La Houille Blanche, n° 4, 2015, p. 21-28 DOI 10.1051/lhb/20150041

The Kembs project: environmental integration of a large existing hydropower scheme

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ABSTRACT. – The environment was a major issue for the Kembs relicensing process on the upper Rhin River. Since 1932, Kembs dam derives water from the Rhine River to the "Grand Canal d'Alsace" (GCA) which is equipped with four hydropower plants (max. diverted flow: 1400 m^3/s, 630 MW, 3760 GWh/y). The Old Rhine River downstream of the dam is 50 km long and has been strongly affected by works (dikes) since the 19th century for flood protection and navigation, and then by the construction of the dam. Successive engineering works induced morphological simplification and stabilization of the channel pattern from a formerly braided form to a single incised channel, generating ecological alterations. As the Kembs hydroelectric scheme concerns three countries (France, Germany and Switzerland) with various regulations and views on how to manage with environment, EDF undertook an integrated environmental approach instead of a strict "impact/mitigation" balance that took 10 years to develop. Therefore, the project simultaneously acts on complementary compartments of the aquatic, riparian and terrestrial environment, to benefit from the synergies that exist between them ; a new powerplant (8,5 MW, 28 GWh/y) is built to limit the energetic losses and to ensure various functions thereby increasing the overall environmental gain.

Key-words: EDF, Kembs, Old Rhine, environmental performance, integrated approach.

Le Projet Kembs : programme intégré pour l'amélioration de la performance environnementale d'une grande centrale hydroélectrique existante

RÉSUMÉ. – Le projet Kembs : programme intégré pour l'amélioration de la performance environnementale d'une grande centrale hydroélectrique existante.
L'environnement a été une question centrale du processus de renouvellement de la concession de l'aménagement hydroélectrique de Kembs sur le Rhin. Le barrage, situé au niveau des frontières suisse, allemande et française, dérive les eaux du Rhin dans le Grand Canal d'Alsace (GCA) d'environ 50 km de long. Celui-ci est équipé de 4 centrales successives (débit maximum 1400 m^3/s, 630 MW, 3760 GWh/y). Le Vieux Rhin en aval du barrage de Kembs, a été fortement affecté depuis le milieu du 19^e siècle par des grands travaux d'endiguement puis de rectification, destinés à la protection contre les crues et à favoriser la navigation. A partir des années 1930, l'aménagement hydroélectrique a entraîné la réduction du débit dans le Rhin. Ces travaux successifs ont provoqué la simplification morphologique du Rhin, transformant un lit en tresses en un chenal unique très incisé et au lit pavé. On a observé en parallèle de fortes modifications écologiques avec une réduction drastique des milieux typiques de la bande alluviale rhénane. Le projet Kembs concernant 3 pays aux réglementations et approches environnementales différentes, EDF a entrepris des réflexions sur près de 10 ans pour définir un projet intégré d'amélioration de l'environnement en lieu et place d'une stricte approche « impact/compensation » de l'hydroélectricité.
Les diagnostics écologiques et l'identification des facteurs environnementaux limitant la biodiversité rhénane ont conduit à proposer un programme d'actions sur l'ensemble des compartiments aquatiques, rivulaires et terrestres, afin de bénéficier des synergies entre eux et accroître le gain environnemental. Ainsi, le débit réservé a été augmenté significativement et surtout a été modulé saisonnièrement, en intégrant une composante journalière de variabilité, fonction du débit naturel arrivant au barrage. Cette composante hydraulique n'étant pas suffisante seule pour améliorer les biocénoses aquatiques, il y a été adjoint une projet de diversification de la morphologie et des substrats via deux modalités : (i) l'érosion maitrisée de certaines berges du Vieux Rhin, via le déroctage des digues et la reconfiguration des épis et (ii) l'injection de matériaux alluvionnaires intéressants pour la faune aquatique issus des travaux d'excavation réalisés pour la construction d'une nouvelle centrale de turbinage du débit réservé. Ces actions permettent aux crues d'éroder les alluvions anciennes et de recréer des formes alluviales dans le lit du Vieux Rhin. En parallèle, l'amélioration des connexions biologiques se fait via l'aménagement de différentes passes à poissons ou à mammifères aquatiques, mais surtout par la re-création d'une rivière (7 m^3/s, 8 km de long) utilisant un bras fossile du Rhin et permettant de reconnecter le Vieux Rhin à l'amont du barrage de Kembs, tout en offrant une diversité de milieux favorables à l'ensemble des biocénoses aquatiques. Ce « bras » traverse un ancien champ utilisé depuis une quarantaine d'années pour l'agriculture intensive, au sein de la Réserve Naturelle de la Petite Camargue Alsacienne. Cette nouvelle rivière a permis ainsi d'envisager la renaturation de l'ensemble de cet espace (100 ha) en recréant une mosaïque d'habitats humides et secs, prairiaux ou forestiers, favorables à l'accueil de flore et faune typiquement rhénanes. Une nouvelle centrale de turbinage du débit réservé a été conçue pour permettre d'assurer les différentes fonctions nécessaires à ces objectifs environnementaux : cette centrale (8,5 MW, 28 GWh/an) permet non seulement de réduire les pertes énergétiques liées à l'augmentation du débit réservé, mais elle permet aussi d'assurer la modulation journalière fine du débit et d'alimenter le bras renaturé, ainsi que

