HyMoCARES Project
WPT3. EFFECTS OF HYDROMORPHOLOGICAL MANAGEMENT AND RESTORATION MEASURES
D.T3.3.1 Technical note on the evaluation of physical and ecological effects of river restoration works

Case study: Wertach and Lech River, Germany

Project: HyMoCARES
Work package: WPT3. Effects of hydromorphological management and restoration measures
Activity: A.T3.2-3.Evaluating physical and ecological effects of management/restoration works
Deliverable: D.T3.3.1. Technical notes on the evaluation of physical and ecological effects of river restoration works
Status: 1st draft
Date: 28-11-2018
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Revision: All the PPs
Approval: PP10 Irstea

This project is co-financed by the European Regional Development Fund through the Interreg Alpine Space programme

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CONTENTS

1 Introduction

Both study site rivers *Wertach* River and *Lech* River are originating in the northern Alps near the border between Austria and Germany, and runs in roughly North direction through Bavaria towards the Danube River. Thereby, the Wertach River represents a tributary of the Lech River, and joins it in the city center of Augsburg (Fig. 1).

Figure 1: Location of the two study rivers in Germany. In orange, the Wertach River, in red the Lech River. (Graphics: M. Carolli, IGB).

Both rivers originally have been typical pre-Alpine rivers with high sediment load. The seasonal discharge regime is shaped by snow melt in spring. This snowmelt regime may be superimposed by sudden floods which may appear after heavy rains (orographic lift rains) occurring with northerly winds at the northern rim of the Alps.

In both rivers, restoration projects have been conducted in some reaches, which are partially continuing up to date. Part of these two restoration projects 'Licca liber' and 'Wertach Vital' serve as case studies within the HyMoCARES project (Table 1).

Table 1. Basic information on the study reaches

River	*Lech*	*Wertach*
Drainage area (km²)*	2350	1441
Location of pilot reaches	From dam '23' until the river joins the Danube River	From dam 'Inningen' until the river joins the Lech River
Length of the study reach (km)	30	14
Active channel width (m)	65	35
Channel slope (m/m)	5,48m/1000m	4,05m/1000m
Planform channel morphology	wandering confined pattern naturally: braided	single-thread pattern, with local wandering confined style naturally: transition braided-meandering
Name of restoration project and internet sites	Licca liber	Wertach Vital
Internet sites Wikis **Restoration website**	https://de.wikipedia.org/wiki/Lech www.augsburgwiki.de/index.php/ AugsburgWiki/Lech www.wwa-don.bayern.de/ fluesse_seen/massnahmen/ liccaliber/index.htm	https://de.wikipedia.org/wiki/Wertach www.augsburgwiki.de/index.php/ AugsburgWiki/WertachVital www.wwa-don.bayern.de/ hochwasser/hochwasserschutzprojekte/ wertachvital/

Both rivers have historically been used for extensive fishing, timber rafting and water mills since medieval times. In the 20th century they have been straightened for flood protection reasons, with subsequent construction of a series of dams and reservoirs (Fig. 2). For the Lech River, even a huge lake reservoir ("Forggensee") has been built in the area where the river leaves the Alps. The lake is operating as a seasonal water reservoir (high water levels in summer, nearly empty in late winter) in order to feed more smoothly the 31 hydropower plants constructed along the downstream course of the Lech river from 1903 until recently.

The Wertach River is the so called little sister of the Lech River and has experienced similar alterations. Here also the river has lost length and width and the channel slope has increased.

However, the many weirs built to stabilize the shortened river channel are not used for hydropower generation.

