Fact sheet: Large, single-thread, lowland rivers

General description

Valley- and planform	The valley form varies from a no distinctive valley to a U-shaped valley and the channel planform from a straight/sinuous to a more meandering planform.
Hydrology	In the natural situation entrenchment is minimal and the floodplain is partly to completely inundated during floods. Large, single-thread, lowland rivers are permanent. The hydrograph is moderately dynamic. In-channel mesohabitats create a large variety in current velocities and depths.
Morphology	The erosion-sedimentation processes are occur in channel and along the river margins. There is only passive meandering shaping a single-thread channel. The banks are irregular, mainly shaped by tree roots or in wet places by reed, rushes or sedges vegetation. The river bottom consists of a combination of mineral and organic microhabitats ranging from silt, sand and gravel, to fine and coarse particulate organic matter (e.g. fallen leaves), mosses, local stands of vascular hydrophytes and course woody debris (logs, debris dams). Macrophytes can take parts of the channel.
Chemistry	Depending on the geology pH can vary from 6 to 8. The water quality is meso-eutrophic, except for peat area fed rivers that are slightly acid. A distinction can be made between siliceous and calcareous rivers. Primary productivity takes place
Riparian zone	The wide floodplain is either dominated by deciduous swamp forest or consists out of higher and drier areas dependent on the geomorphology of the valley. The river channel is accompanied by mainly *Alnus*, *Fraxinus*, and *Salix* trees that only partly shade the river bed.

Photo: Large, single-thread, lowland river Dinkel in the Netherlands.

Pressures

Major pressures

The prevailing hydromorphological pressure in large, single-thread, lowland rivers is channelization, in combination with flow alteration (resulting from impoundment and drainage of agricultural and urban land), and alteration of the riparian vegetation and the floodplain water infrastructure.

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

Pressure category	**Pressure**	**Score**
Point sources	Point sources	H
Diffuse sources	Diffuse sources	H
Water abstraction	Surface water abstraction	L
	Groundwater abstraction	L
Flow alteration	Discharge diversions and returns	M
	Interbasin flow transfer	L
	Hydrological regime modification including erosion due to increase in peak discharges	H
	Hydropeaking	No
	Flush flow	H
	Impoundment	H
Barriers/Connectivity	Artificial barriers upriver from the site	M
	Artificial barriers downriver from the site	H
Channelization	Channelisation / cross section alteration (e.g. deepening) including erosion due to this	H
	Sedimentation	L
Bank degradation	Bank degradation	H
Habitat degradation	Alteration of riparian vegetation	L
	Alteration of in-channels habitat	H
Others	e.g. Maintenance	L
	e.g. Exotic species	H

Problems and constraints for river restoration

Impoundment results in a reduction of natural flow velocity, causing the deposition of transported sediments, especially silt. Overall channelization and impoundment strongly lowers microhabitat and flow velocity variety. Clearing of riparian forests reduces the amount of course woody debris in the channel and lowers the amount of shade which results in higher temperatures and temperature dynamics. Incision of the river bed due to channelization and flow alteration reduced the hydrological connectivity between river and floodplain.

Depending on the catchment groundwater lowering plays an important role in river degradation due to increase of peak flows and decrease of low flows, sometimes to stagnation. Surface water abstractions may indirectly lower the discharge of rivers, thereby decreasing the flow velocity, especially in dry periods. Reductions in base flow can lead to a drop in water level, stagnation with high temperatures and low oxygen levels.

The decrease in flow velocity often results in strong macrophyte growth. Deeper river parts become siltated. In many cases maintenance consisting of removing of aquatic vegetation and/or dredging is performed to counteract these effects.

Apart from hydromorphological pressures lowland rivers often suffer from eutrophication/ organic pollution resulting from a high proportion of agricultural land use in the catchment.

Measures

Common restoration practice

Most of the measures taken in large, single-thread, lowland rivers aim to reconnect old river meanders, remove weirs and restore river banks. Sometimes these measures are combined with in-channel measures, like removal of bank fixation and/or adding local structures such as tree logs. Probably this is because of the low cost of in-channel measures compared to changes in channel planform that needs adjacent land. Measures that deal with the upstream part of the river or the whole floodplain are rare. Restoration of the riparian zone is always limited to local areas where re-wetting is a possibility. Often water safety arguments support rewetting areas or creating inundation – water storage areas.

