MODEL OF BACKWATER-INDUCED ABIOTIC–BIOTIC INTERACTIONS IN GRAVEL-BED RIVER

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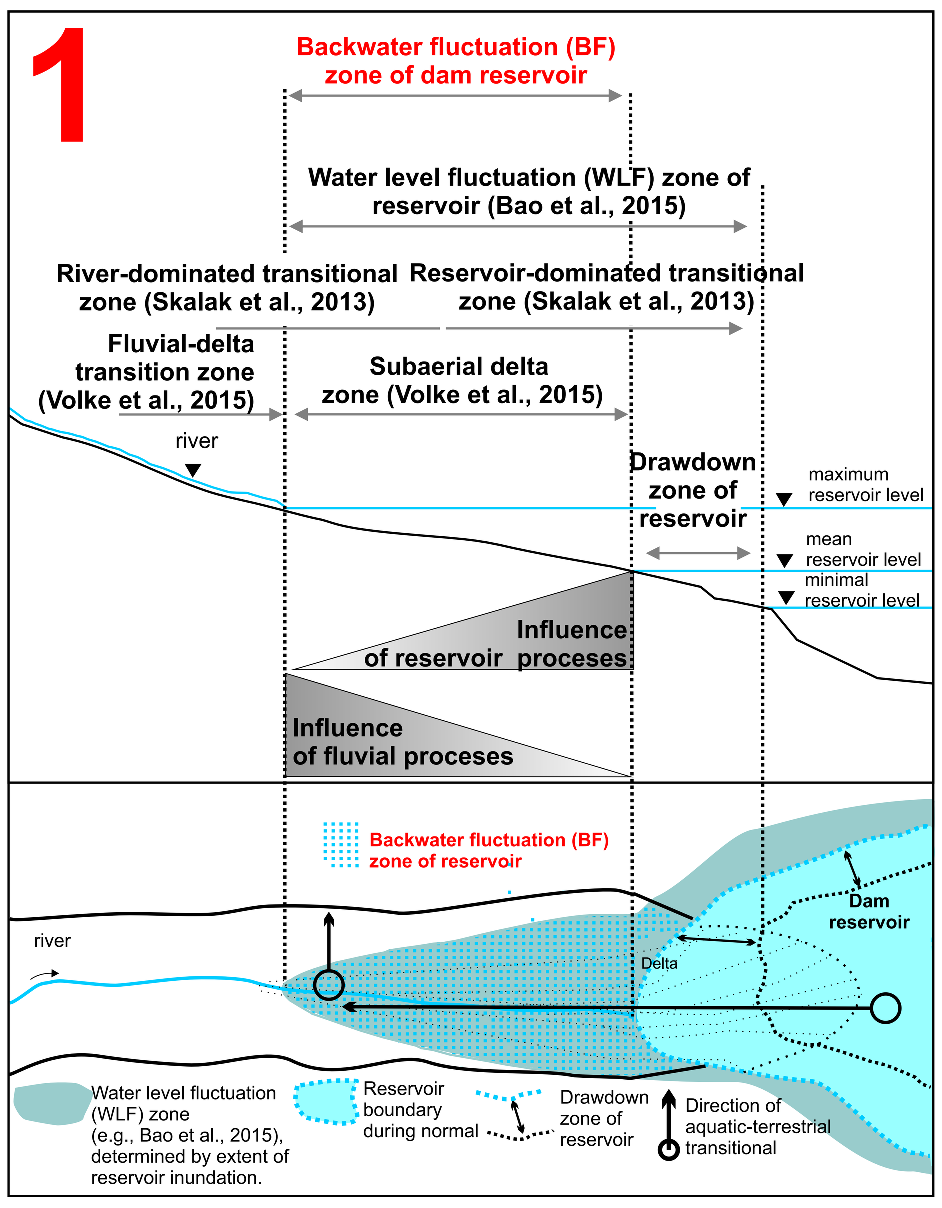
BACKWATER FLUCTUATIONS ZONE AND RELATED DEFINITIONS



In fluvial geomorphology, a river section temporarily inundated by water from a downstream dam reservoir is typically called a backwater or **fluctuating backwater zone** (e.g., Xu, 1997, 2001; see also terms **"backwater curve"** (Fig. 13 in Rubey 1952) and "drop down curve" (Fig. 15a in Lane 1955)).