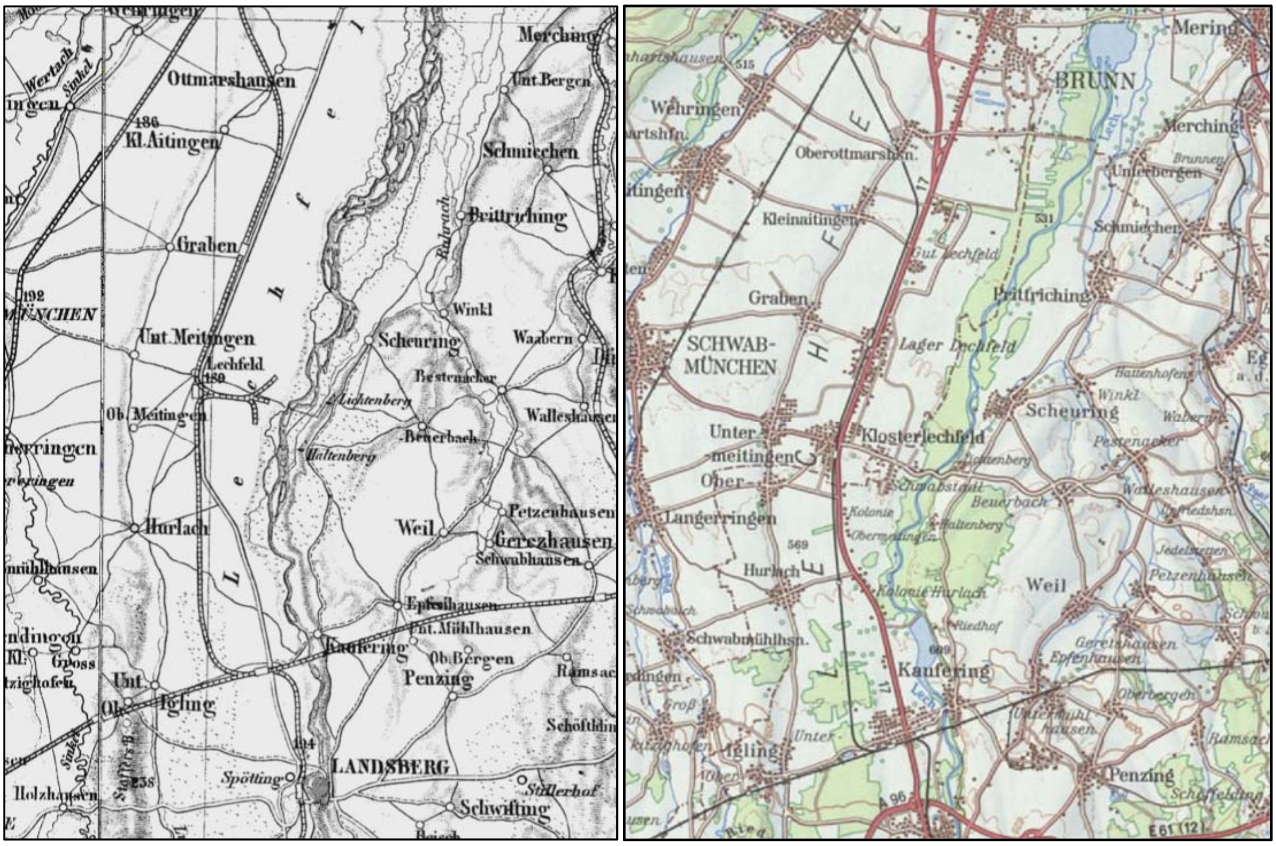

Figure 2: Morphological evolution of the Lech River from 1884 (left) to1984 (right) (source: Geoportal Bayern https://geoportal.bayern.de/)

When rivers were historically channelized, the longitudinal slope of the channel increased, and the width decreased, which resulted in higher flow velocity. Also, the input of new sediment into the river was decreased by artificial bank stabilization, and by the construction of dams in the mainstream river as well as in tributary streams. As a result, both rivers incised their river bed for several decades, and thus lowered their river beds by several meters. Nowadays incision represents the major management problem at both the Lech River and Wertach River, as sediment load that is fully retained in reservoirs. Huge efforts and expenses have been made to artificially stabilize the banks of the incised river channels. As an unwanted effect of river channelization, the water retention capability of the river channel was lost, so that the flood risk has risen again. Floods with huge damages of several hundred millions Euros have occurred. In addition, the ecological integrity of river habitat and of the former river floodplains has been greatly affected by channel incision.

Fragmentation of the river by hydropower dams, and hydropeaking operation of hydropower plants has resulted in a severe reduction of fish density and diversity. Especially, formerly typical, abundant and economically valuable fish species as Huchen (Danube salmon, *Hucho hucho*) and Grayling (*Thymallus thymallus*) have mostly disappeared. Therefore, for both rivers multi-targeted restoration projects have been initiated by the water authorities called “Wertach Vital” and “Licca liber”. Both projects aim to mitigate channel incision, to improve the ecological status of both rivers, and to improve the access to the river for recreational activities. Both projects accompanied by extensive communication actions with local residents and stakeholders, including the collection of opinions by questionnaires.

2 Monitoring approach

The monitoring approach selected for both Lech River and Wertach River is a Before-After protocol. For the Wertach River, the restoration project is still on-going.

2.1 Physical monitoring

2.1.1 Lech River case study

At the Lech river case study an oxbow was newly built (Figure 3, Figure 4 and Figure 5), because of the large structural deficits natural recruitment of rheophilic fish was not very likely.

