Fact sheet: Medium-large, cascade, step-pool/plain bed, riffle-pool, highland rivers with (very) coarse sediments

General description

Valley- and planform	The valley form varies from a gorge to a V-shaped valley and the single-thread channel is mainly characterized by a straight to sinuous planform.
Hydrology	These rivers are dominated by a discharge maximum at early summer (May, June) due to snow melt; except glacial rivers – see fact sheet 14
Morphology	The morphology of these river types varies according to the dominating bed material and the gradient. Very steep streams with coarse bed material consisting mainly of boulders and local exposures of bedrock that split the flow and allow throughput of bed material finer than the large clasts dominating the bed structure. Sequence of channel spanning accumulations of boulders and cobbles (steps) support broken, fast-flowing, turbulent, shallow flow threads, separated by pools that frequently span the channel and are usually lined with finer, cobble-sized material, and support deeper, slower flowing water that is also often turbulent. If the gradient is getting lower, flows are fairly uniform, comprised of glides and runs with occasional rapids. Total sediment transport is low and is supplied mainly by bank erosion / failure and fluvial transport from upstream, but debris flows may occur in some locations. Coarse cobble-gravel sediments are sorted to reflect the flow pattern and bed morphology (REFORM D21 Typ 4-7).
Chemistry	Depending on the geology pH can vary from 7 to 8. The trophic level is oligotroph, the saprobic indices are between 1,00 and 1,75 (oligosaprob - β-mesosaprob). A distinction can be made between siliceous and calcareous rivers.
Riparian zone	Due to the narrow valley there is no floodplain developed. The river channel is accompanied mainly by bedrock banks or by pioneer vegetation. The valley sides are dominated by typical montane tree species.

Photo: Medium-large, cascade, step-pool/plain bed, riffle-pool, highland rivers with (very) coarse sediments in Austria (BOKU, IHG).

Pressures

Major pressures

The prevailing hydromorphological pressure in *medium-large, cascade, step-pool/plain bed, riffle-pool, highland rivers* in the alpine region is flow alteration (impoundment, hydropeaking and/or discharge diversions) resulting from hydroelectric power production.

Score of pressure level imposed on small, cascade, step-pool/plain bed, riffle-pool, highland 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	L
Diffuse sources	Diffuse sources	L
Water abstraction	Surface water abstraction	No
	Groundwater abstraction	No
Flow alteration	Discharge diversions and returns	H
	Interbasin flow transfer	M
	Hydrological regime modification including erosion due to increase in peak discharges	M
	Hydropeaking	H
	Flush flow	H
	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	L
	Sedimentation	No
Bank degradation	Bank degradation	L
Habitat degradation	Alteration of riparian vegetation	L
	Alteration of in-channels habitat	L
Others		

Problems and constraints for river restoration

In alpine regions, the continuity of small headwaters is often interrupted by blocking debris. As a consequence, sediment and wood are stored, causing a decrease of sediment and wood in downstream river sections and catchment-wide impacts on the ecosystems.

Large impoundments of storage power plants in the alpine region result in a reduction of the natural flow and a disruption of the sediment regime at a local scale. These impoundments also affect the downstream sections particularly with regard to altered water temperature or flow regime and/or decreased water quantity, depending on the operating method of the storage power plant.

Hydropeaking impacts medium-large river sections through a high variation of artificial discharge changes with highly variable water levels within a day, due to the need to satisfy the temporally fluctuating demand of electric power (through storage and pump-storage hydropower plants). Biota is strongly affected by several artificial peaks per day through stranding and drifting.

Water abstraction due to hydropower production leads to residual water flow in the river channel, which can result in a completely dry riverbed at its maximum extent. Furthermore, water abstraction from rivers through inter-basin flow transfer schemes causes reduced flow of the donor river system.

Flush flow of water storage basins aiming to get rid of accumulated fine sediments, creates artificial flood events and affects the whole river system downstream of the dam.

Measures

Common restoration practice

Most of the measures taken in *medium-large, cascade, step-pool/plain bed, riffle-pool, highland rivers with (very) coarse sediments* aim to restore the flow alteration.

Most important is the restoration of the natural flow regime, the re-establishment of the natural flow dynamics and the increase of water flow quantity in case of residual water flow. Furthermore, natural sediment regime and wood delivery must be restored. Sometimes, in-stream habitat restoration is performed to mitigate the negative effects of hydropeaking.

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

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

Measure category	Measure	Relevance	Effect in-channel	Effect floodplain	Costs	Prioritisation
	Create a shallow water course	No				
	Narrow over-widened water course	No				
	Create low-flow channels	No				
	Allow/initiate lateral channel migration	No				
	Create secondary floodplain	No				
Floodplain	Reconnect backwaters, oxbow-lakes, wet-lands	No				
	Create backwaters, oxbow-lakes, wetlands	No				
	Lower embankments, levees or dikes	No				
	Replace embankments, levees or dikes	No				
	Remove embankments, levees or dikes	No				
	Remove vegetation	No				

Problems and constraints with common restoration practice

Hydrology must be considered as the most important process because it affects the whole river system.

Hydropeaking, impoundment and water abstraction are relevant topics because of the dynamism of the hydropower sector and the need to mitigate and remediate adverse ecological impacts.