I define **backwater fluctuation (BF)** zone as a river section upstream of a reservoir, that is inundated during reservoir stages higher than the normal or average (**1**). Such a defined backwater zone is easy to delineate in the river course. The backwater fluctuation zone is defined here only in the river valley, not in the whole area along the reservoir (cf. Bao et al., 2015, Tang et al., 2014, 2016). It may not be necessarily related to the delta development (cf. Volke et al., 2015), however it is situated within the same range of reservoir levels. The backwater fluctuation zone may be also treated as a part of **river-dominated transitional** and **reservoir-dominated transitional zones** (Skalak et al., 2013). This area is situated or adjacent to the previously used definition **water-level fluctuation (WLF) zone** (Bao et al., 2015), **fluctuating backwater riparian zone** (Wang et al., 2016), **artificial riparian zone** (Tang et al., 2014, 2016) and **drawdown zone of reservoir** (e.g., Azami et al., 2013) **(1)**.

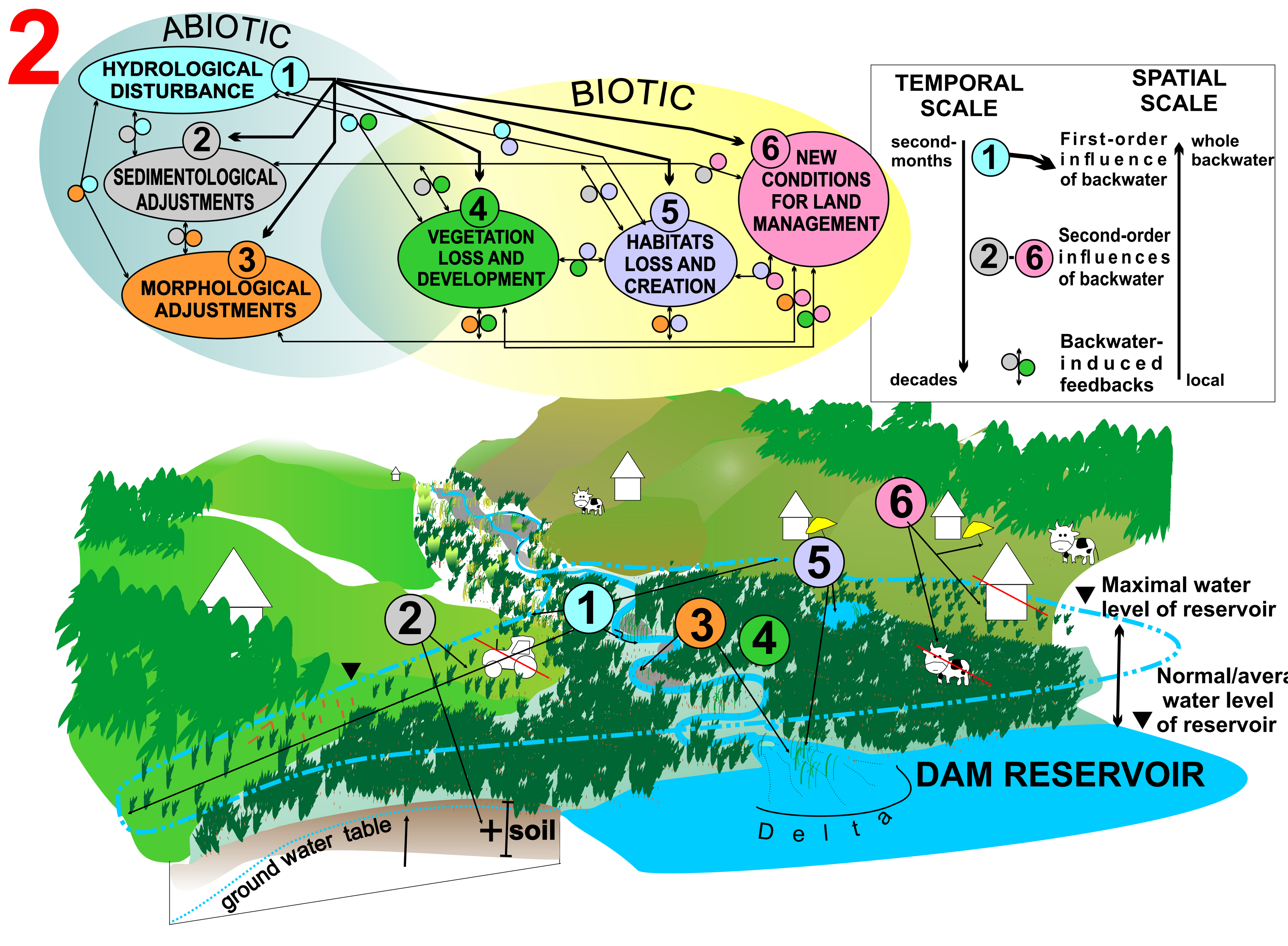
STATE-OF-THE-ART

Generally, little is known about the impact of the base-level rise upstream from dam reservoirs on geomorphological changes in the channel and floodplain of gravel-bed rivers (see reviews by Leopold et al., 1964; Knighton, 1998; Petts and Gurnell, 2005; Liro, 2014; Foley et al., 2017a, b), and to date only few works have analyzed biogeomorphological adjustments of gravel-bed rivers in this zone (see e.g., Klimek et al., 1990 in Table 1)

TABLE 1. Key studies on upstream effects of dams on alluvial channels

River type	Component analysed	Key findings	Location, reference
		Upstream from large dam reservoirs or check dams	
Ephermal, coarse- and fine-grained streams	M, S	Steeper depositional slope upstream from check dams related to the deposition of coarse gravel	southern USA (Kaetz and Rich 1939 after Leopold et al., 1964)
	M, S, V	Vegetation-induced erosion during morphological adjustments upstream from check dams	southern USA (Maddock, 1966)
Gravel-bed rivers	M, S	Deposition of coarse sediments upstream from check dams increases the original channel slope	Sheep Creek, western USA (Van Haveren et al., 1988)
	M, S, V	Backwater induces willow vegetation expansion and deposition of fine sediments on the banks	Dunajec River, southern Poland (Klimek et al., 1990)
	M	Lower mobility of a gravel bar upstream from a small dam	Huron River, northeast USA(Evans et al., 2007
	M, A	Longer riffles, shorter pools and higher macroinvertebrates biomass upstream from dam	Kinu River, Japan (Kobayashi et al. (2012)
	H, S	Higher flood-water level in backwater zone	Skawa River, southern Poland (Książek, 2006)
