Fact sheet: Medium-large, single- and multi-thread, mid altitude rivers

General description

Valley- and planform	Usually unconfined rivers in wide valleys. River planform is extremely varied, including braided, island braided, and high-energy anabranching multithread types through transitional wandering planforms to sinuous and meandering single thread types.
Hydrology	Naturally, cross-sections are wide and shallow, and the floodplain is inundated several times a year. Rivers are permanent (except for the Mediterranean region) and the discharge regime is often flashy with pronounced high flow events.
Morphology	In their natural state, these alluvial rivers can adopt widely-varying morphologies. A sequence of channel patterns occurs as river slope / energy and thus sediment dynamics decrease, bed material becomes finer, bar stability increases (indicated by vegetation encroachment), bank strength increases (influenced by sediment fining and cohesion and vegetation reinforcement), and width and the number of bars in a typical cross section decreases. Braiding is typical of relatively high energy rivers and is usually found where the supply of sediment is high. Braiding rivers display relatively wide bankfull channels with multiple, mainly unvegetated, bars in their cross-section separating multiple flowing channels during low flow conditions. If sufficient bar surfaces become stabilised by vegetation and wood, finer sediment is retained and the vegetated areas grow and form an island-braided pattern, ultimately leading to a high-energy anabranching pattern when the vegetated area exceeds the area of unvegetated bar sediments. A similar high-energy anabranching pattern can develop when parts of the floodplain are excised by avulsion (e.g. caused by wood jams or sediment accumulations). These islands consist of floodplain material, are more stable and above bankfull stage (in contrast to islands of the anabranching pattern evolving from braid bars) and can develop in rivers with less energy than even the transitional wandering rivers described below (but still much higher stream power compared to the low-energy anabranching silt-bed rivers). As stream power decreases, bed material becomes finer and the banks are more able to resist erosion, especially when they are well-vegetated. As a result, the bankfull river width tends to narrow, the number of bars in a typical bankfull channel cross section decreases, revealing planform types ranging from transitional wandering patterns, which show a mix of single thread sections and sections with mid-channel islands, and relatively mobile single-thread sinuous to meandering types. In these single thread rivers, sediment accretion on the inside of bends leads to the formation of one free point-bar on the inside of each bend and bank erosion and scour to form a pool at the outer bend. The bends are connected by relatively straight sections containing riffle bed forms at the inflection points.
Chemistry	Depending on the geology pH can vary. A distinction can be made between siliceous and calcareous rivers, with the siliceous rivers being vulnerable to acidification.
Riparian zone	The floodplain is dominated by deciduous trees mainly *Alnus* in the upper catchment and *Salix* in the lower catchment, with smaller parts of the channel-bed being shaded with increasing river width (especially in braiding rivers).

Photo: Medium-Large, mid altitude rivers with a transitional wandering (top), and high-energy anabranching (bottom, A. Lorenz) channel pattern.

Pressures

Major pressures

The medium-large rivers in lower-mountain areas are mainly affected by three types of pressures: First, point sources (e.g. organic pollution) are still the main pressure in some regions (e.g. Eastern Europe). Water quality has substantially improved in other regions (e.g. Central Europe) but recent studies indicate that even moderate water pollution might still affect biota, especially sensitive macroinvertebrate species. Second, diffuse source pollution including nutrients and fine sediment input. Third hydromorphological alterations: The prevailing morphological pressures are missing riparian vegetation, bank fixation, narrowing / entrenchment, and straightening, as well as migration barriers for biota and sediment, and associated upstream impoundments. Moreover, the remaining riparian and aquatic vegetation and in-channel large wood are often removed during maintenance. In addition to these morphological pressures, there are several severe hydrological alterations like increased peak flows from impervious areas, hydrological changes downstream of reservoirs, and water abstraction (especially in Mediterranean rivers).

Score of pressure level imposed on small, single-thread, mid altitude rivers categorised according to pressure category and pressure, respectively (score in comparison to other pressures within this river type and according to the typical pressure situation: No = no pressure/stress, L = low pressure/stress, M = moderate pressure/stress, H = high pressure/stress).