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différents organes de montaison et dévalaison piscicoles. Les travaux permettent également d'injecter des graviers dans le Vieux Rhin dès l'aval du barrage de Kembs dans un secteur où l'érosion des berges n'était pas envisageable. Ce projet de grande envergure démontre la capacité de l'aménagement hydroélectrique de Kembs à produire dans la durée une électricité à haute performance environnementale.

Mots-clés : EDF, Kembs, Vieux Rhin, performance environnementale, approche intégrée.

I. INTRODUCTION

Located on the upper Rhine River, near the Swiss-German-French borders, the Kembs dam allows derivation of waters for hydropower generation to the 'Grand Canal d'Alsace' (GCA) (Figure 1). The GCA is equipped with four hydropower plants that were built between 1932 and 1954 (Kembs, Ottmarsheim, Fessenheim and Vogelgrun – 630 MW, 3760 GWh/y). The maximal diverted flow is 1400 m^3/s. The mean interannual flow of the Rhine at Kembs is about 1070 m^3/s.

The Old Rhine River downstream of Kembs dam is 50 km long and has been strongly affected by engineering works since the mid 19th century: embankment works (Tulla's dikes) aimed to protect against floods and to allow navigation. Then, damming for hydropower generation (from about 1930's) diverted a main part of the flow in a canalized section, whereas the Old Rhine (bypassed section) received a minimal flow.

Between Kembs and Breisach, engineering works induced morphological simplification and stabilization of the channel pattern from a formally braided form to a single incised channel, with a bottom armoured layer and generating important ecological modifications (Piégay *et al.*, 2010). The incision (estimated about 7 m during 120 years) induced the transformation of the typical alluvial forest into dry terrestrial environment ; the channelization and reduction of flow deeply modified the aquatic ecosystem.

Therefore, environmental issues were of major importance for the Kembs hydropower plant relicensing process in the 2000's. As the Kembs scheme concerns three countries with different national regulatory frameworks and different views on how to address environmental aspects, EDF undertook a 10 years long process (lasting until 2010), to design an integrated environmental project as opposed to a strict 'impact/mitigation' balance. This broad approach addresses environmental issues in a comprehensive and global way rather than separately focusing on the mitigation of each single impact.

