# Near-natural bypass channel development: focus on a highly dynamic river reach in the MONDAU project area between Neuburg and Ingolstadt

*Peter Fischer: Aueninstitut Neuburg/Donau, Germany,*
*e-mail: peter.fischer@ku.de*

## Introduction

The aims and measures in river restoration projects are multifarious. For example, one prevalent measure to improve the longitudinal connectivity is the installation of a fish migration pass (nature-like fishway). Constructed fishways that imitate morphodynamic components of natural fish habitat, such as substrate clusters, shelters, pools, riffles in rivers and streams, may provide a fully functioning surrogate habitat for a wide range of organisms living in the river or at the riverside. Side channels for upstream migration also affect all other components of hydromorphological conditions such as morphology, hydrology, physical and riparian habitats, therefore, often referred to as eco-hydromorphological conditions. As a matter of course, lateral connectivity is usually influenced as well and even the two other dimensions of hydrological connectivity, vertical and temporal connectivity, always play a major role in a holistic approach of riverscape restoration.

In the MONDAU (MONitoring DonAUauen) project area, one of these side channels was established as a key component of the local restoration project.

The state-of-the-art in science and technology about fish migration and bypass structures is for example presented in the DWA (Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V.) information sheet 509 (DWA 2014). In Bavaria a practice handbook is available online (http://lfvbayern.de/download/fischaufstiegsanlagen-in-bayern). Katopodis & Williams (2012) give an insight into the development of fish passage in a historical context. The paradigm shift from mere keeping chemico-physical values to simultaneously saving and improving the ecological status required by the European Water Framework Directive (EG WRRL 2000) revealed a new interdisciplinary field. Howsoever, to improve connectivity in rivers four elements are involved:

1. water
2. sediment and bedload
3. fish and benthos
4. vegetation (plants and deadwood)

In the meantime, self-dynamic development and hydromorphological assessments are common terms in restoration projects and/or explicitly required. Planning and construction of a bypass is still elaborate and costly and it is uncertain whether the desired dynamic will be generated. A near-nature style is recommended to maximize the variety of structures. In well-functioning rivers, sediment transport and deposition lead to a variety of habitats, the classic mosaic structure. And in dependence on irregular floods, also banks and surrounding floodplain have always been in constant change. Attributes for the ecological functioning of natural rivers and streams can also be applied to side channels:

- dynamic (environmental) runoff and transfer of sediments
- migration of fishes and benthos
- highly diverse instream habitats and structure elements
- interaction and connectivity of side channel and surrounding

Finally, features for functional rivers are well known, but self-development forecasts and minimum standards are still unsatisfactory. But running water, at any given location, can no longer be managed without an active understanding of the drivers and impacts of the three other elements (see above). Without a sound knowledge of the structures and biocoenosis of semi-natural streams it is not possible to properly assess degraded streams or to plan their successful “restoration”. To support the understanding of fluvial eco-hydromorphological process dynamics, point clouds (derived from the terrestrial laser scanner) and orthophotomosaics (derived from unmanned aerial vehicles) are used as a basis for mapping.

## Study site and MONDAU restoration project

The investigated stream reach is part of the fish migration bypass system “Ottheinrichbach”. This is situated in the MONDAU floodplain area of the Upper Danube River segment between Neuburg and Ingolstadt (between kilometers 2473 and 2464, *fig. 1)*. Between two hydropower dams, there are around 1200 ha of high biodiversity riparian forests with individual endangered floodplain species (Cyffka et al. 2016). The altitude is about 372 m above sea level with local relatively steep steps to the next postglacial terrace or meander scars. An average annual precipitation of 744 mm and an average mean temperature of 8.8°C is being recorded at surrounding weather stations. The daily discharge at the gauging station “Ingolstadt Luitpoldstraße” is listed in table 1. A detailed description of the hydrological regime and the Danube floodplain formation is given by Fischer (2016).