Pressure category	**Pressure**	**Score**
Point sources	Point sources	M to H*
Diffuse sources	Diffuse sources	H
Water abstraction	Surface water abstraction	L to H+
	Groundwater abstraction	L
Flow alteration	Discharge diversions and returns	L
	Interbasin flow transfer	L
	Hydrological regime modification including erosion due to increase in peak discharges	M
	Hydropeaking	L
	Flush flow	M
	Impoundment	H
Barriers/Connectivity	Artificial barriers upriver from the site	H
	Artificial barriers downriver from the site	M
Channelization	Channelisation / cross section alteration (e.g. deepening) including erosion due to this	H
	Sedimentation	H
Bank degradation	Bank degradation	H
Habitat degradation	Alteration of riparian vegetation	H
	Alteration of in-channels habitat	H
Others	e.g. Maintenance	M
	e.g. Exotic species	M

*differs between regions, high in e.g. Eastern Europe, moderate in e.g. Central Europe

+high in dry Mediterranean region, low in Northern Europe

Problems and constraints for river restoration

Bank fixation limits (lateral) channel dynamics and sediment delivery to the river which naturally would be high due to the relatively high stream power of many mid-altitude rivers.

In free flowing sections, bed substrate coarsens and armouring layers develop due to the high flow velocities and sediment deficit, especially in gravel-bed rivers with a wide range of grain sizes (poorly sorted substrate) and platy sediment, which are prone to develop armour layers. Moreover, the interstitial spaces often become filled with fine sediment because of the lack of mobility of the armoured coarse particles lining the bed surface. In addition, the lack of large wood further contributes to a uniform channel morphology and uniform high flow velocities and water depth.

In impounded sections, coarse sediment is deposited, causing a sediment deficit downstream. Moreover, fine sediment is accumulated in impounded sections and, in addition to the low flow velocities, does not provide any habitat for typical species inhabiting fast-flowing gravel-bed rivers.

Furthermore, missing riparian vegetation reduces the input of organic material (including large wood) and reduces shading. Although the riparian vegetation does not fully shade the river bed, this still affects water temperatures and temperature dynamics.

In addition to these effects on instream habitat conditions, the pressures significantly affect the natural controls that have governed river planform in the past, and these changed controls will continue into the future:

- Some past pressures have caused irreversible changes (e.g. massive deposition of cohesive floodplain sediments during the middle-ages in Central Europe).
- Some rivers have not yet adapted to past anthropogenic pressures or pressures changed over time, and hence, rivers are often on a trajectory of change, adapting to these modifications (e.g. deforestation / forestation of riparian areas and floodplains resulting in river widening / braiding and river narrowing / meandering).
- Some restoration projects are restricted to reach-scale measures and do not address large-scale pressures that affect river planform controls (e.g. hydrological and sedimentological changes).
- Climate change will potentially have an effect on channel forming discharges and in addition, environmental change (land-use changes) on bank stability and sediment loads.

Measures

Common restoration practice

Most of the restoration projects in medium-large, mid altitude rivers have applied in-channel measures to increase habitat complexity (~75%), most frequently by removing bank fixation and creating shallow slow-flowing areas. Most projects have also aimed to restore a more natural planform (~54%), mainly by widening and some by remeandering. Moreover, many projects have developed a riparian buffer strip (~30%) and restored floodplain habitats (~48%), while measures to explicitly restore natural sediment dynamics (e.g. by adding sediment, restoring natural sediment transport or limiting fine sediment input) were rarely applied (~6%).

Score per measure category/measure of relevance , effect in-channel, effect on the floodplain and costs the measure in comparison to other measures within this river type

(No = no relevance or effect, L = low relevance or effect, M = moderate relevance or effect, H = high relevance or effect of the measure) and indication a prioritisation of measures (L = low priority, M = moderate priority, H = high priority).