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	H	H	H
Water flow quantity	Reduce surface water abstraction	L	L	M	M	L
	Improve water retention	H	H	H	H	H
	Reduce groundwater abstraction	M	M	M	M	M
	Improve water storage	H	H	H	M	H
	Increase minimum flow	H	H	M	H	H
	Water diversion and transfer	M	M	M	H	M
	Recycle used water	L	L	No	L	L
	Reduce water consumption	L	L	No	L	L
Sediment quantity	Add/feed sediment	H	H	M	M	M

	Reduce undesired sediment input	M	M	L	H	M
	Prevent sediment accumulation	No	No	No	No	No
	Improve continuity of sediment transport	M	M	L	M	M
	Trap sediments	No	No	No	No	No
	Reduce impact of dredging	M	M	L	M	M
Flow dynamics	Establish natural environmental flows	H	H	H	H	H
	Modify hydropeaking	No	No	No	No	No
	Increase flood frequency and duration	H	H	H	H	H
	Reduce anthropogenic flow peaks	H	H	M	H	H
	Shorten the length of impounded reaches	H	H	M	H	H
	Favour morphogenic flows	H	H	M	H	H
Longitudinal connectivity	Install fish pass, bypass, side channels	H	H	L	M	M
	Install facilities for downriver migration	H	H	L	M	M
	Manage sluice, weir, and turbine operation	M	M	L	M	M
	Remove barrier	H	H	L	M	M
	Modify or remove culverts, syphons, piped rivers	No	No	No	No	No
In-channel habitat conditions	Remove bed fixation	No	No	No	No	No
	Remove bank fixation	H	H	M	M	M
	Remove sediment	No	No	No	No	No
	Add sediment (e.g. gravel)	L	L	No	M	L
	Manage aquatic vegetation	H	H	M	H	H
	Remove in-channel hydraulic structures	M	H	L	M	M
	Creating shallows near the bank	M	H	L	M	M
	Recruitment or placement of large wood	H	H	M	L	H
	Boulder placement	No	No	No	No	No
	Initiate natural channel dynamics	H	H	M	L	H
	Create artificial gravel bar or riffle	L	L	No	M	L
Riparian zone	Develop buffer strips to reduce nutrients	M	M	M	M	M
	Develop buffer strips to reduce fine sediments	M	M	M	M	M
	Develop natural vegetation on buffer strips	H	H	H	M	H
River planform	Re-meander water course	M	M	M	H	M
	Widening or re-braiding of water course	M	M	H	H	M
	Create a shallow water course	H	H	H	M	H
	Narrow over-widened water course	H	H	H	M	H
	Create low-flow channels	M	M	L	H	M
	Allow/initiate lateral channel migration	H	H	M	M	H
	Create secondary floodplain	H	M	H	H	H
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	H	M	H	L	M
	Replace embankments, levees or dikes	M	L	M	H	M
	Remove embankments, levees or dikes	H	M	H	L	M
	Remove vegetation	No	No	No	No	No

Problems and constraints with common restoration practice

The most often applied measure in lowland rivers is reconnecting old meanders and oxbow lakes. Sometimes former secondary channels are reconnected or are newly dug. In large, single-thread, sand-bed, lowland rivers there is limited potential for substrate sorting, except when the river bed is heightened and made wider.

Hydrological measures are more often only limited applied without solving the hydrological dynamics that results from catchment wide activities, like drainage, water abstraction and paved surfaces. Morphological measures often most common and are easy to take, like removal of bank fixation or placement of inchannel habitat structures. Such measures favor engineered solutions that create more static habitats of which it remains a question whether they sustain under the current hydro-morphological regime.

Measures that tackle chemical substances are often limited to point sources. Large parts of the chemical load though enter the river system as diffuse inflow.

Promising and new measures

Four basic principles in future process-based restoration must be kept in mind:

1. Target the root causes of lowland river ecosystem change and do this at different scales.

Restoration actions that target root causes of degradation rely on knowledge of 1) the processes that drive river ecosystem conditions, and 2) effects of human induced alterations onto those driving processes. Restoration of natural processes fitting the natural geo-hydrological, -morphological, and –chemical conditions will sort highest success.

2. Tailor restoration measures to the river ecosystems' potential, starting at the large scale and follow the hierarchical pathway to the local scale.

Each river ecosystem is part of a large catchment and the river itself depends strongly on the range of channel and riparian conditions. Both catchment and riparian valley should be or become the logical outcome of the physiographic and climatic setting. Furthermore, understanding the processes controlling restoration outcomes helps to design restoration measures that redirect river valley, river channel and river habitat conditions.