Reduced connectivity between the Danube and its backwaters has fostered tendency towards terrestrialization and changed groundwater table and dynamics. Natural floods hardly reach the floodplain, due to the constant degradation (bed erosion) and the dropping water level. There were no

| Danube | |
|---|---|
| MNQ (low water) | 131 m³/s |
| MQ (mean) | 311 m³/s |
| MHQ (high water) | 1.120 m³/s |
| HQ5 | 1.320 m³/s |
| **Bypass system Ottheinrichbach** | |
| Water level dynamics | 2,44 m |
| MQ (mean) | 2,1 m³/s |

*Table 1. Mean discharge at Ingolstadt gauging station (1924–2014) and gauge 10 (2010–2014, see fig. 1)*

significant fluctuations in water levels and sediment dynamics. The nowadays fixed channel structure and standardized flow conditions have led from a former dynamic to a rather stable and well-balanced situation in the riparian ecosystem.

The pre-restoration state, technical preconditions and expectations are described by Stammel et al. (2011). First results presented by Fischer & Cyffka (2014) and the final report are available in the NaBiV (Naturschutz und Biologische Vielfalt (Nature Conservation and Biodiversity)) series 150: "Neue dynamische Prozesse im Auenwald" (Cyffka et al. 2016). A short explanation of the three restoration measures of the MONDAU project is provided here:

- The bypass called 'Ottheinrichbach' runs through the floodplain. Depending on the Danube discharge, a water volume from 1.0 up to 5.0 m³/s is provided by the Danube. Within the first 2 km a completely new nature-like channel was carved into the alluvial sediments and old (dry) meanders (and the AOI (Area of Interest) as well). The following 6 km the river uses pre-existing water bodies like former oxbows and other temporary water bodies.
- Controlled floodings with an additional amount of 25 m³/s of water, equally controlled by a sluice, depending on a peak discharge of the Danube of 600–1000 m³/s, statistically take place 2–3 times a year for a few days.
- Groundwater draw-down in the eastern project area during low water conditions (Danube runoff <150 m3/s, MNQ in summer): A gate *(fig. 1)* in combination with stoplogs and a diversion trench allows a lowering of the groundwater level to amplify the hydrological dynamics.

The overall goal of the project is to bring back hydrological dynamics as a key process at least to a part of the floodplain in order to achieve better interaction between Danube, riparian zone and floodplain and to improve natural dynamics along the near natural fish bypass system. The controlled flooding was designed to bring water into the whole area as well as to initiate erosion at the river banks and bring new dynamics to the channel belts to create "natural site conditions".

All surveys were conducted at one of the return flows of the nature orientated stream (bypass system). The entire length of the investigated river reach is about 220 meter, from the bridge to the river mouth *(fig. 2)*. The channel with a mean discharge of 1.6 m³/s (more or less half of the complete discharge volume of the bypass) is carved into sediments and has an average slope of 0.4%. This place is the favourite location for fish to enter the bypass and has meanwhile become a natural spawning ground for sundry species (Pander et al. 2015).

The upper part, close to the bridge, is widened and a scour established in 2013. In front of the bridge, a huge amount of fallen wood as colonisable substrate has accumulated (since 2014). A mid-channel gravel bar has piled up in the centre (since 2012 and still under development),