II. OVERALL PRESENTATION OF THE PROJECT

Based on existing ecological diagnostics and identification of the factors which limit the typical Rhenan biodiversity and ecological functions, EDF proposed to act simultaneously on complementary compartments of the aquatic, riparian and terrestrial environment in order to benefit from the

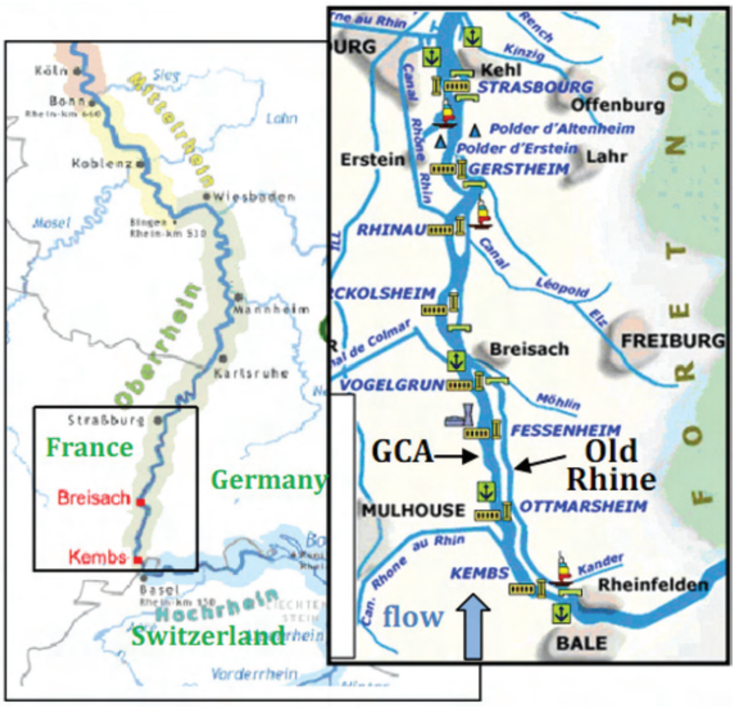

Figure 1: *Location of Old Rhine River between Kembs and Breisach dams. Rhine is flowing Northward.*

DOI 10.1051/lhb/20150041

synergies that exist between them and thus to increase the environmental gain. The main measures concern:

• the ecological flow released downstream Kembs dam (A on Fig 2): the minimum flow is increased and it varies seasonnaly to adapt to ecological needs (fish populations, riparian and aquatic flora, birds, insects…).

• the diversification of alluvial forms and alluvial dynamics, which when combined with ecological flow measures allows for the restoration of typical aquatic ecosystems. The measures undertaken include an innovative and technically ambitious morphodynamic restoration program through gravel injections (C on Fig 2) and controlled (left) bank erosion (B on Fig 2). This innovative concept aims at using the natural erosion capacity of floods to supply the Old Rhine River with aggregates, after local dismantling of Tulla's dikes. The recovery of a non-fixed gravel bed will (in conjunction with the variable flow) enable fish spawning and growth, and the establishment of pioneer vegetation.

• actions to restore biological connections (D and E on Fig. 2), including: (i) an aquatic mammal pass (across Kembs dam) on the German side; (ii) installation of a fish ladder on the French side; (iii) an artificial river connects the GCA to a network of ponds and small waterways in the 'Petite Camargue Alsacienne' (PCA) protected area close to the Kembs hydropower plant; (iv) re-creation of a naturalized new channel in a former bed of the Rhine, connecting the upstream Rhine and the Old Rhine, thereby creating a new passage route and new habitats for fauna.

• the recovery of wetlands in an area which was previously included in the minor bed of the Rhine (F on Fig 2) and which has been used for intensive agricultural for the last forty years,

• the limitation of energetic losses (G on Fig 2): a new hydropower plant (Kembs power plant B) is built to turbine the ecological flow, allowing daily variability and the supply of water for the fish pass and the naturalized new channel.

III. MAXIMIZE THE EFFICIENCY OF THE ECOLOGICAL FLOW BY RESTORING ALLUVIAL DYNAMICS

The environmental impact assessment (EIA) (EDF, 2006) showed that the ecological quality and biodiversity of the Old Rhine were suboptimal, due to a minimum flow that was too low, a lack of solid transport and a channel too narrow to ensure a good functioning of alluvial forest and riparian habitats (hydraulic constraints too high during floods). So it was necessary to define the minimum ecological flow in accordance with a restoration of the alluvial dynamics and a widening of the bed: increasing the minimum flow in a incised and armoured bed wouldn't have been efficient for fish or aquatic biocenoses, because no new suitable habitats would have been created.