3. Match the scale of restoration to the scale of the problem.

When disrupted processes causing degradation are at the reach scale (e.g., channel modification, levees, removal of riparian vegetation), restoration actions at individual reaches can effectively address root causes. When causes of degradation are at the catchment scale (e.g., increased runoff due to impervious surfaces, increased eutrophication), restoration actions can only be taken at catchment level to restore the root causes.

4. Be explicit about expected outcomes.

Process-based restoration is a long-term endeavor, and there are often long lag times between implementation and recovery. Ecosystem features will also continuously change through natural dynamics, and biota may not improve dramatically with any single individual action. Hence, quantifying the restoration outcome is critical to setting appropriate expectations for river restoration.

Process oriented restoration focuses on restoring critical drivers and river functions. Process oriented actions will help to avoid common pitfalls of engineered solutions, such as the creation of habitats that are beyond a river stretch's natural potential. Restoring natural processes in long reaches, such as giving freedom to erosion-sedimentation processes by removal of bed and bank fixation, re-profiling and free flow has a higher effect on recovery compared to local scale interventions, such as wood addition. Especially, in large, single-thread, lowland rivers catchment wide measures and measures restoring the natural system conditions (processes that fit to the current climatological and geo-morphological conditions) are most effective (table 3).

Table: Promising measures and respective scale. The higher the scale the more effective the measure.

<table>
<tr><td></td><td colspan="5">Ecological key factor</td></tr>
<tr><td>Schaal</td><td>Temperature and light regime (System conditions)</td><td>Flow regime (Hydrology)</td><td>Profile variation, substrate heterogeneity and organic material (Morphology)</td><td>Oxygen regime, nutrient and toxic load (Chemistry)</td><td>Connectivity (Biology)</td></tr>
<tr><td>Catchment</td><td colspan="2">Ground water</td><td></td><td></td><td></td></tr>
<tr><td>↓</td><td></td><td>Surface water hydrology</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td>Free flow</td><td>↔</td><td colspan="2">Connectivity</td></tr>
<tr><td></td><td></td><td></td><td></td><td>Nutrients and organic load</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>Toxicants</td><td></td></tr>
<tr><td></td><td colspan="5">Riparian zone</td></tr>
<tr><td>River stretch</td><td></td><td colspan="2">Profile</td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="2">Maintenance</td><td></td><td></td></tr>
<tr><td>Site</td><td></td><td colspan="2">Habitat</td><td></td><td></td></tr>
</table>

Hydrology must be considered as the most important driving process of which effects reach over the whole floodplain. Hydrological measures should therefore focus 1) on groundwater balances and flows at catchment level and 2) on catchment wide hydrological surface water infrastructure and its functioning. Upscaling of many current hydrological measures to reduce discharge dynamics and increase water- and groundwater levels is a promising trend (figure 1).

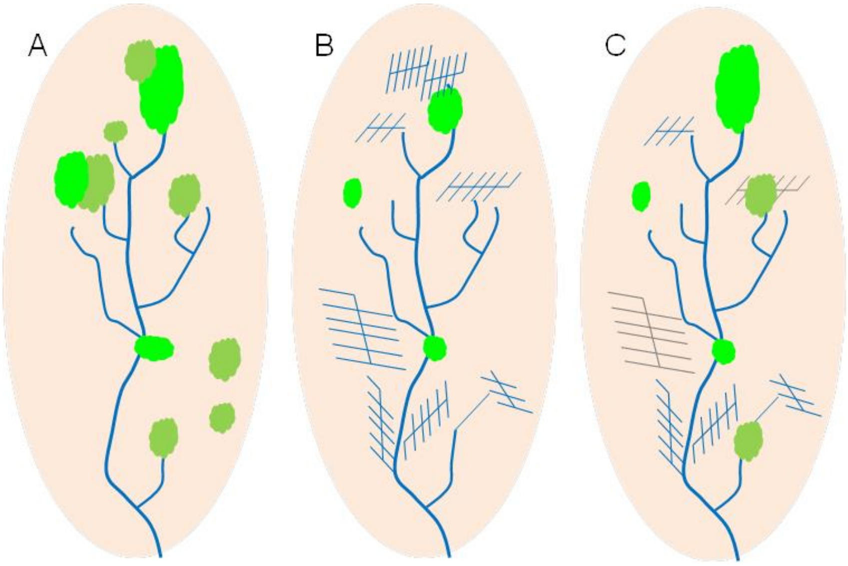

Figure: Process oriented hydrological restoration of combined ground water and surface water flows by restoring infiltration capacity and recreating water storage areas. (A: Natural catchment, B: Present situation; with a high drainage intensity, C: Restored catchment with water infiltration, reduced drainage intensity, water storage areas (green) and water flow retarding by remeandering).