	M	Channel widening and sediment slug formation during the initial phase of river adjustments in backwater zone	Dunajec River, southern Poland (Liro, 2015; 2016)
	M, V	Long-term (>50 years) backwater-induced channel narrowing and sinuosity increase depend on the initial accommodation space available in the river channel for further vegetation expansion	Smolnik and Dunajec Rivers, southern Poland (Liro, 2017)
Fine-grained-bed rivers	M, S	First model of channel pattern adjustments upstream from a large dam reservoir	Weihe River, west-central China (Xu, 1990)
	M, S,	Channel narrowing and capacity decreasing due to fluctuating backwater-induced deposition	Illinois, Mississippi River, USA (Bhowmik et al. (1988)
	M, S, V	First model of channel–floodplain morphological adjustments incorporating the role of vegetation in the morphological changes)	Laohahe River, northeast China (Xu and Shi, 1997)
	M, S	First study describing morphological interaction between main river and its tributary in the base-level raised zone of a large dam reservoir	Laohahe and Yangchangzihe Rivers, northeast China (Xu, 2001)
	M, S, V	Vegetation expansion in the fluctuating backwater zone	Słupia River, northern Poland (Florek et al., 2008)
	H, M	Channel narrowing in backwater (results from 2D modeling)	TGR, Yangtze River, central China (Lu et al., 2010)
		Water level fluctuation zone (WLF) or drawdown zone around large dam reservoir	
Gravel-bed river	M, V	Dominance S. subfragilis within the drawdown zone of reservoir	Miharu dam reservoir, northestern Japan (Azami et al., 2013)
Fine-grained-bed rivers	V	Temporal water inundation reduces the number of plant species	TGR, Yangtze River, central China (Huang, 2001 after Tang et al., 2014)
	S	Deposition of heavy metal-enriched sediments in the WLF zone of dam reservoir	TGR, Yangtze River, central China (Tang et al., 2014)
	M, S, V, A, H	Development of specific morphological zonation in the WLF zone of dam reservoir resulting from backwater–human interactions	TGR, Yangtze River, central China (Bao et al., 2015)
	V	Alien species invasion in WLF zone of TGR	TGR, Yangtze River, central China (Chen et al., 2015)
	M, S	Initial channel morphology and pioneer local topography constitute the key geomorphological factors accounting for rapid sedimentation in WLF zone	TGR, Yangtze River, central China (Tang et al., 2016)
	S	Water level fluctuations change soil dynamics in reservoir shoreline	TGR, Yangtze River, central China (Su et al., 2017)
	S, V	Soaking plant decomposition due to the inundation change nutrient budgets in the WLF zone (fine-grained-bed river)	TGR, Yangtze River, central China (Xiao et al., 2017)