III.1. Ecological flow

The minimum flow was defined following a multidisciplinary approach : an hydraulic model was elaborated for the entire Old Rhine to understand how physical parameters (flow velocity, water depth and substrate) varied with flow; then the fish habitat model CASiMiR was used (Schneider *et al.*, 2001) to determine the flow creating optimal fish habitat availability. Model tests showed that the minimum

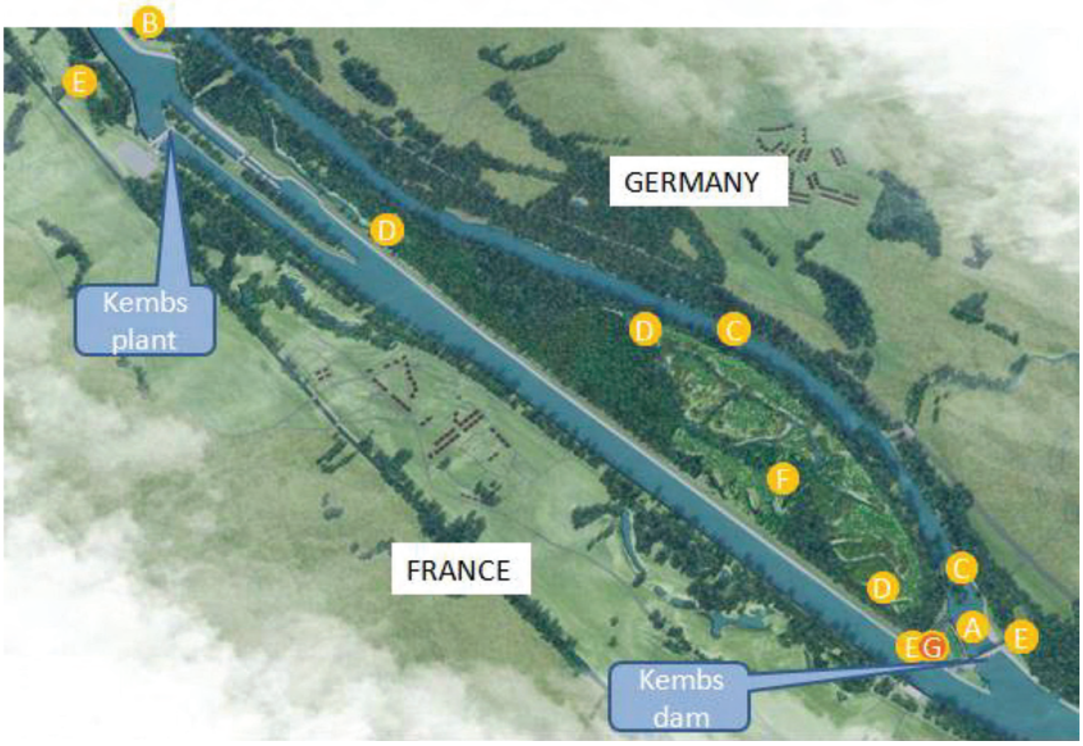

Figure 2: *Location of the main environmental measures : ecological flow (A), "controlled erosion" (B, and other locations further north), injection of gravels (C), fish and aquatic mammals connection (E), recovery of wetlands (F) and new hydropower plant (G). (Artist view).*

flow had to vary seasonnaly according to the preferenda of the different fish species and that a new supply of gravel would greatly increase habitat availibilty for spawning and young fish. The gain of aquatic habitat with increasing flow comes with a cost of reduced terrestrial habitat. Therefore, the minimum flow had to be a compromise between different objectives (Figure 3) for fish, vegetation, birds, insects, etc. For each period of the year, minimal et maximal values of flow were determined according to the environmental objectives and biological needs. To avoid risks for fauna, the flow had to vary progressively. Therefore, a daily hydraulic component was added, with:

$$Q_D = F \cdot (Q_{upstream} - Q_B)$$

where : Q_D = daily hydraulic component [m³/s]
F = factor (0 < F < 1) [-]
$Q_{upstream}$ = Flow entering Kembs dam [m³/s]
Q_B = entering flow from which the daily component is applied [m³/s]

The objectives are to generate progressive little floods, to limit rapid variations of flow for average floods, and to allow a certain progressivity of the flow when great floods occur. Values of these parameters are determined empirically according to the period of the year between April and October.