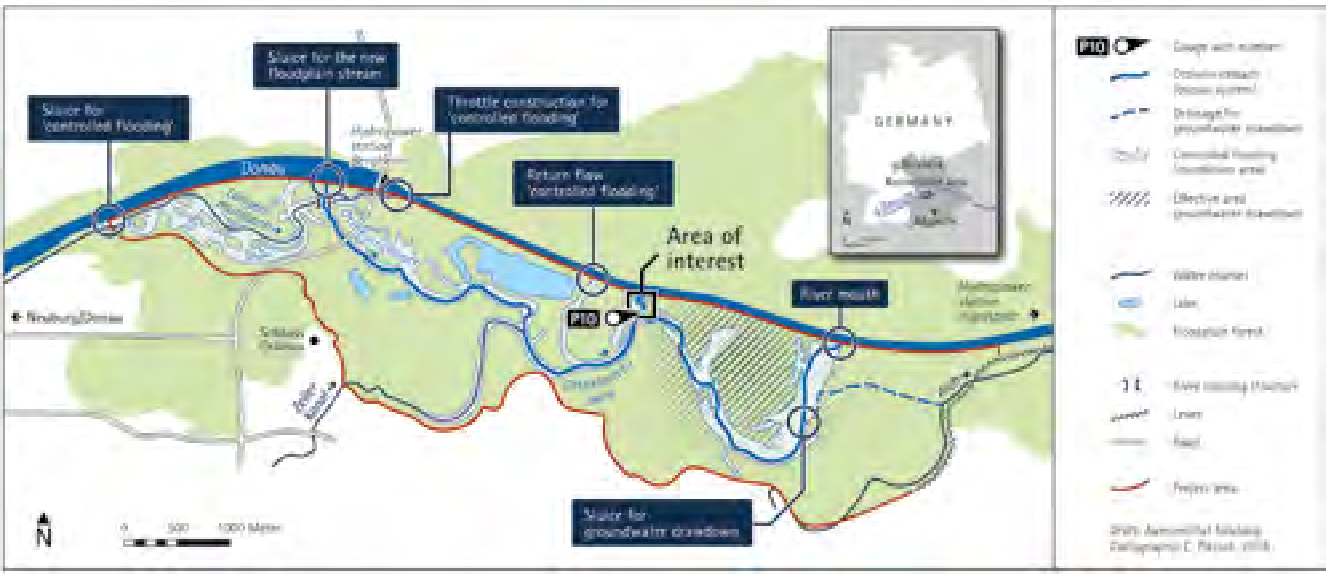


*Figure 1. Simplified map of the study area and location of the measures (new floodplain stream, controlled flooding and groundwater draw-down) and the area of interest with gauging station "P10" for water level measurements*

*Figure 2. Stream reach from the bridge to the river mouth. Diverse instream structures and the new depositional gravel bars and the complex deadwood structure in front of the bridge, formed by the last flood event (photo P. Fischer).*

followed by an 80 m section with a 65°-curve and a bank-attached bar. In the last 40 meters, close to the river mouth, the slope rises up to 1.5 % in combination with or therefore a highly dynamic undercut bank on the right hand side has accrued (formed and reworked with every flood event). On the opposite side, meanwhile, a compound bank-attached gravel bar (reflecting a range of various flow conditions) has developed. In short, a very dynamic reach with a large number of instream geomorphic units.

## *Tools and methods*

### Eco-hydrogeomorphic measurements using ground-based LiDAR and photogrammetry tools:

During the last decade, the application of ground-based LiDAR data in geomorphology, and especially in fluvial research, has rapidly increased (Heritage & Large, 2009), as high resolution Digital Terrain Models (DEMs) can be used to quantify the change of fluvial landforms and river morphology (e.g. bars, bank failure and other geomorphic units). Unmanned Aerial Vehicle (UAV) photogrammetry and Structure from Motion (SfM) processing can now be used as a basis for mapping research sites (Flener et al. 2013, Javernick et al. 2014, Eltner et al. 2015). In this contribution, a simple, convenient way to quickly produce mapping bases for a highly dynamic river reach was chosen.

To document the morphological changes – the sediment shifting processes in the channel and self-dynamic development of the water course – a combination of two methods (data sources) was used in this case study. The channel reach was actually well surveyed for a PhD thesis between 2010 and 2014 using a terrestrial laser scanner for generating high resolution digital elevation models (Fischer 2016). Thus, the point cloud was reused in a top view perspective as a basis for mapping instream structures and bank line development for the first period *(fig. 3, top left)* and changed to UAV photogrammetry for the second period to ensure further bank retreat monitoring *(fig. 3, top right).*

### Tools for data acquisition

TLS-system: Terrestrial Laser Scanning was conducted with a Riegl LMS Z420i. This long-range 3-D laser scanner has a maximum measurement range of up to ~ 700 m and the distance accuracy is 0.01 m (by single shot). To detect colour information, the scanner is equipped with a mounted digital SLR camera (Canon 350D, Nikon D70).

UAV-system: aerial image acquisition was done with a DJI Phantom 4, a low cost quadrocopter with an integrated camera.