MODEL OF BACKWATER-INDUCED ABIOTIC-BIOTIC INTERACTIONS IN FLUVIAL SYSTEM

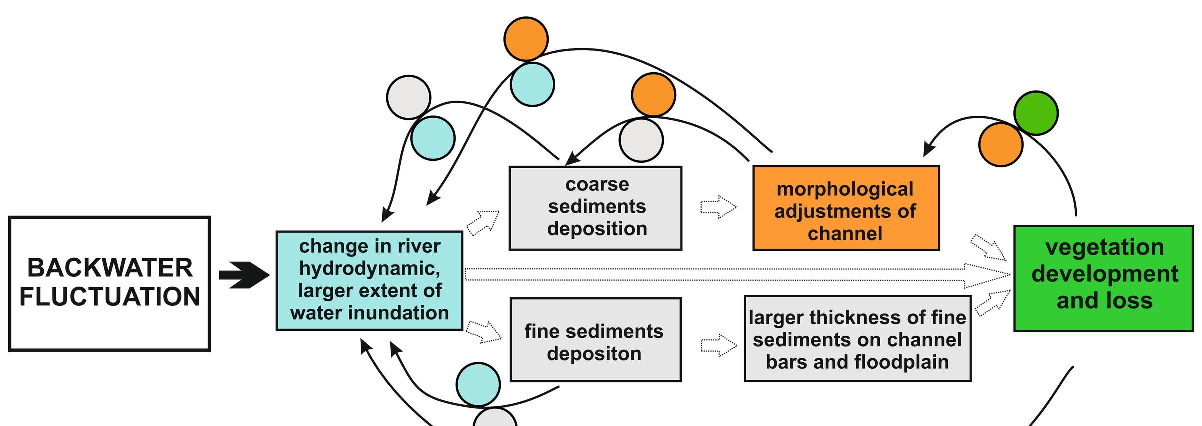


To synthesize the findings revised above, I developed a conceptual model which systematizes backwater fluctuation influences on abiotic (hydrology, sedimentology, morphology) and biotic (vegetation, animals, human) components of a fluvial system and provides a conceptual guidance for the formulation of new hypotheses concerning interactions between the altered components **(2)**. The model includes animals and humans because the above review suggests that these components are influenced by and interacting with backwater fluctuation effects and other abiotic and biotic components of rivers **(2)**. Based on their sequence of occurrence and temporal and spatial extent, backwater fluctuation influences can be divided into: **(i) first-order influences**, **(ii) second-order influences**, as well as **(iii) feedbacks induced by backwater fluctuation (2)**. The timescales for their occurrence may last from seconds for first-order changes in river hydrodynamics to decades or centuries for feedbacks between biotic components (e.g., vegetation–animals interactions).

IMPLICATIONS FOR GRAVEL-BED RIVERS

Model implies that in the backwater zone of a gravel-bed river in the temperate climatic zone, geomorphic and vegetation structures **(3, 4)** as well as the zonation of vegetation–hydromorphology interactions **(TABLE 2)** and biogeomorphic succesion phases may be significantly changed **(TABLE 3)**.