III.2. Alluvial dynamics restoration

III.2.1. Controlled bank erosion

As mentioned previously, the lack of solid transport limits aquatic and riparian habitat availibility, of the flow. EDF proposed an innovative concept of 'controlled bank erosion': as almost no sediment material can be supplied naturally from upstream, sediment supply must be obtained from riparian areas. The bank is therefore weakened (removal of riprap protection and/or groynes rearrangement) and the floods are allowed to erode the bank and transport former Rhine gravel sediment that compose the embankment back to the river and generate new morphological patterns favorable for habitats. A multi-criteria screening and prioritization analysis of bank sites favorable for such controlled erosion was conducted considering expected environmental net gain (new wetlands *vs* loss of terrestrial land), hydraulic conditions, safety of adjacent existing structures (bridges, GCA), bed load transport capacity of the river, etc.(Aelbrecht *et al.*, 2014).

This concept was tested on a scaled physical model by EDF LNHE, to optimize the different modes of bank erosion initiation depending on the local geometry of the bank (El Kadi *et al.*, 2013). Using the physical model, it was possible to verify that erosion stops naturally (self stabilization of the process). Then, a *in situ* test was conducted in 2013 on a pilot site: engineering work occurred in april-may and were immediately followed by a Q10/Q15 statistical flood approximately (Figure 4). In September, the first results of the fish survey showed that presence of juveniles of some fish species were 3 to 4 times greater in the newly eroded zone than in non-eroded zones. Furthermore, fish species diversity or richness was 2 times greater.

III.2.2. Input of gravels

Although the upstream part of the Old Rhine is favorable to controlled bank erosion from an hydraulic point of view, it is not the case from an ecological point of view: the left bank presents a relatively high diversity of riparian habitat with the presence of protected insects, batracians and birds species. In this case, the ecological balance is not positive (no net environmental gain expected). Therefore, EDF decided to supply gravels in this upstream part of the Old Rhine, by artificial sediments input from excavation works for the new hydropower plant (see below). The technical work will benefit from the experience gained from a similar and successfull test realized by the Interreg project en 2010 (Interreg, 2012).

The injection of former alluvions will take place at two sites within 3 km downstream of Kembs dam; about 65 000 m³ of materials will be placed in the river as shown in Figure 5. The Interreg test showed that the bar (20 000 m³, 600 m long) was destroyed by a ≈Q2 flood, confirming the first estimation of the bed load capacity transport of the Old Rhine (Béal *et al.*, 2012). The test also showed that materials were redistributed to the whole bed, with a granulometric arrangement increasing the potential of colonization by riparian vegetation and spawning for fish.

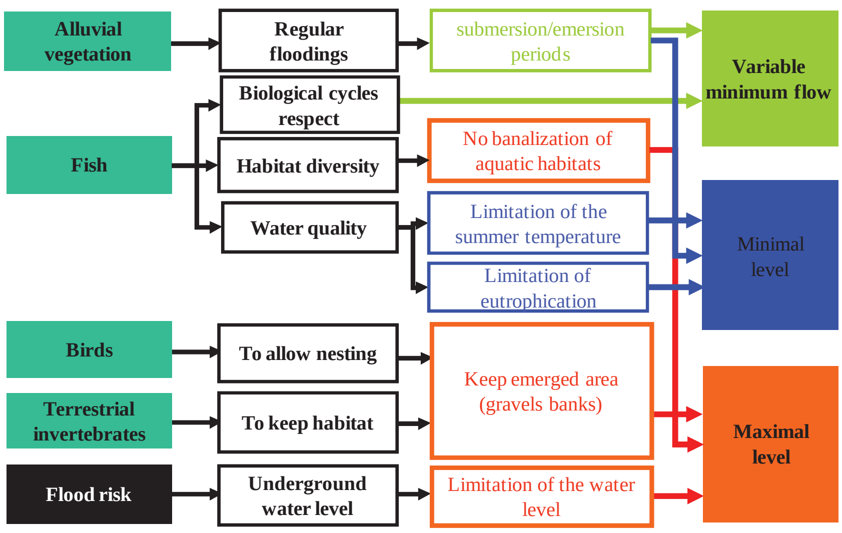

Figure 3: *Main environmental constraints to define the ecological flow (after EDF, 2006).*