Especially, at the scale of the catchment and floodplain such measures will sort strong effects. The river is not considered in solitude but is seen and dealt with as part of its catchment and floodplain.

Furthermore, free flow and thus connectivity provides continuous potential of exchange of water, substances and propagules. For example, natural levees develop by spill-over of sediment during periods of high flow. Parallel to the channel mostly sand is deposited at the highest flow velocities, and sand compacts less than the mud that is deposited farther away onto the floodplain. Over time the near-channel sand deposits will rise above the more spread and compacted floodplain and form natural levees. A meandering river migrates laterally by sediment erosion on the outside of the meander bend, as that is the part with erosion, and deposition on the inside. The processes of helicoidal flow, deceleration, channel lag, point bar sequence, and fining upwards shape the longitudinal profile. Parallel to the channel bank levee deposits build up, and gradually raise up the river over the floodplain which is covered by more fine sediments. In a more humid climate the floodplain area beyond the levees may be covered with water longer periods of time and may form a swamp (backswamp). Meanders cut into each other as they grow (neck cutoffs), and then the river shortcuts. So, growing meanders reduce the slope and cutoffs increase the slope again (a feedback loop). When the old meander is abandoned anoxbow lakes is formed. This lake slowly fills with fine sediment during floods and with organic material due to macrophyte production. As a river builds up its levees and raises itself over the floodplain, the slope and the transport power of the stream decrease, the channel fills gradually with sediment, and finally (often during a flood) the river will breach its levee and avulsion in a new channel that follows a steeper path down the valley will occur.

Also tackling nutrient, organic and toxic load by legislation and control will sort most effect when tackled at catchment level. Here obligatory guidelines are needed.

But nutrients, organic and toxic substances and sediments can also be reduced at river stretch level by introducing wider riparian buffers (Figure 3). There is clear and, in many cases, strong evidence for the role of wooded riparian buffers in controlling nutrient and sediment retention and improving in-channel habitat structure. For large rivers these measures should also be implemented at many (>50%) of the upstream channels in the catchment.

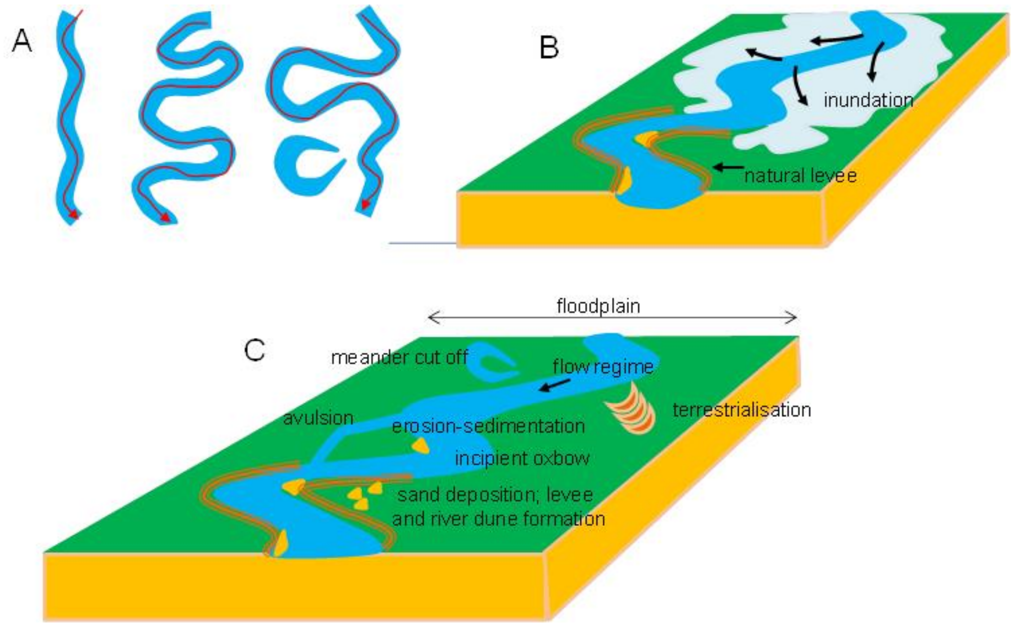

Figure: Process oriented hydromorphological restoration by providing space for free meander processes (A: meanders grow laterally through erosion of the outside bend and sedimentation at the inside bend, often through a point bar. When the channel bend gets too large and consumes too much energy, the river will eventually form a less energetically shortcut, and a part of the old channel will be abandoned and becomes an oxbow lake.), inundation by a shallow river depth and a high water level so avulsions and natural levee development occur (B), and in-channel erosion-sedimentation and in the floodplain, oxbow terrestrialisation and other processes give room for valley formation processes (C).