3 FLOW-SEDIMENT-MORPHOLOGY-VEGETATION INTERACTIONS IN GRAVEL-BED RIVER



4 HYPOTHESIZED BIOGEOMORPHOLOGICAL STRUCTURE OF GRAVEL-BED RIVER IN BACKWATER ZONE

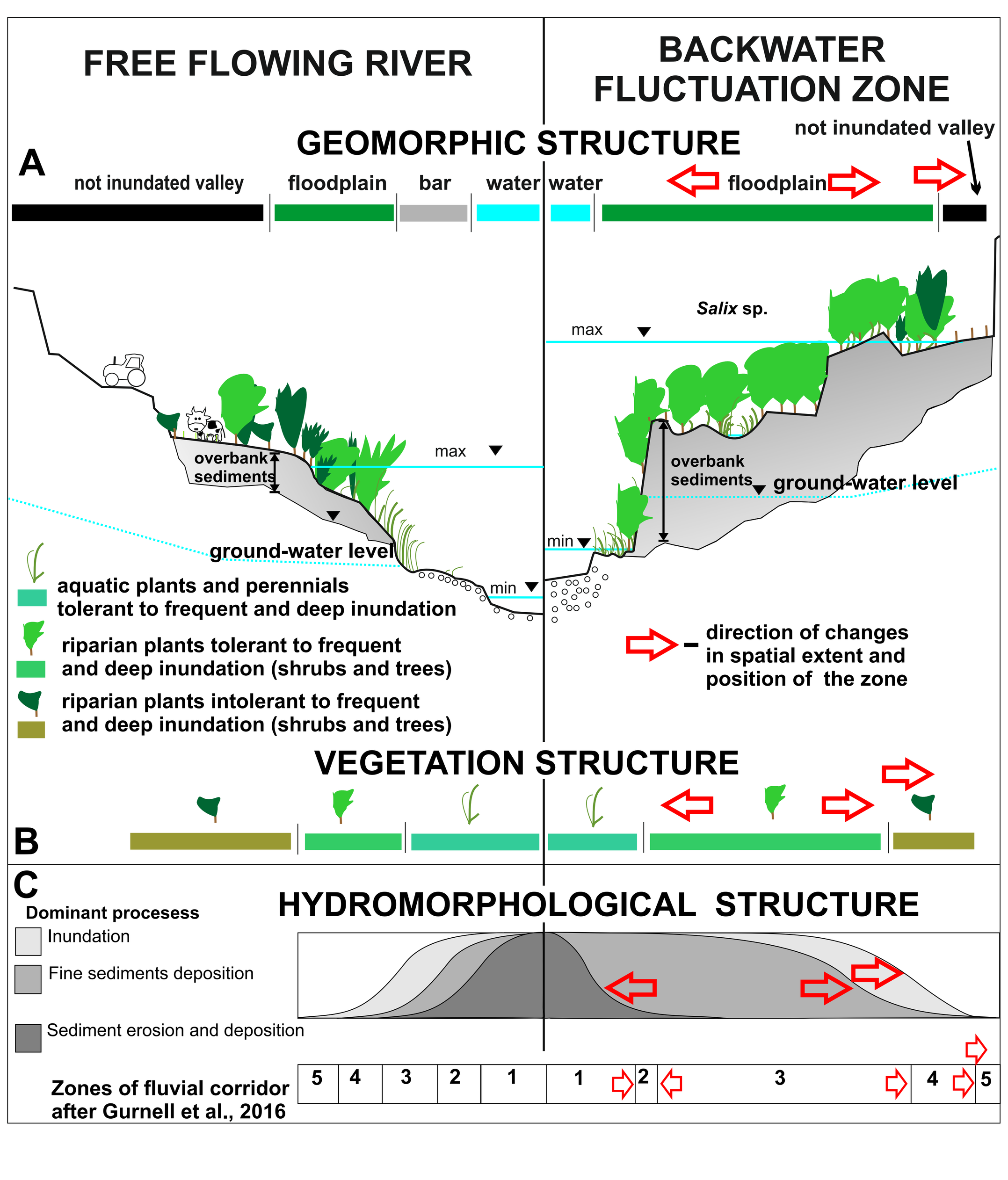


TABLE 2. Hypothesized changes of the zones of vegetation –hydromorphology interactions distinguished by Gurnell et al.(2016) in the backwater fluctuation zone of gravel-bed river.