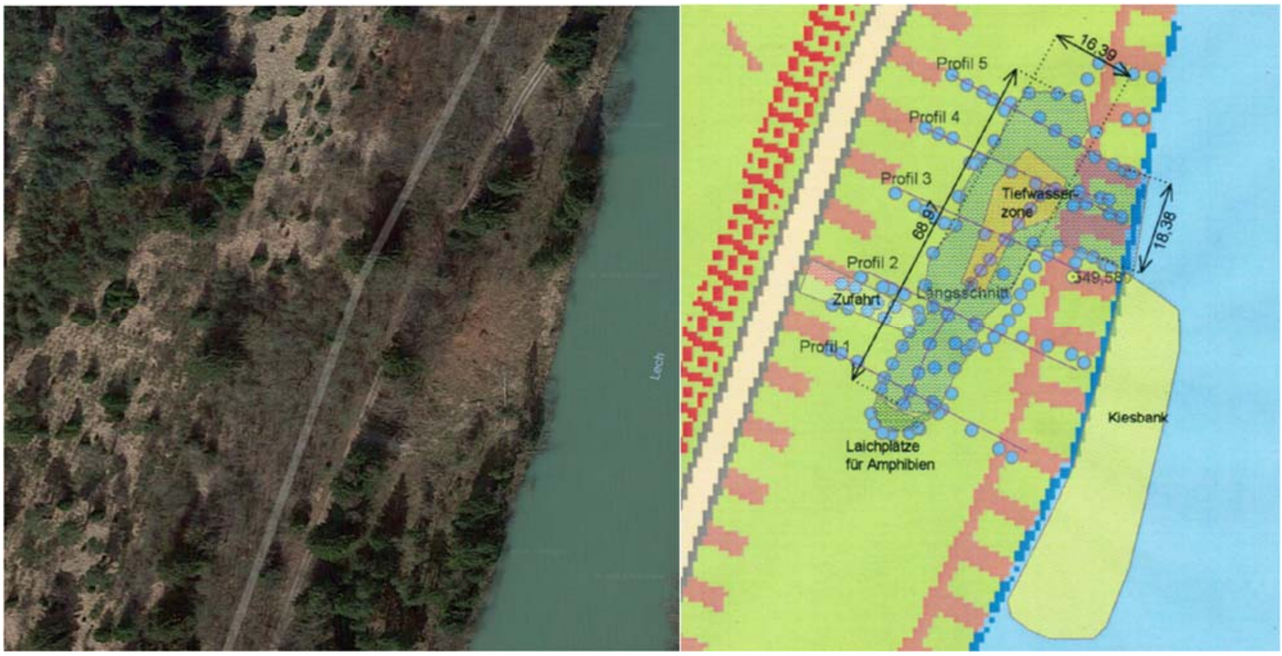

Figure 3 Aerial picture and project planimetry of the oxbow reactivation.

Figure 4 Pictures of the oxbow.

Figure 5 Oxbow view from the bank after the end of the project.

To monitor the changes in structure and depth before and after the measure, an echobathymetrical monitoring (Figure 6) with an echo sounder was used to collect hydraulic variables. This technique allowed to map water depths and substrate data at the reach scale. Echo sounding allows to detect depth changes and movement of gravel bars beneath the surface without time consuming cross-section measurements. In addition, the data recorded is coupled with GPS data and thus combined can be transferred into a very high resolution depth chart or depth model (Figure 10) of the river section. These data can be taken to monitor sediment transport off the gravel bars and help to maintain, as well as to detect, pools or other hidden structures inside large or deep rivers. In our case study, we want to monitor the process of sediment transport away from the gravel bar that was created by excavation of the oxbow, and determine the timeline in which this gravelbar will be functional as a spawning habitat for grayling (*Thymallus thymallus*) and danube salmon (*Hucho hucho*). The echobathymetric generated depth chart of the Lech river can also be used to get cross section measurements of big rivers. These cross sections can then be used to apply CHEVO models on the sites.

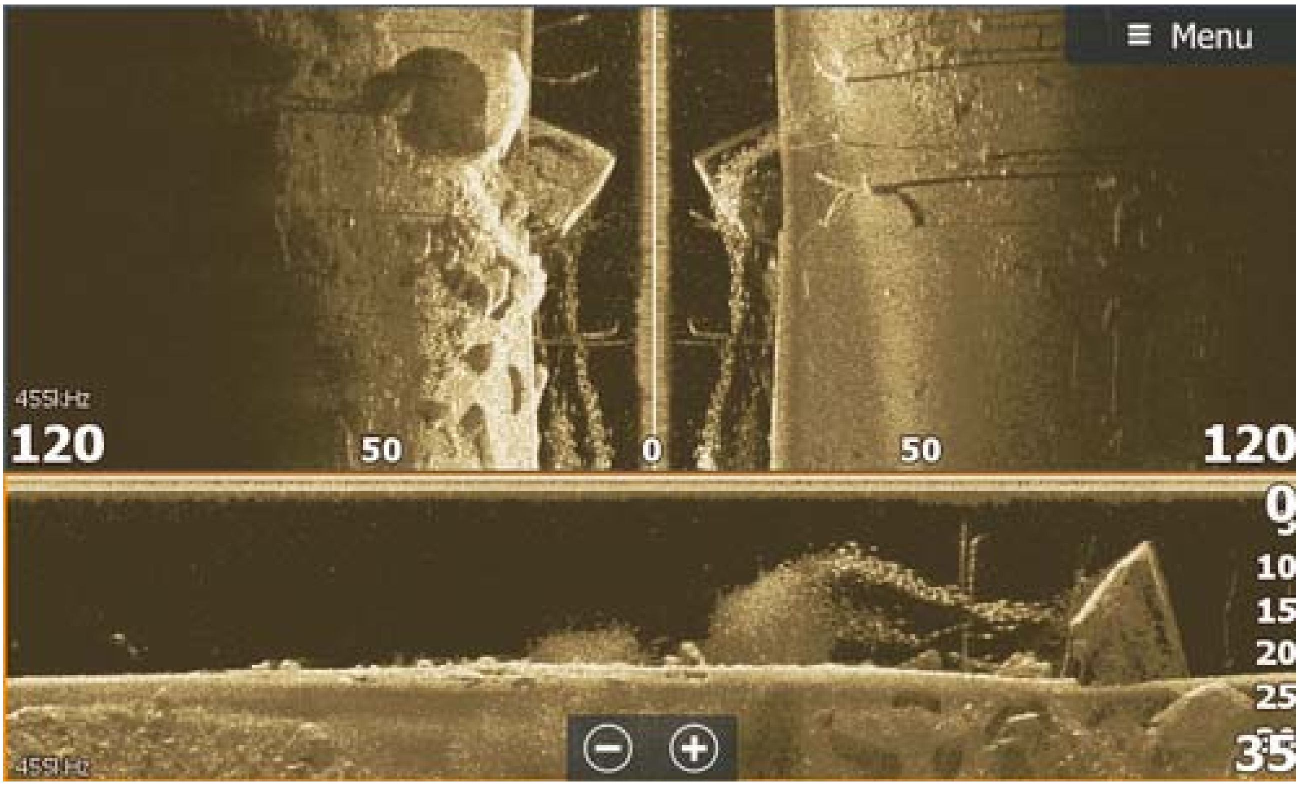

Figure 6 Screenshot of the echobathymetrical instrument.

2.1.2 Wertach River case study

At the Wertach River case study, a channel widening and a reshaping of the river cross-section have been realized (Figure 7, Figure 8 and Figure 9).