Measure category	**Measure**	**Relevance**	**Effect in-channel**	**Effect floodplain**	**Costs**	**Prioritisation**
Decrease pollution	Decrease point source pollution	M	M	M	H	M
	Decrease diffuse pollution input	H	H	M	H	H
Water flow quantity	Reduce surface water abstraction	L	L	L	L	L
	Improve water retention	M	M	H	H	M
	Reduce groundwater abstraction	L	L	L	M	L
	Improve water storage	M	M	H	H	M
	Increase minimum flow	L	L	L	M	L
	Water diversion and transfer	L	L	No	L	L
	Recycle used water	L	L	No	L	L
	Reduce water consumption	L	L	No	L	L
Sediment quantity	Add/feed sediment	M	M	L	M	M
	Reduce undesired sediment input	H	H	L	M	H
	Prevent sediment accumulation	No				
	Improve continuity of sediment transport	H	H	No	M	H
	Trap sediments	No				
	Reduce impact of dredging	L	L	No	L	L
Flow dynamics	Establish natural environmental flows	M	M	M	M	M
	Modify hydropeaking	No				
	Increase flood frequency and duration	L	M	M	H	M
	Reduce anthropogenic flow peaks	M	M	L	H	M
	Shorten the length of impounded reaches	M	M	No	M	M
	Favour morphogenic flows	M	M	L	M	M
Longitiudinal connectivity	Install fish pass, bypass, side channels	M	H	No	M	H
	Install facilities for downriver migration	M	M	No	M	M
	Manage sluice, weir, and turbine operation	M	M	No	M	L
	Remove barrier	H	H	L	M	H
	Modify or remove culverts, syphons, piped rivers	L	L	No	M	L
In-channel habitat conditions	Remove bed fixation	M	M	No	M	M
	Remove bank fixation	H	H	L	M	H
	Remove sediment	L	L	No	M	L
	Add sediment (e.g. gravel)	M	M	No	M	M
	Manage aquatic vegetation	L	L	L	L	L
	Remove in-channel hydraulic structures	L	L	No	M	L
	Creating shallows near the bank	M	M	L	M	M
	Recruitment or placement of large wood	H	H	L	M	H
	Boulder placement	L	L	No	M	L
	Initiate natural channel dynamics	H	H	M	L	H
	Create artificial gravel bar or riffle	M	H	No	M	M
Riparian zone	Develop buffer strips to reduce nutrients	H	H	H	M	H
	Develop buffer strips to reduce fine sediments	H	H	M	M	H
	Develop natural vegetation on buffer strips	H	H	H	M	H
River planform	Re-meander water course	M	M	L	H	M
	Widening or re-braiding of water course	M	H	M	H	H
	Create a shallow water course	M	M	M	M	M
	Narrow over-widened water course	L	L	L	M	L

Measure category	Measure	Relevance	Effect in-channel	Effect floodplain	Costs	Prioritisation
	Create low-flow channels	L	L	L	M	L
	Allow/initiate lateral channel migration	H	H	L	L	H
	Create secondary floodplain	M	L	H	H	M
Floodplain	Reconnect backwaters, oxbow-lakes, wetlands	M	L	M	L	M
	Create backwaters, oxbow-lakes, wetlands	M	L	M	M	M
	Lower embankments, levees or dikes	L	L	M	M	L
	Replace embankments, levees or dikes	L	L	M	M	L
	Remove embankments, levees or dikes	L	L	M	M	L
	Remove vegetation	L	L	H	L	L

Problems and constraints with common restoration practice

In general, instream measures in gravel-bed lower-mountain rivers have a higher and positive effect on aquatic organism groups like fish and macroinvertebrates compared to pure planform measures. Especially the placement and recruitment of large wood is an effective restoration measure, for example in comparison with boulder addition, to increase macroinvertebrate richness and fish abundance. Therefore, the approach to mainly apply instream measures to restore instream habitat complexity is supported by recent research findings. The effect of restoration is especially high in catchments with a relatively high share of forested areas, probably because water quality is usually high in forested catchments (water pollution and fine sediment not constraining restoration effects), riparian vegetation is present and has beneficial effects on biota (e.g. large wood input, shading), and source populations are present to colonize the restored habitats.