### Methods (workflow in field and office) for data acquisition

TLS-system: the scanning system is operated with the software RiSCAN PRO by Riegl on a tablet PC, and for post-processing steps the same software was used. 1–2 scanpositions were selected to cover the cut off bank (Fischer 2016), and 4–8 positions were needed to cover the area of interest. For one scanposition, including re-arranging and scanning tie points, about 45 minutes are required. So, total data acquisition takes around 5 hours. TLS data have been acquired over a period of three years between October 2010 and April 2013. Permanently fixed tie points were used to co-register point clouds from different scan positions and surveys. For post-processing, several steps are necessary (e.g. Haas et al. 2016); vegetation and artificial objects and flying points (e.g. insects and birds) were deleted. The final point cloud can be used in GIS as mapping basis *(fig. 3, top left).*

In this contribution, a rather rare approach pulled up in practice. Because of inadequate data quality for change detection and volume calculation in a satisfied manner (point density, gaps or distortion), the decision was taken to use top view 2 D data instead of 3D point cloud data.

UAV-system: Ground Station Pro (App, 1.6.0) was used for flight planning and for controlling the UAV with an external tablet iPad. The images were collected at flying heights of about 50 m with an overlap of 85 % (front) and 75 % (side) in order to capture the complete river reach in less than 5 min. The ground sampling distances after processing is 2 cm for the orthophotomosaic. In total, 110 images were taken during each flight. The final products, orthophotomosaics, were created using the software PhotoScan Professional by Agisoft. The photogrammetric software produces 3D spatial geodata from digital imagery using a SfM workflow (i.e. Javernick et al. 2014, Eltner et al. 2015, Haas et al. 2016). The orthophotomosaics were also used in GIS as mapping basis *(fig. 3, top right).*

In highly dynamic riverscapes, multitemporal measurements are sometimes required during one day. So, the use of UAV seems to be a very efficient way for data acquisition. Aerial images and orthophotomosaics present a view of the features of the study site and they offer a useful method for creating new maps. Maps are updated by digitizing the features from the mapping basis.

## Results and discussion

The dynamic discharge (measured at gauge 10, P10 in *fig. 1)* and varying flow directions (at discharges > 850 $m^3/s$ the flow direction rotates) cause erosion and deposition along the water course, thereby generating continuous alteration to the river reach. In addition to the width variability, the depth variability is also high in single cross sections, as well as throughout the examined reach. The morphology reflects the balance of erosion and deposition processes occurring along the bank and bed. Sediment shifting processes in the bypass were measured by mapping instream structures. Both differentiation and development of new habitats could be ascertained. Deadwood elements have proven essential to increasing the structural variety of the river, aggregations in some cases leading to pool formations which changed the depth variability along the riverbed.

In the first period (42 days after opening), only one controlled flooding took place and the bank line reacted at a few stretches only, where changes were visible *(fig. 3, centre left side).* Due to the water level, a decrease of river width is indicated in the data. In the survey of 22nd April 2013, after 271 days and six flood events, a clear difference is visible when comparing the orange and blue line *(fig. 3,* centre left side). The channel widening appears on both sides over the whole stream reach. The bank line is now separated in small inlets and "micro" cut banks (concave bank) and slip-off banks (convex bank). In figure 3 (centre left and right side), the widening of the stream from 2013 to 2017 is apparent, particularly in the first part of the reach. Bank retreat changed during the last period from 2017 to 2018, affected by the last flood event from 19th to 22nd of January *(fig. 3, centre right side).*

Looking at instream structures like mid-channel and bank-attached bars and deadwood accumulation, massive changes can be observed. In this contribution, only the bigger ones (> 1$m^2/s$) have been focused on. As a result of river widening, gravel bars and a relatively big island were formed. All structures that can still be seen developed on their own and were not artificially created. The deposition zones are e. g. visible in bright areas in the orthophotomosaic *(fig. 3, top right side).*

In the following, three different patches or geomorphological units are picked out *(marked with red cycles in fig. 3, top right).* Understanding the changes compare *figure 3,* bottom left and right side:

I: The "new" gravel island just a few meters downstream behind the bridge, close to the scour: In the early days, the unusual composition of materials was conspicuous, because it primarily consisted of river engineering stones which were introduced by river training measures. Sorting, however, ranges from boulders and cobbles at the top to pebbles at the end of the island (downstream size decreases).