Figure 7 Wertach River case study pre and post restoration

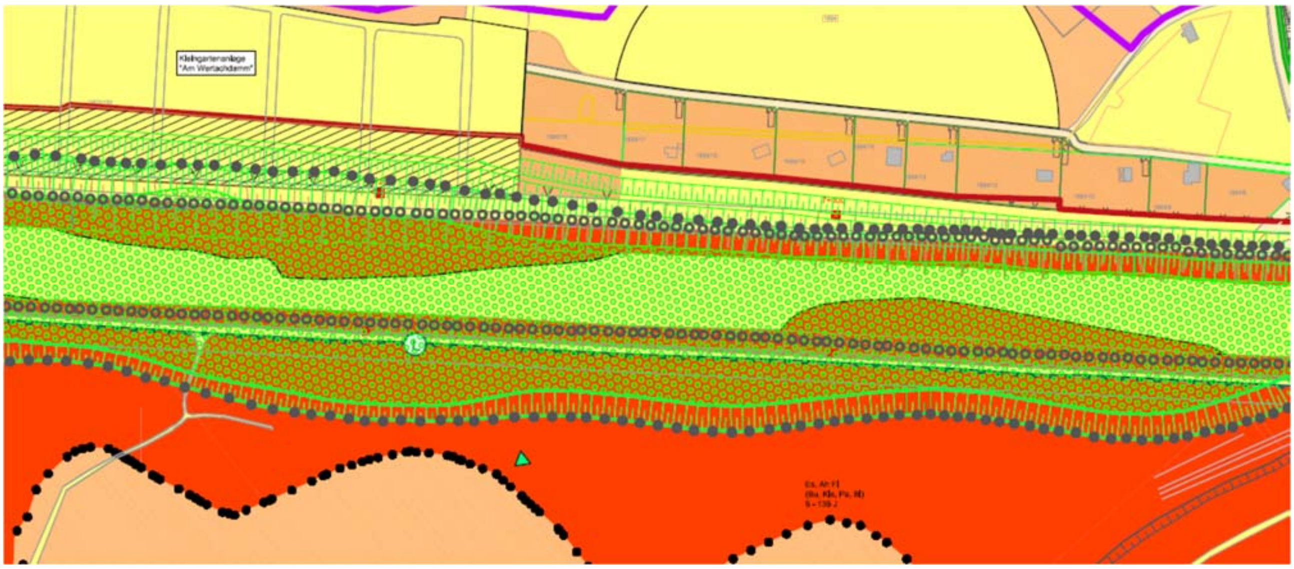

Figure 8 Planimetry of the Wertach River restoration project. Full dots are the new bank protection structures, empty dots show the old bank protections which have been removed.

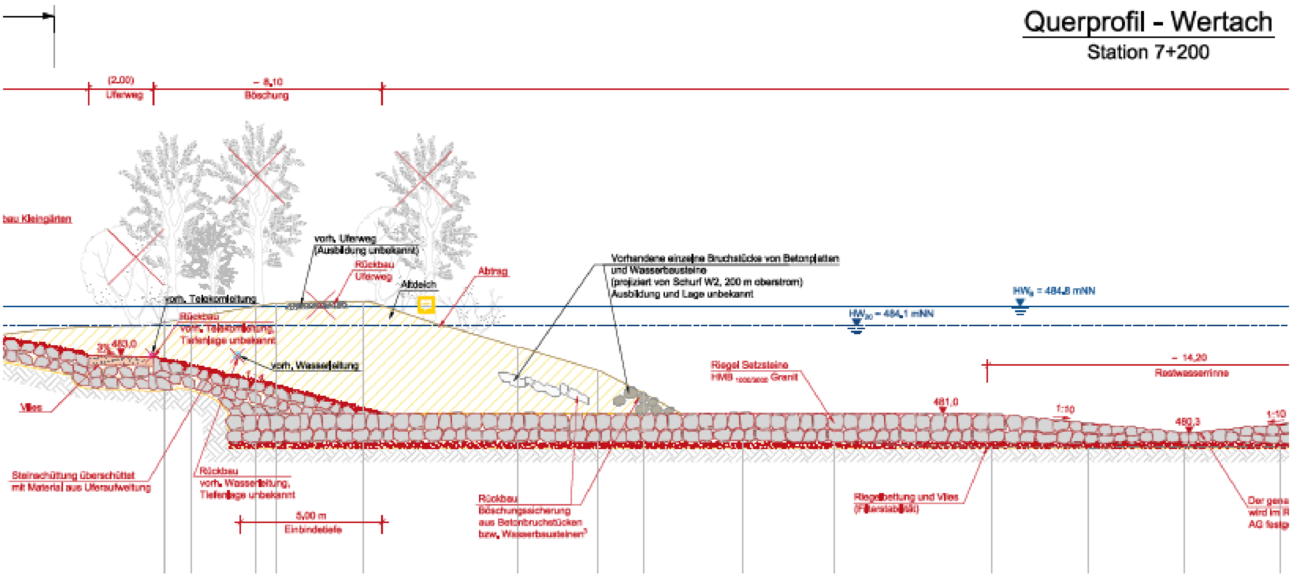

Figure 9 Example of the reshaping of one cross-section.