DOI 10.1051/lhb/20150041

Figure 4: *Upstream part of the pilot site of controlled erosion before (left), during (middle) and after (right) the flood.*

IV. MAXIMIZE THE EFFICIENCY OF HABITAT GAINS BY RESTORING BIOLOGICAL CONNECTIONS …

Several measures concern the restoration of biological connections. A new aquatic connection has been realized between the GCA and a network of ponds and small waterways located in the 'Petite Camargue Alsacienne' protected area. This new connection (≈270 m long, 1 to 3 m^3/s) has various morphological facies creating new habitats for fauna (Figure 6). A pass is also planned at the right side of Kembs dam, which will be adapted for beavers and others aquatic mammals, as well as for batracians and reptiles. To be attractive, this aquatic pass will be vegetalized with different local species which are well-liked by beavers. The pass will use the drainage canal parallel to the Old Rhine and will permit fauna to go upstream or downstram the dam.

Another 'natural' measure concerns the creation of a 'river' (7 m^3/s, 8 km long) between the new hydropower plant located at the Kembs dam, and the Old Rhine close to the Kembs plant. This river will go through a former bed of the Rhine that is still visible in a large field, which has been used for agriculture for the last forty years, and in the forest further north (Figure 7).

Using existing thalwegs reduces levelling works (about 340 000 m^3 of sediments are displaced in the field), especially in the forest area where the ecological issues are of great interest. To minimize the impact in the forest, the width of the channel is reduced along with the flow, which is reduced to about 2 m^3/s. The remaining 5 m^3/s returns to the Old Rhine at the northeast of the field (upstream the forest), allowing fish to migrate (Figure 8). As the Old Rhine is about 7m lower than the field, the connection consists of a a series of rapids, similar to a natural fish pass. With its riparian and adjacent wet habitats, this new river was designed to offer various habitats and morphological diversity, for typical rhenan rheophilic fish, including salmonids. This river will be especially favorable to salmonid spawning and growth, as it is an important objective for the Rhine.

Figure 5: *experimental input of sediment excavated from the right bank of the Old Rhine (Interreg project, 2009-2012) (source : Region Alsace).*

The junction of the river and the GCA is done through the new hydropower plant and the new associated fish ladder that links the outside channel of the plant to the GCA (difference of level is about 12 m) (see below).

V. … AND BY RECREATING MOIST ENVIRONMENTS IN THE FORMER MINOR BED OF THE RHINE

EDF chose to maximize the expected environmental gain resulting from the new river by re-creating a mosaic of moist environments of ecological interest, in an agricultural field. The surface was large enough (1 km^2) to plan complementary mosaics of wet / dry, prairial / forest environments. This ambitious project required multi-disciplinary expertises (geomorphology, bioengineering, applied ecology) and much concertation with partners, such as 'Petite Camargue Alsacienne', local naturalist associations and scientists (Lachat *et al.*, 2012). The restoration of various habitats aims to allow the return of typical alluvial species of invertebrates, macrophytes, helophytes, batracians, birds and mammals. The chances of success are increased by the fact that the field is included in the PCA protected area (possible incremental colonization) and that it is located in the former minor bed of the Rhine (favorable substrate, presence of underground water…). The mosaic of recreated habitats will be distributed as shown in Figure 9.