Furthermore, widening (removing bed and bank fixation, flattening river banks, and in some projects considerably widening the cross-section) is one of the most effective restoration measure, especially for terrestrial and semi-aquatic organism groups like floodplain vegetation, ground beetles, and macrophytes compared to its effect on fish and the low or missing effect on macroinvertebrates. There is some empirical evidence that the missing effect on macroinvertebrates might at least be partly due to the low effect of widening projects on microhabitat / substrate diversity. Although widening generally enhances macro- and mesohabitats which often is visually appealing, it still may fail at increasing microhabitat diversity relevant for macroinvertebrates. Moreover, there is empirical evidence that the high effect on terrestrial and semi-aquatic organism groups is mainly due to the creation of open, non-shaded pioneer habitats like gravel bars and shallow areas. Unfortunately, these habitats may vanish over time (i) if morphodynamic processes have not been restored to rejuvenate them or (ii) the restored channel pattern does not correspond to the planform that naturally would develop given the (altered) controls like discharge, sediment load, and bank stability. The latter is especially true for Central Europe where several winding projects have been carried out where present stream power and/or sediment loads are too low to support a braiding pattern. This is problematic especially because over-widening reduces flow velocities and water depths to the extent that natural form recovery is unlikely or takes an excessively long period. There is empirical evidence that these rivers would rather develop a high-energy anabranching channel planform from floodplain avulsion.

Promising and new measures

The effect of local instream and planform measures in medium-large, mid altitude rivers can potentially be improved by (i) ensuring that catchment-scale pressures do not constrain the effects, (ii) restoring natural sediment dynamics, i.e. processes, and (iii) the restored channel pattern corresponds to the channel planform which would develop naturally given the (altered) controls like discharge, sediment load, and bank stability.

The most important catchment-scale pressures which potentially constrain the effects of local restoration projects are water pollution, excessive fine sediment, coarse sediment deficit, and missing source populations. If present, these pressures should be addressed in addition to restoring local habitat conditions.

- There is empirical evidence that even moderate organic pollution might still limit biota, especially macroinvertebrates, and hence, saprobic indices should indicate a good or high status.
- Source populations can be identified based on information from monitoring sites, species distribution models or expert knowledge. Based on present knowledge, for fish, source populations should be at a maximum distance of about 5 km up- or downstream of the restored section. Fish dispersal models have recently been developed to assess the re-colonization potential for different fish species in detail (e.g. FIDIMO). For macroinvertebrates, source populations should be located upstream since they are less mobile than fish and purely aquatic invertebrates (hololimnic species) mainly disperse by downstream drift. Moreover, source populations should be located less than 1.0 - 2.5 km upstream of the restored sections.
- Several methods are available to quantify the fine sediment content and oxygen depletion in gravelly sediments (e.g. freeze-cores, infiltration bags, dissolved oxygen logger). There are also less labour-intensive and costly methods available for a rough assessment of fine sediment stress like (i) visual estimates of percentage cover, (ii) the shuffle index (assessing the degree and duration of reduced visibility above a white tile placed on the river bed caused by the plume resulting from disturbing the sediment upstream), and (iii) the nail test (length of rusted part of nails placed in the sediment indicating well oxygenated conditions and grey parts oxygen depletion). Moreover, some biological metrics have recently been developed indicating fine sediment stress.
- Removal or modification of upstream channel barriers and bank reinforcements can reinstate the supply of coarse sediment and restore a more natural flow regime, resulting in increased coarse sediment mobility and reduced bed armouring.

Restoring forms like a braiding, transitional wandering, meandering or high-energy anabranching channel patterns or channel features like gravel bars is not sustainable and has very limited effects in the long-term if the respective channel planform is not supported by the present conditions (e.g. discharge, sediment load, riparian vegetation and bank stability) and the underlying processes which rejuvenate the channel features have not been restored as well. Therefore, it is necessary to restore an adequate channel-planform with an adequate channel-width, natural sediment loads and dynamics, and a natural flow regime. For example, if there is a sediment deficit, river continuity for sediment transport has to be restored or - at least - sediment has to be continuously added to mitigate the sediment deficit. Moreover, the flow regime must not be substantially altered e.g. by increased peak flows from impervious areas or reduced peak flows by excessive flow regulation. If these anthropogenic changes cannot be mitigated, the restored channel pattern and features will not persist without continuous interventions.