The Wertach River case study site is monitored by the responsible authority (WWA DON) that realized the restoration. The monitoring of the project "Wertach vital" started after the restoration had finished in 2009. The authority collects river cross-sections at an interval of 2-5 years (since

1986 up to 2014) to survey the evolution of the river bed before-after the channel widening. The data was already provided to Boku for further use, but the data is already processed, so the tools are not applicable, because they need raw data as an input.
The monitoring process is very important, because the planning process was developed openly to achieve a multitude of goals, i.e. flood risk mitigation, riverbed stabilization against incision and recreational use. The restoration project aimed to tackle in a sustainable way the structural problems of the Wertach River due to straightening in the 19th century as the loss of river sinuosity and lacking sediment supply.
Major aim though was to achieve flood risk mitigation and river restoration by following nature-based solutions. Hence, the natural river corridor and the natural floodplain should be restored in all natural habitat diversity, where possible.
After the Project "Wertach vital" between the Inningen Dam and the Ackermann weir the results were rebalanced against the aims and goals.

2.2 Ecological monitoring

2.2.1 Lech River case study

The ecological monitoring for the Lech river is conducted accordingly with WFD monitoring and its referring intervals by the responsible water authorities, the LFU Bayern and the Bavarian fisheries institute. There is no additional ecological monitoring to the above mentioned. Measures that have been made or maintained are only monitored qualitatively i.e. restored spawning grounds are observed if the target species use the newly restored sites. If possible videos and pictures are made, like the ones uploaded in the project storage system.

2.2.2 Wertach River case study

Rheophilic riverine species had been monitored before the restoration in 1999 and afterwards in 2011. The results of this monitoring were used to define a maintenance plan for the Wertach River. Therein also the results of public hearings were included to achieve nature preservation, agricultural, fisheries and recreational use alike.
The river structure is mapped in 100m sections and a set of multiple parameters according to LAWA method are collected. Then the structure in total can be evaluated on the basis of a seven scores rank.
Fish are one of the most important indicators to evaluate the ecological state of our waterbodies. They are the most retrospective bioindicator in riverine systems, because of their clear reaction on structural changes. This means they are very useful to picture the effects of instream measures of a

restoration project. For example, the grayling (*Thymallus thymallus*) has benefited clearly from the restoration.

The introduction of logwood debris as a fish hot spot and shelter has brought several natural structures back to the Wertach River. These structures provide winter habitats as well as refugial areas and also protect against piscivorous birds. Because of deterioration and abrasion logwood has to be maintained, but due to willow growth and beaver activity a natural supply of logwood is observed.

Macroinvertebrates have been monitored and evaluated according to WFD standards. It is still recognizable that weirs and dams have still measurable effects on the temperature profile.

3 Physical effects

3.1.1 Lech River case study

The use of echobathymetrical instruments allowed to assess the variations of the river bed and substrate in the restoration project area. The generated charts (Fig. 10) allow the assessment of depth variations and changes, in a second step a bottom hardness chart (Fig. 11) can be generated out of the sonar reflection pattern of the ground. The grain sizes are more special to detect and to get a reliable result the system has to be calibrated according to depth and surrounding and/or supplied material.