To vegetalize the whole area, a vast program of seed collection and cultivation of local vegetal species have been undertaken over the two last years: willow branches and several m^3 of seeds have been recolted in the PCA and around 5000 helophytes plants and 90 000 young plants were cultivated by local nurseries. Levelling works are in hand (winter 2014); as the risk of colonization by invasives plants was important, the surface layer of soils is removed (and placed under other soil layers). Plantation in the field is planned in spring 2014 and the supply of the river and hydraulic annexes will take place in summer. Afterwards, a 3 year survey of the plantation will be undertaken.

DOI 10.1051/lhb/20150041 La Houille Blanche, n° 4, 2015, p. 21-28

Figure 6: *Artificial river connecting the GCA and small waterways in the PCA (left); drainage canal on the right bank which will be used by fauna to pass Kembs dam (right).*

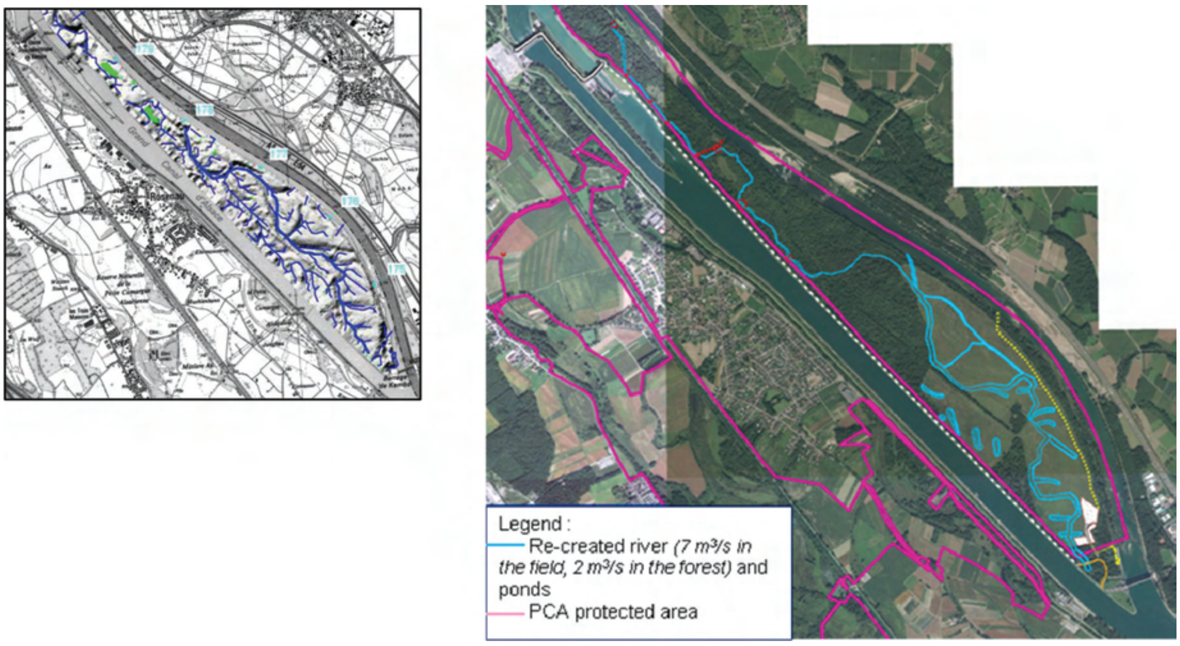

Figure 7: *The recreated river (right) runs through former beds of the Rhine (see topography on left image) and connects the Old Rhine and the GCA close to Kembs dam.*

Figure 8: *connection between the recreated river and the Old Rhine where the flow will be 5 m^3/s (left) and levelling works in the field: see the separation in 2 arms of the future river. Work is in hand (mars 2014).*