Therefore, it is crucial to first check if anthropogenic changes of the controls, especially discharge, sediment load, and bank stability, potentially have resulted in a shift of the resulting channel pattern. There are several empirical or semi-physical models to assess the channel-planform based on the given controls, some of which have been compiled in Appendix G of the REFORM deliverable D 2.1, Part 2 (also see e.g. Kleinhans and Van den Berg 2010). Moreover, there are catchment to reach scale methods to assess changes in processes and controls as well as historical trajectories of channel adjustment described in the REFORM deliverable D2.1 Part 1, that can support decisions regarding potentially sustainable restoration designs. In case the models indicate that the river is transitional or might still adjust to historical or recent changes in the controls, restoring processes should be favoured over restoring forms since the risk for failure (created forms being destroyed by channel dynamics) is high. In general, there is an increasing awareness that - if possible - restoring processes (natural morphodynamics including flow regime and sediment transport) and keeping anthropogenic interventions to a minimum is the most sustainable restoration approach. More active restoration approaches might be only necessary where the anthropogenic alterations of the natural processes and controls cannot be mitigated.

Monitoring scheme

Monitoring schemes should follow some basic principles that apply to all river types:

- Biotic as well as abiotic variables should be monitored. The restoration measures might have succeeded to create the desired habitats but the effect on biota might be limited due to other pressures at larger scales which have not been addressed in the restoration project.
- In-channel, riparian, as well as floodplain conditions should be monitored. Besides the biological quality elements relevant for the Water Framework Directive, restoration can also have positive effects on other semi-aquatic and terrestrial organism groups, like ground beetles and floodplain vegetation. Indeed, there is empirical evidence that effects on other organism groups can be larger.
- Monitoring has to be conducted at appropriate spatial and temporal scales that reflect (i) the habitat needs of the organisms (e.g. monitoring microhabitat substrate patches for macroinvertebrates, mesohabitat features for fish, consider habitats at river margins and in floodplain like side channels and ponds), (ii) all life stages (e.g. monitoring in-channel and riparian habitats for macroinvertebrates with terrestrial life-stages), (iii) the reproductive cycle as well as dispersal abilities (long-term monitoring to also cover effects of restoration on long-lived species and weak dispersers), and (iv) seasonal changes and patterns that occur during the year.
- Looking at the spatial and time scale of many current restoration measures, macro-invertebrates are most suited for river monitoring. Fish population are strongly managed and reflect larger scale conditions, macrophytes bear a long history as they disappear only slowly and algae reflect to short time scales and very, very local conditions. Floodplains are large scaled and best be monitored by vegetation. The riparian zone can be monitored by using vegetation or carabid beetles.
- A Before-After-Control-Impact design should be applied to allow disentangling the effect of restoration from general trends in the whole river or catchment.
- However, the final selection of the organism groups, and spatial / temporal scales monitored strongly depends on the objectives and applied measures. Of course, it is reasonable to focus on the abiotic and biotic variables and scales that potentially have been affected by the restoration measures (e.g. in-channel habitat conditions by in-channel measures).
- Monitoring results should be used for adaptive management, i.e. to react on unanticipated effects and trends, and this should be included in the planning from the beginning (“Plan-B”).

For further reading and practical guidelines we refer to the handbook of the River Restoration Centre (River Restoration Centre 2011).

The relevance of a variable at the scale of the river, riparian zone and floodplain scored in comparison to other variables within this river type (No = no relevance, L = low relevance, M = moderate relevance, H = high relevance)

Variable group	Variable	River	Riparian zone	Floodplain
River hydrology		H	M	M
In-channel hydraulics		H	M	No
Floodplain morphology		L	L	M
In-channel morphology	Profile (longitudinal, transversal)	H	M	M
	Meso-/micro-structures	H	L	No
Chemistry	Nutrients	H	M	L
	Toxicants	H	M	L
	Others			
Biology	Algae	L	No	No
	Macrophytes	M	L	No
	Macroinvertebrates	H	L	No
	Fish	H	L	No
	Floodplain/riparian vegetation	H	H	H
	Terrestrial fauna	No	H	M