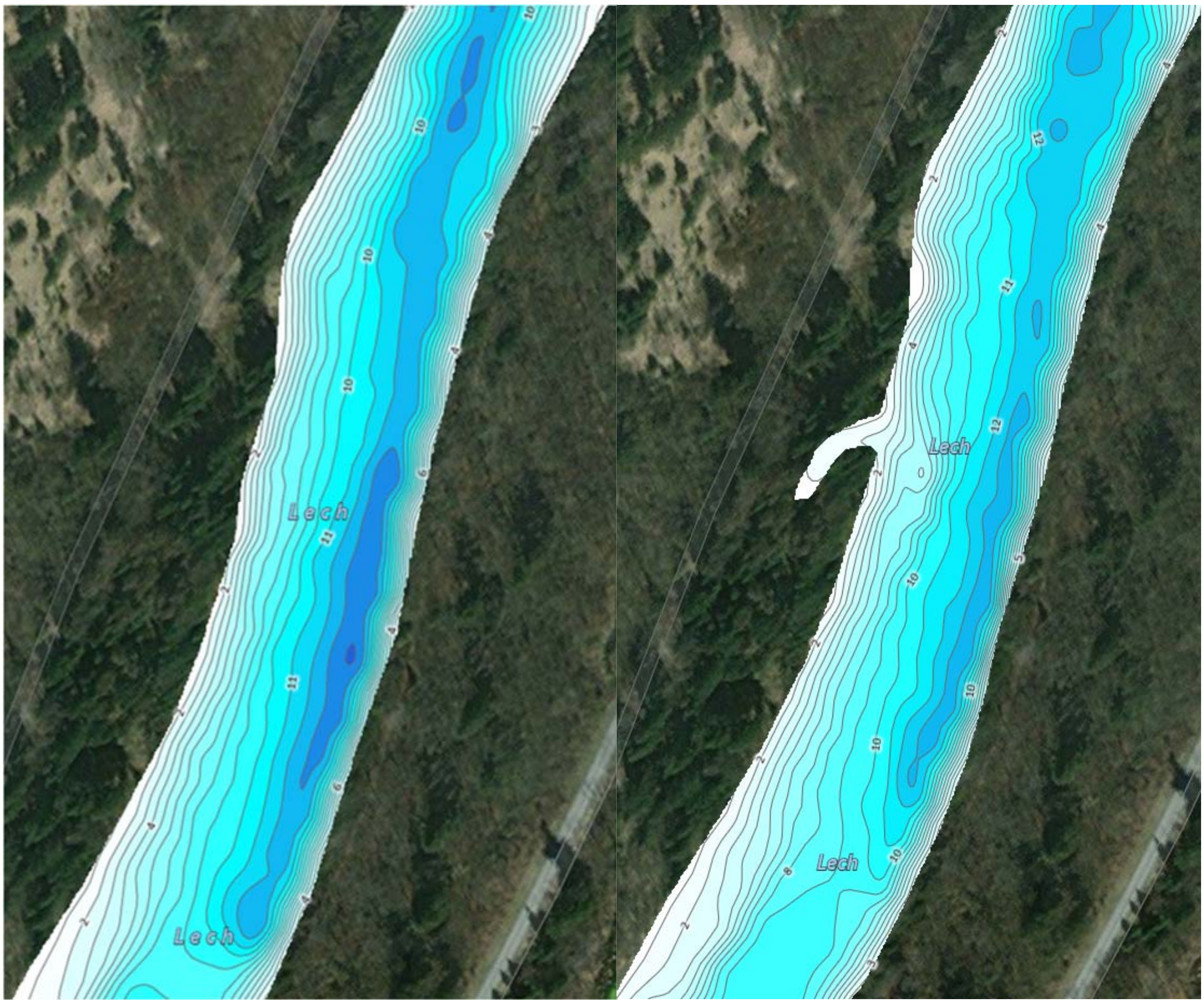

Figure 10 Depth chart of the surveyed river reach before and after the project.

As Fig. 11 shows there are several soft patches in amongst the introduced and newly dug sections. These are of clay/loam that has been dug out by the excavator and partly introduced. The variation of bottom hardness of the newly introduced material in the map can be explained by the mixture of materials during the process of the oxbow construction, so a change of substrate is always shown as a change of density or hardness.

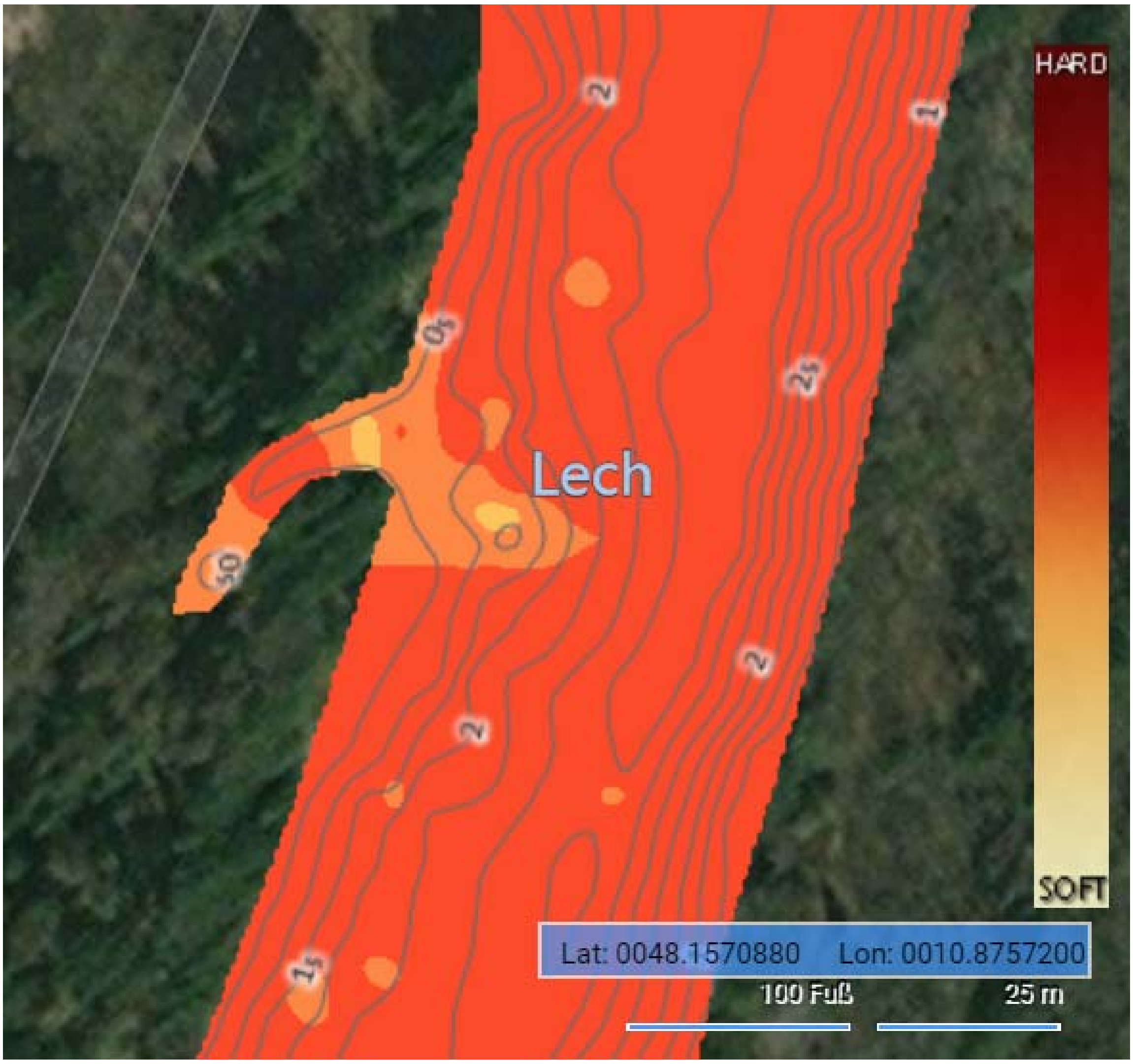

Figure 11: Depth chart with integrated bottom hardness map (color scheme).