Zone of vegetation–hydromorphology interactions in fluvial corridor	Zone characteristics (based on Fig. 1A in Gurnell et al. (2016)	Implications for extent and location of the zone in backwater reach of gravel-bed river
Zone 1	*Permanently inundated.* High sediment dynamics. Aquatic plants tolerant to permanent inundation, scour and burial.	*Slight extension or stability*. Some parts of zone 2 may be included in zone 1 because of increased low-water stages and bar submergence as well as reduced potential for the formation of new bars.
Zone 2	*Fluvial-disturbance dominated.* Frequently inundated. High dynamics of coarse sediment. Riparian and emergent aquatic plants tolerant to regular inundation and moderate intensity of sedimentation.	*Slight shrinkage or stability.* Because of the lower potential for fluvial disturbance in backwater (coarse sediments erosion/deposition) and higher low-water level, part of this zone will change to zone 1.
Zone 3	*Fluvial-disturbance dominated.* Regularly inundated. Significant fine sediment deposition. Riparian plants tolerant to regular inundation and moderate intensity of sedimentation.	*Significantly extended*. Higher and more frequent water inundation in backwater results in thicker layers of fine sediments. The zone will occupy parts of the former zone 2 (bars and islands transformed to floodplain) and zone 4 (now more frequently inundated by backwater).
Zone 4	*Inundation-dominated.* Occasionally inundated but no significant sediment dynamics. Riparian plants with varying inundation tolerance according to local microtopography.	*Extended and pushed to the higher elevation.* As a result of the higher extent of inundation of the valley floor in backwater, this zone will occupy higher position. The potential for extension will depend on the valley floor morphology.
Zone 5	*Soil moisture-regime dominated*. Inundation absent or extremely rare. Soil moisture regime is a primary physical control. Plants tolerant to local soil moisture/alluvial groundwater regime.	*Pushed to the higher elevation.* The zone will occupy areas previously not subjected to inundation.

TABLE 3. Characteristics of the biogeomorphic succession phases distinguished by Corenblit et al. (2007) and implications for their occurrence and trajectory in the backwater fluctuation zone of a gravel-bed river.

Biogeomorphic succession phase of Coreblit et al. (2007)	Phase characteristics and duration	Implications for phase occurrence and trajectory in backwater reach of a gravel-bed river
1 Geomorphic	Vegetation removal, rejuvenation and bare surface formation (large flood). Driven by flow and sediment characteristics. Continuous at a local scale, punctual at larger scale.	*Inhibited.* Decreased potential to occur effectively, especially in the lowermost part of the backwater, because of decreased energy of flood flows and limited effectiveness of morpho-sedimentological changes needed for the phase to occur.
2 Pioneer	Vegetation recruitment on bare surfaces. Control by unidirectional effects of hydrogeomorphic processes on plants seed dispersal and depositon, germination and seedling survival. A few days to a few months.	*Facilitated.* The phase may occur more rapidly in the backwater zone because of the lower flow energy and erosion potential. However, the decreased possibility of the occurrence of the previous *geomorphic phase* in backwater may reduce the amount of bare surfaces for vegetation expansion in comparison with a free-flowing river.
3 Biogeomorphic	Strong interactions between hydrogeomorphic processes and the establishing vegetation, e.g. enhanced sediment deposition around vegetation leading to vegetated landform development. A few years to a few decades.	*Strongly facilitated.* The phase may occur more rapidly and effectively because of the lower potential for erosion of previously developed vegetation and of the continuous deposition of fine sediments resulting from backwater inundation.
4 Ecological	Aggradation and stabilization of raised islands, banks and floodplains. Vegetated areas become disconnected from hydrogeomorphic influences. Control mainly for biotic interactions. A few decades to a few centuries.	*Strongly facilitated.* The phase may occur more rapidly because of the sediment deposition resulting from backwater influence. Elevated banks and floodplain may be disconnected from the direct influence of hydrogeomorphic processes. Plants resistance to the temporal inundation from reservoir backwater or human impact may be a key factor shaping biotic interactions.

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All references in: Liro, M. 2019. Dam reservoir backwater as a field-scale laboratory of human-induced changes in river biogeomorphology: A review focused on gravel-bed rivers. Science of The Total Environment 651:2899-2912. open acces link -> https://authors.elsevier.com/a/1XvudB8ccgffm