Hydrological measures focused on mitigating the flow alteration are often applied at a local/small scale without solving the hydrological dynamics that result from catchment-wide activities. Individual measures at each hydropower plant are usually set without considering the downstream or upstream situation.

Considering the restoration of the sediment regime, the catchment scale approach is essential. Even though the sediment regime in highland river types is usually not compromised, the building of check dams and the subsequent retention of sediment and wood can cause negative effects. These effects (e.g. increased bed and bank erosion, bed incision, and negative sediment budget in wide floodplains) are visible far downstream at the lowland rivers. The input of sediment at downstream reaches is a common but unsustainable countermeasure. Restoring natural processes (e.g. restoration of water and sediment regime by removing blocking debris in the upper catchment) has a better effect on recovery, compared to local scale interventions (e.g. wood or gravel addition at a lower part of the river catchment).

Promising and new measures

Individual mitigation measures at each hydropower plant should be coordinated at a catchment scale. A master-plan at larger scale is necessary.

Dam or weir removal is a promising measure in the alpine region to re-activate the stored sediment and to ensure a continuous sediment flow. Especially, at the scale of the catchment such measures will sort strong effects. The river is not considered in solitude but is seen and dealt with as part of its catchment.

The restitution of the peak flow directly into a lake, a compensation reservoir or into a parallel tailwater channel, and the controlled restitution of turbine water into the river in order to improve flow regime and re-establish natural-like condition are the most common measures.

Hydropeaking has a strong impact on aquatic fauna. Drift and stranding are the most important mechanisms. Morphological improvements of river sections, affected by hydropeaking, were set as promising new measure recently. Hereby, the restoration of river morphology has to focus on the development of keystone habitats, preferential for spawning and fry, and the improvement of existing habitats. First evaluations showed that the restoration of river morphology is only an additional tool to mitigate hydropeaking impacts. These measures will not be sufficient to fully mitigate strong hydropeaking effects that can only be done by the improvement of the flow regime such as slower changes in discharge variation or higher low flow level.

Another promising new measure is the building of multiple purpose reservoirs. These basins are located in wider valleys downstream and act as compensation basin to dampen the peak flow, provide additional flood protection, create aquatic/terrestrial biotopes and can be used for leisure activities by the local population.

	Year 0	Year 1	Year 2	Year 3	Year 4+
Flush event	Flush	Short time slot for			Extended time slot for
Spring (April-May)		--	>80/130 m^3/s	>80/130 m^3/s	>90/160 m^3/s
Early summer (June-July)		--	--	--	>90/160 m^3/s
Late summer (Aug.-Sep.)		>80/130 m^3/s	>80/130 m^3/s	>90/160 m^3/s	>90/160 m^3/s
		Perennial flush at flood event (starting from HQ 5 peak – 130/300 m^3/s)			

Figure: Optimized flushing scheme of the hydropower plant Bodendorf at the river Mur in Styria, Austria. Result of the EU Interreg IIIB Project ALPRESERV.

Water sections affected by residual water flow are restored by re-establishing a nature-like flow regime. Increasing the base flow and morphologically improving the key habitats could additionally mitigate the pressure.

Large impoundments situated at highland rivers affect bedload transport of the rivers and create a sediment deficit in downstream sections. Flush flow of the water storage basins, aiming to get rid of accumulated fine sediments, creates artificial flood events associated with high loads of suspended sediment and affect the river’s biocoenosis. Within the EU Interreg IIIB Project ALPRESERV a water resources management concept was developed based on an extensive ecological survey. The optimised flushing programme integrates demands of water management, hydropower production and ecology.

Especially, in *medium-large, cascade, step-pool/plain bed, riffle-pool, highland rivers with (very) coarse sediments* catchment wide measures and measures restoring the natural system conditions (processes that fit to the current climatological and geomorphological conditions) are most effective (see table below).

Table 3. Promising measures and respective scale. The higher the scale the more effective the measure.

	Ecological key factor				
Scale	Temperature and light regime (System conditions)	Flow regime (Hydrology)	Profile variation, substrate heterogeneity and organic material (Morphology)	Oxygen regime, nutrient and toxic load (Chemistry)	Connectivity (Biology)
Catchment	Ground water				
		Surface water hydrology			
		Sediment regime			
		Free flow	⟷	Connectivity	
				Nutrients and organic load	
				Toxicants	
River stretch	Riparian zone				
		Profile			
		Maintenance			
Site		Habitat			

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 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. 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	Water quantity, flow regime type, average monthly flows	H	L	No
In-channel hydraulics	Peak flow, baseflow index, Qmax/Qmin, hydropeak frequency, morphologically meaningful discharges	H	M	No
Floodplain morphology		No	No	No
In-channel morphology	Profile (longitudinal, transversal), sediment regime and budget,	H	M	No
	Meso-/micro-structures	H	L	No
Chemistry	Nutrients	L	L	No
	Toxicants	L	L	No
	Others			
	Water temperature	H	No	No
Biology	Algae	L	No	No
	Macrophytes	L	L	No
	Macroinvertebrates	H	H	No
	Fish	H	H	No
	Floodplain/riparian vegetation	L	L	No
	Terrestrial fauna	No	L	No