To generate a map with grain size estimations etc. a further step of calculation would be necessary, wherein the down- and/or side image files need to be processed together with the bottom hardness map. As all grain size estimations of aerial images etc. a more in-depth look would be needed to get the real grain size distributing of the sediment. Therefore, a calibration of surface grain sizes in relation to sediment grain size distribution would be needed.

Figure 12 Artificial gravel bar in the Lech River.

3.1.2 Wertach River case study

Regarding the flood risk mitigation, the protection for a 100-years occurring flood event was achieved, thus the flood events of 2002 did not cause damages. In between Inningen and the Göggingen bridge incision was stopped by use of open covering. Sediment supply for active sediment transport is provided by a free flowing section with riverbank erosion and the riverbank as a sediment depot.

Kilometrierung	Datum	Flaeche	MittlereSohle	Talweg	Änd. Talweg Epoche m	Änderung Talweg gesamt in m	Änderung mittl. Sohle Epoche m	Änderung mittl. Sohle gesamt m
1,200	09.11.1977	138,288	460,386	460,271		0		0
1,200	15.09.1986	139,324	460,359	460,281	0,01	0,01	-0,027	-0,027
1,200	19.07.1995	149,904	460,083	459,951	-0,33	-0,32	-0,276	-0,303
1,200	12.08.1999	140,136	460,338	460,191	0,24	-0,08	0,255	-0,048
1,200	26.09.2005	144,784	460,217	459,998	-0,193	-0,273	-0,121	-0,169
1,200	27.05.2008	149,973	460,081	459,948	-0,05	-0,323	-0,136	-0,305
1,200	29.06.2010	151,624	460,038	459,88	-0,068	-0,391	-0,043	-0,348
1,200	18.12.2012	158,307	459,863	459,661	-0,219	-0,61	-0,175	-0,523
1,200	03.09.2014	159,391	459,835	459,607	-0,054	-0,664	-0,028	-0,551
1,400	09.11.1977	106,197	460,177	459,973		0		0
1,400	15.09.1986	105,32	460,209	460,073	0,1	0,1	0,032	0,032
1,400	24.04.1995	107,382	460,135	459,983	-0,09	0,01	-0,074	-0,042
1,400	12.08.1999	97,548	460,489	460,283	0,3	0,31	0,354	0,312
1,400	26.09.2005	101,739	460,338	460,193	-0,09	0,22	-0,151	0,161
1,400	27.05.2008	100,794	460,372	460,313	0,12	0,34	0,034	0,195
1,400	29.06.2010	106,579	460,164	460,001	-0,312	0,028	-0,208	-0,013
1,400	18.12.2012	113,646	459,909	459,743	-0,258	-0,23	-0,255	-0,268
1,400	04.09.2014	114,046	459,895	459,766	0,023	-0,207	-0,014	-0,282
1,600	09.11.1977	79,573	461,072	460,992		0		0
1,600	15.09.1986	79,601	461,071	460,992	0	0	-0,001	-0,001
1,600	21.04.1995	84,022	460,908	460,862	-0,13	-0,13	-0,163	-0,164
1,600	26.09.2005	83,872	460,913	460,672	-0,19	-0,32	0,005	-0,159
1,600	26.05.2008	84,84	460,878	460,752	0,08	-0,24	-0,035	-0,194
1,600	29.06.2010	85,411	460,857	460,735	-0,017	-0,257	-0,021	-0,215
1,600	05.12.2012	91,883	460,618	460,499	-0,236	-0,493	-0,239	-0,454
1,600	16.09.2014	93,728	460,551	460,417	-0,082	-0,575	-0,067	-0,521
1,800	09.11.1977	89,187	461,551	461,254		0		0
1,800	15.09.1986	90,396	461,504	461,325	0,071	0,071	-0,047	-0,047
1,800	21.04.1995	93,076	461,4	461,125	-0,2	-0,129	-0,104	-0,151
1,800	12.08.1999	95,724	461,298	460,785	-0,34	-0,469	-0,102	-0,253
1,800	26.09.2005	95,407	461,31	460,955	0,17	-0,299	0,012	-0,241
1,800	26.05.2008	94,22	461,356	461,185	0,23	-0,069	0,046	-0,195
1,800	28.06.2010	95,146	461,32	461,149	-0,036	-0,105	-0,036	-0,231
1,800	05.12.2012	101,543	461,073	460,938	-0,211	-0,316	-0,247	-0,478
1,800	16.09.2014	105,527	460,919	460,659	-0,279	-0,595	-0,154	-0,632
2,000	09.11.1977	82,074	462,124	461,838		0		0
2,000	11.09.1986	82,019	462,126	461,938	0,1	0,1	0,002	0,002
2,000	21.04.1995	85,512	462,003	461,828	-0,11	-0,01	-0,123	-0,121
2,000	10.08.1999	88,682	461,892	461,658	-0,17	-0,18	-0,111	-0,232
2,000	29.05.2008	87,131	461,947	461,74	0,082	-0,098	0,055	-0,177

Figure 13:The green marked columns show bed elevation, the red incision over the timescale

4 Ecological effects

4.1.1 Lech River case study

The WFD indicators for year 2015 show as the Lech River is in moderate status for almost all its water bodies. This value is mostly due to the moderate conditions of the fish fauna, while other parameters as macroinvertebrates show good or high potential or status.
The ecological effects of the newly built structures inside the Lech River channel are expected to be very positive for fish and macroinvertebrates. The building process finished in the end of November 2018, thus the evaluation can start this spring, so there are not results that can be shown yet.