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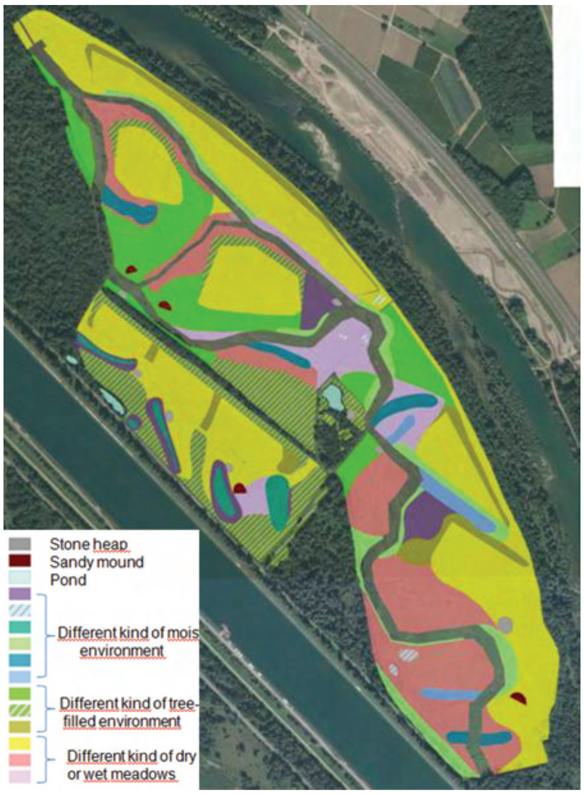

Figure 9: *Distribution of the various recreated environments in the field (1 km^2). Work is in hand (March 2014).*

VI. NEED OF A NEW HYDROPOWER PLANT TO ENSURE THE ECOLOGICAL FLOW, SUPPLY WATER TO THE NEW CHANNELS AND LIMIT ENERGETIC LOSSES

The increase of the ecological flow creates a great energetic loss, through four plants along the Grand Canal d'Alsace. In addition, the large gates of Kembs dam cannot manage the daily variation of this flow (the precision of adjustement is not compatible with the values of daily variations). So EDF decided to build a new hydropower plant in order to be able to:

- reduce the energetic loss (nevertheless, only 20% of initial loss is recovered)
- be able to manage small daily variations of ecological flow,
- feed out of water the recreated river.

The edification of this new plant gives the opportunity to create new fish passes that will allow fishes to

- go upstream from old Rhine to Swiss Rhine
- go upstream from the recreated river to Swiss Rhine
- go downstream from Swiss Rhine to the recreated river.

Each offered path to the fishes will be monitored.

Thus, this new power plant is not only a production unit, but also an environmental device.

The following figure shows the complexity of the design, including separated paths for fishes according to their origin and the alimentation of the recreated river.

The main figures of the power plant project are:

- maximum flow: 90 m^3/s
- capacity: 8,6 MW, yearly production about 28 GWh
- two Kaplan turbines.

VII. CONCLUSION

EDF wished to get out of the strict environmental legislation to place its measures in the global context of rhenan ecosystems restoration. This approach had two mains issues :

- to define measures that are consistent with the objectives and actions of other rhenan environmental stakeholders;
- to establish sustainable partnerships with stakeholders who have the same vision of the sustainable development of the rhenan area.

This "integrated project" aims to recover more typical alluvial rhenan habitats, biodiversity and functions. Systematic long-terme environmental monitoring is planned to verify the

Figure 10: *3D view of the new hydropower plant B with the fish pass and the upstream part of the new river, wich is supplied in water through the fish pass and the plant.*

achievement of these objectives. It is however evident that the projet has already drastically enhanced the environmental quality of the scheme; despite the energetic losses due to the increased ecological flow (partially recovered by the new plant), it perpetuates the legitimacy of the Kembs powerplant to sustainably produce a green energy over time.

This project is certainly the greatest in Europe, as regards of the great surface interested, the flow in the recreated river (many of natural rivers in Alsace don't have such an available natural flow).

Though we decided in this paper to develop the environmental performance of this project, technical issue was not forgotten. Since three years, a lot of technical steps are managed, as turbine refurbishments, dam gates refurbishment, lock gate replacement, and so on. Performance in Kembs power plants means both technical and environmental performance.

VIII. ACKNOWLEDGEMENTS

We would like to acknowledge Biotec and Ecotec companies (CH) who helped EDF to design the environmental Kembs project. Biotec helped design the agricultural area restoration project and realization; Ecotec helped define ecological flows and the morphodynamic restoration program.

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