At river stretch scale also profile adaptations (both making the bed more shallow and, if necessary for safety reasons wider) are in benefit. As the stream power of this river type is low active measures for re-profiling (shallower, wider, profile diversity) are considered beneficial. Also changing maintenance from a negative to a positive measure by lowering the maintenance frequency and diversifying the frequency and intensity depending on local plant growth and flow conditions, improves the river stretch.

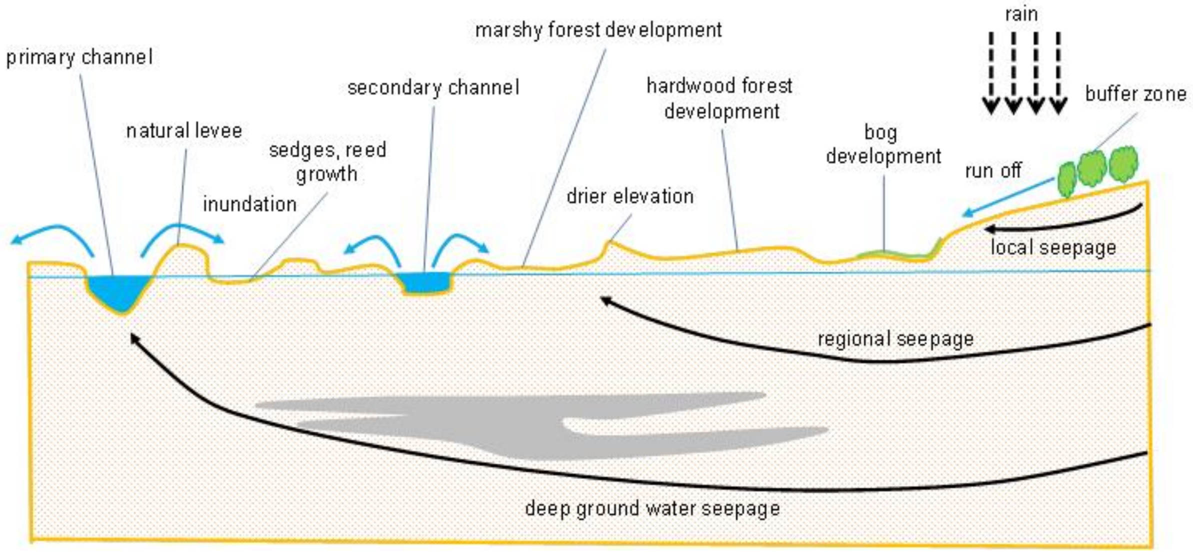

Figure: Stretch scale processes for river floodplain development with natural ground water, rain water and surface water flows that provide the basis for morphological processes. Buffer zone and measures to reduce nutrient levels provide the basis for lowland river restoration.

At local scale morphological processes (e.g. sorting of bed material, creation of pools, bars and cutbanks) are generally the result of high flows in rich structured beds. Best is to restore those processes that create local habitat and substrate variety. By addition of wood or gravel habitat morphology can be improved. Placing logs into the river will structure the river bed, increase the flow variability and improve habitat heterogeneity.

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), (ii) all life stages (e.g. monitoring in-channel and riparian habitats for macroinvertebrates with terrestrial life-stages), (iii) and the reproductive cycle as well as dispersal abilities (long-term monitoring to also cover effects of restoration on long-lived species and weak dispersers).
- Looking at the spatial and time scale of many current restoration measures macroinvertebrates 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. 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**	**Wetland zone**	**Floodplain**
River hydrology		H	H	H
In-channel hydraulics		H	L	L
Floodplain morphology		L	M	H
In-channel morphology	Profile (longitudinal, transversal)	H	M	L
	Meso-/micro-structures	H	M	L
Chemistry	Nutrients	H	H	L
	Toxicants	H	M	L
	Others			
Biology	Algae	L	L	No
	Macrophytes	H	H	L
	Macroinvertebrates	H	H	M
	Fish	H	M	M
	Floodplain/riparian vegetation	L	H	H
	Terrestrial fauna	No	H	M