After the first formation phase, a mid-channel teardrop-shaped structure, then a mid-channel bar similar to a transverse bar had established before a little vegetated bar formed. The primal establishment of pioneer vegetation took place in summer 2012. This stabilisation induced further sedimentation. Nowadays the structure is "young", but a real gravel island, because even floods (natural or controlled) are not strong enough to remobilise the material. Just small gravel is rearranged. Vegetation has a stabilising effect and fosters the vertical growth of the island e.g. with deposition of foliage and other floating debris.

II: The bank-attached bar, previously composed of gravel, at present of coarse sand, located in the 65°-curve: the scroll bar developed between July 2012 and April 2013 (in fact during the "Christmas flooding 2012") along the inner bend. Today it has a very long shape running parallel to the bank line, and it is self-designed by two-dimensional flow paths (helicodial flow). At this patch, a significant material sorting in flow direction could be observed. Fluvial entrainment and undercutting are the dominant bank erosion processes. A more or less single gravel bar

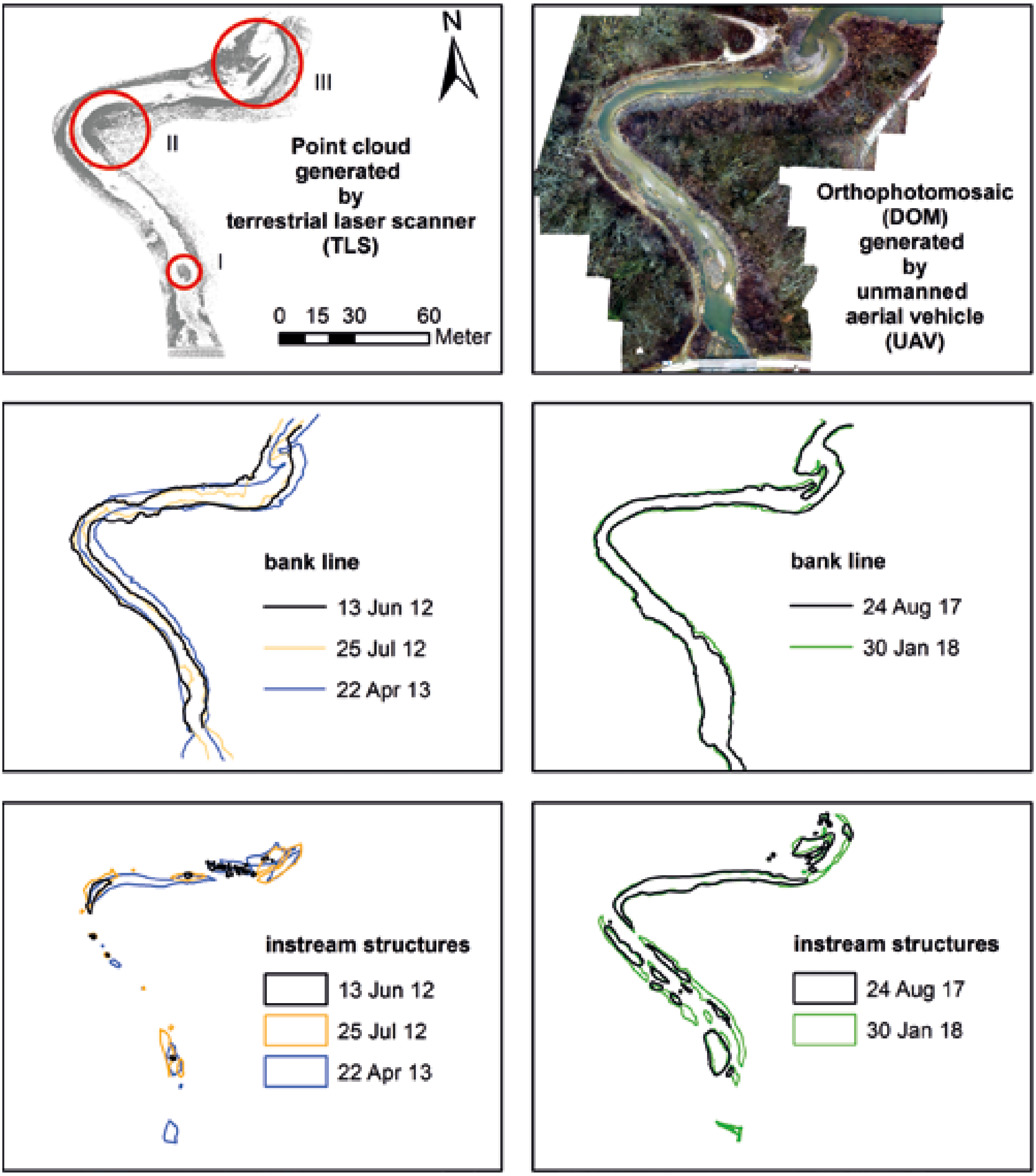


*Figure 3. Erosional and depositional features along the stream reach: top left: 3D point cloud generated by a Terrestrial Laser Scanner (TLS) with red marked area of interest, top right: orthophotomosaic generated by Unmanned Aerial Vehicle (UAV), center left: digitized channel course (TLS-data), center right: digitized channel course (UAV-data), bottom left: digitized instream units (TLS-data) and bottom right: digitized instream units (UAV-data).*

transformed into a bank-attached parallel sand bar. The initial bar *(fig. 4)* made up of gravel, becomes a fine material layer directly in the inside bend. The longitudinal extension ranges from 15 m on June 13th 2012, over 18 m, 53 m, 90 m to 105 m on January 30th 2018

III: The expanded gravel bar close to the river mouth: composed of local sediments which were eroded upstream. A structure that comprises an array of smaller scale units like chutes, channels, ramps or ridges. The bar may be reworked by every flood event or sediment deposited by temporary flow obstructions. At low flow conditions, especially decreasing limb fine deposits cover the top of the bar. Continuous development leads to a more than 60 cm thick sediment layer. The outer bend of the point bar follows the bank retreat of the cutoff bank. The concave bank follows the typical cycle of bank retreat with mass failure (slab failure and sloughing) and toe accumulation.