4.1.2 Wertach River case study

In comparison with the state of the Wertach River before restoration, the structural benefits showed an increase of two classes in the LAWA class, in the first five years post restoration (Figure

14). The before restoration data for a map like the one, shown in Fig. 12 is not available. Though according to the found ecological effects, the rank score increase of two on average.

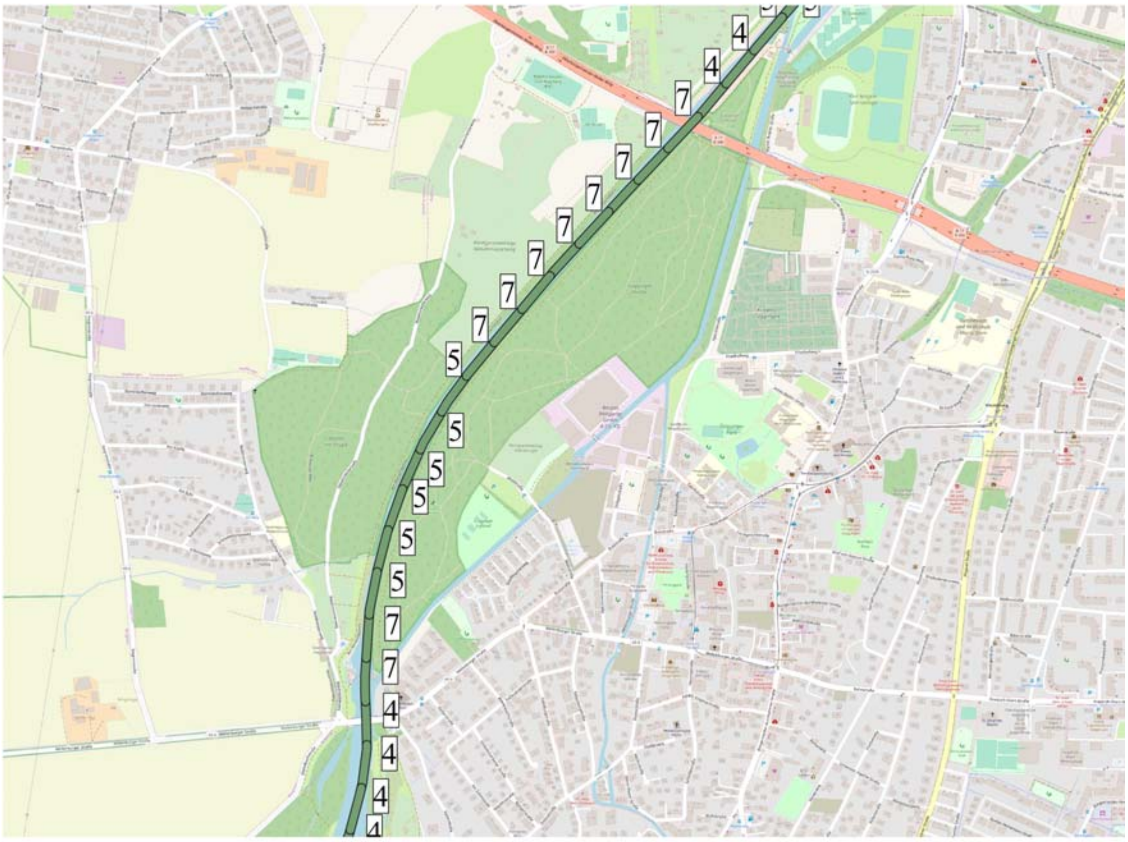

Figure 14 River bed value according to the LAWA rank in 2017, after the restoration.

The reoccurrence of rheophilic riverine species formerly gone to the system, shows the benefits of the restoration for the riverine ecosystem. Generally, the fish community of the Wertach River has changed towards naturally occurring riverine species, after the restoration. The successful spawning and recruitment of red listed species like grayling (*Thymallus thymallus*), barbel (*Barbus barbus*), Danube salmon (*Hucho hucho*), minnow (*Phoxinus phoxinus*) and spirlin (*Alburnoides bipunctatus*) shows clearly the positive effects of the project. Also the return of species like Danube salmon, burbot (*Lota lota*), European bullhead (*Cottus gobio*) and loach (*Barbatula barbatula*) that were not detected in 1999 are a success for the restoration project. The return of species and natural recruitment is an evidence for a successful restoration. The development of the still endangered species common nase (*Chondrostoma nasus*) though is still subject of concern, because this potamodromous fish is very dependent on longitudinal connectivity within the Lech-Wertach system.

Figure 15: ***Ch. nasus*** **in spawning mode**

Figure 16: ***Ch. Nasus*** **close up of the mouth that is made for grazing rocks and stones for algae**

The WFD indicators for year 2015 show a moderate status for the Wertach River. In particular, macroinvertebrates community shows a good status but nutrition loads from the catchment under agricultural use and punctual sources are in not good status. This is also shown by the macrophytes assessment, which shows still only a moderate state.

5 Conclusions and perspectives

The restoration projects conducted in the Wertach and Lech River had positive effects on the river system. In the Wertach River, the reshaping of the cross-sections and the sediment replenishment in slected section slow down or stopped river incision, with an increase of ecological conditions and the recolonization by several relevant fish species. In the Lech River, artificial construction of a lateral area with slow water (construction of bed forms) led to an increase in substrate diversity, although it is still not clear if it was only an effect of the construction works. The ecological effects of this action are still unclear, but it is expected to increase the suitable area for reproduction of fish species.

6 References

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