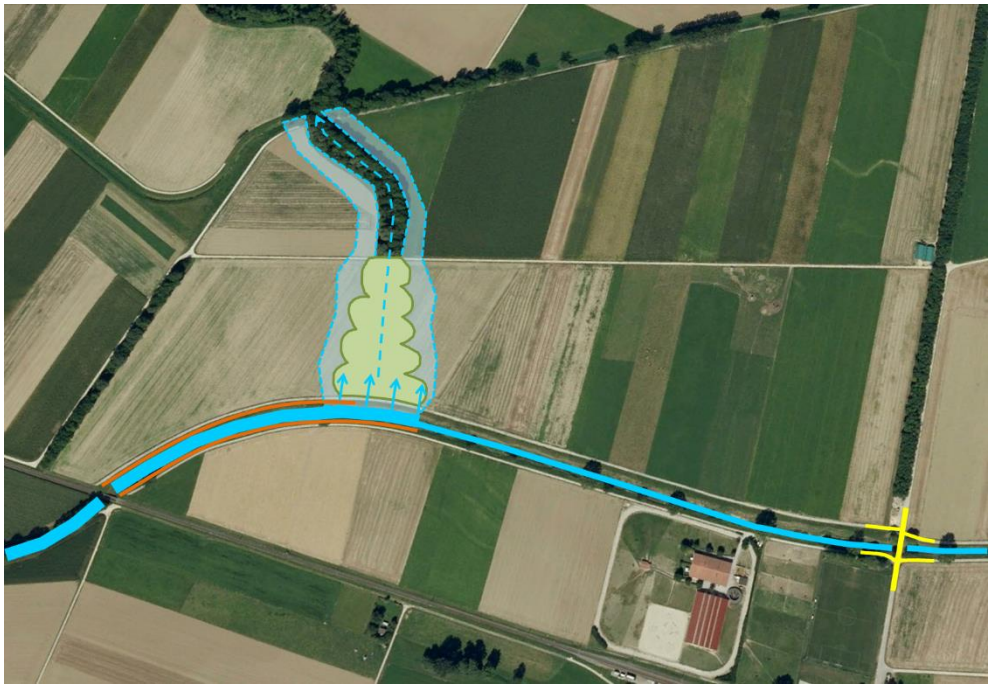

Figure 5 Alternative 5 Ecological corridor for controlled and deviation to a neighboring drainage canal to be adapted.

5. Multi-criteria analysis of the alternatives

The analysis is based on the alternative's capacities to improve or to worsen the situation compared to the current conditions. The following criteria classes are applied, each one having between 3 to 5 sub-criteria:

1. Hydraulic and sediment transport
2. Uncertainty and risk
3. Environmental impact
4. Impact on agriculture
5. Cost

After a first round, and in order to have well defined criteria, point 2 uncertainty and risk as well as point 4 impact on agriculture were put as sub-criteria into the remaining three evaluation criteria.

The criteria are all equally weighted, the points per criteria ranges from worsening -2 (- -), to neutral (0) to very favorable 2 (+ +). Table 2 summarizes the result of the analysis.

Table 2 Multi-criteria analysis of the four main alternatives.

Alternative and short description		Hydr.	Environ	Cost	Global
0	do nothing	-1.8	-0.1	0	-1.9
4	derivation "limited land use"	0.8	-0.1	-0.3	0.3
5	derivation "ecological corridor "	0.8	0.6	-0.3	1.0
8	flood and sediment transit	0.4	-0.7	-0.7	-1.0

The deviation alternative using an ecological corridor linking the Arbogne River to the nearby Sésines drainage canal in case of flooding obtained the best score. All solutions have been presented to the authorities and the decision has not yet been taken.

The detailed technical feasibility of the best alternative 5 has yet to be confirmed by assessing the hydraulic capacity of the nearby Sésines drainage canal, a detailed DEM of the used land for the derivation is under way in order to evaluate the necessary terrain movement, as well as the lateral overfall structure on the Arbogne levee.

6. Conclusions

The overall problem regarding flood protection of the investigated Arbogne River Reach is complex and recurrent. The situation before the river training works terminated in 2009 was already prone to regular flooding. The former intervention was part of an environmental compensation measure, which has solved temporarily the problem. However, the strong vegetation development with reduction of flood discharge and sediment transport capacity in a vicious circle compromised the situation. With regard to flood protection the hydraulic conditions resemble the situation from before the river training works. The general public thinks that the money for the training works was improperly invested as flooding still occurs and even intensified. However, the ecological value of the river section improved significantly after the river training works.

Various alternatives to solve the problem of insufficient flood protection have been established. The multi-criteria analysis showed the manifest lack of sediment transport and discharge capacity in case of floods. In general, the useful life of river training works can be increased by vegetation control measures as well as river cross section conservation on a regular basis. Even if the sediment transport calculation involves uncertainties, it relates clearly the considerable reduction of sediment transport capacity by the continuous obstruction of the flood plain by sediment and vegetation, while the upstream sediment supply remains more or less constant. Nevertheless the project team proposes a long term solution, addressing hydraulics and sediment transport aspects, without negative effects on the currently good ecological state of the river section.

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