Hydrologic investigations were carried out through a nearby gauging station to record vertical water level variations over the whole period. In response to channel widening and scouring, a shift in water level measurements was recorded in summer 2012. At the selected locations, different processes were observed due to further influencing factors (vegetation, substrates, etc.). Noteworthy among these processes is that numerous locations showed a rapid development particularly in the early stages of observation. Various bar structures were created during that time, occurring in several activity phases.

## Conclusion

The semi-natural bypass acts just like a natural river, shifting its course and creating new structures. Nevertheless, the man-made status will always remain, shown for example in an unnatural runoff, strongly changed sediment transport rates and sediment characteristics. A development of a secondary floodplain, a narrow riparian margin, will occur at topography lower than the Danube floodplain and on very limited space. This element is also an irreplaceable part of a semi-natural stream, but even in the early stages, this self-improved floodplain has developed habitats with eco-hydromorphological dynamics for typical floodplain species and will continue to do so. This significant potential opportunity can be realised through clever water body and floodplain development.

The use of TLS and, in particular, UAV data for river structure mapping is a helpful tool for improving the understanding of eco-hydromorphological processes and for the application of assessment methods. However, there is a clear relation between technical capability, resources and availability of time. The researcher needs to strike a careful balance between these variables.

Nature-orientated hydraulic engineering, limited to the creation of undercut slopes, gravel bars and deadwood structures is not enough to revitalise such ecosystems. River habitats are generally controlled by physical processes (flow, water quality, sediment transport). So we can make big changes to the biodiversity of rivers by managing (or mis-managing) the flow. Rather, the dynamic processes and the driving forces leading to these structures must be promoted. Therefore, a new bypass system with man-made discharge variations is not enough to successfully restore a floodplain. But hundreds of kilometres of many "small streams" and their accompanying small secondary floodplains will have an impact.

*Figure 4. The stream reach with the bank-attached gravel bar in January 2012.*

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