Floodplain Restoration

INTERVENTION CATEGORY: RESTORATION

DESCRIPTION

Although representing less than one percent of the earth's land surface, river floodplains provide nearly 25% of overall terrestrial ecosystem services, with primary benefits including attenuation of flood flows, fisheries productivity, groundwater recharge, and water purification.[1] The natural functionality of floodplains has however been compromised in many areas, due to land drainage, intensive urbanization and river channelization. Floodplain soils are generally very fertile and have often been drained for agricultural purposes. Floodplains in many places have also been separated from the river by structures designed to control the flow of the river.[2] However, levees close to the channel come with several disadvantages, as they suffer from erosion due to high-velocity water (and thus require high maintenance costs), strongly affect natural habitats along river edges, often increase flood risks upstream and downstream of levees, and are prone to failures.[3]

When restoring river floodplains, the objective is usually to restore their retention capacity and ecosystem functions by reconnecting them to the river. Typical interventions include modification of the channel, removing of any legacy sediment, creation of (oxbow) lakes or ponds, modification of agricultural practices, revegetation, wetland creation, invasive species removal, and riparian buffer installation and development.[2] Levees can be moved away from the channel to allow for more natural flood dynamics, and/or flood bypasses can be created to reconnect large portions of historical floodplain to the river for inundation under high-water conditions.[4, 3]

The Nature Conservancy
Protecting nature. Preserving life.

AFD
AGENCE FRANÇAISE DE DÉVELOPPEMENT

PHOTO: © ERICH SCHLEGEL

WATER SECURITY CHALLENGES (WSCs) ADDRESSED

TYPE		IMPACT	MAGNITUTE	DEPTH OF EVIDENCE BASE
Water availability	Groundwater recharge	Increased mean annual groundwater recharge	★★☆	★★☆
	Dry season flows	Maintained dry season flows	★★☆	★★☆
Disaster risk	Flood risk	Reduced peak discharge	★★★	★★★
Water quality	Erosion and sedimentation	Reduced on-site erosion and sediment yields	★★☆	★★★
	Nutrients and pollutants	Reduced in-stream nutrient and pollutant concentrations	★★☆	★★☆

Reduction of flood risk is a major water security benefit provided by ecologically well-functioning floodplains.[5] By increasing conveyance through a section of a river, floodplain restoration can relieve "bottleneck" points on a river where floodwaters would tend to back up and potentially cause flooding.[6] Water storage is enhanced as river water spills into the floodplains. Retention can be improved by breaches in summer dikes, by-pass channels and oxbow lakes in the floodplain.[2] The greater roughness of vegetated floodplains reduces flow velocity. During overbank flooding, a portion of floodwaters can percolate into the shallow groundwater, depending on geology and presence of (potentially impervious) legacy sediments.[7] Land use changes associated with floodplain restoration (from artificial or agricultural to forest or wetland) typically increase annual evapotranspiration, thus increasing local humidity and regulating temperature. Increased soil organic matter content and enhanced soil structure further improve access to water for the vegetation.

Floodplain restoration will help to recover natural erosion and sedimentation processes in the river, by increasing deposition of fine sediment on the floodplain and reducing siltation of the channel. By reducing flood intensity, floodplain restoration decreases streambed and bank erosion during extreme events. River morphology may change as the water and sediment discharge conditions are restored.[2]

Another effect of sediment deposition in floodplains is the reduced nutrient load in the river, as substances adsorbed to sediment particles are removed from streamflow. This could improve water quality of downstream water bodies. Biogeochemical processes within floodplain wetlands, such as denitrification, can also reduce nitrogen loads in river water. A review of field studies across North America and Europe found that floodplain restoration resulted on average in removal of nitrate-N (NO_3^--N) of 200 kg-N ha^{-1} yr^{-1} and of total particulate P of 21 kg-P ha^{-1} yr^{-1}.[8]

OTHER BENEFITS

WHAT?	HOW?
Water temperature control[2]	Trees and shrubs help shade the stream, keeping it cooler and healthier for aquatic wildlife.
Provisional ecosystem services[9]	Provision of food, fiber, timber, medicinal resources, etc.
Carbon sequestration[9]	By increasing biomass volumes, floodplain restoration measures have an impact on CO_2 absorption and retention. Carbon is also stored in the soil profile.

Enhanced aquatic habitat	Floodplain restoration has a positive impact on baseflow and other aquatic habitat conditions, enabling recovery of the aquatic ecosystem and increased fish populations. Leaf litter from riparian woody plants provides food for macroinvertebrate life in t he stream.
Enhanced terrestrial biodiversity[2]	Floodplain restoration, especially when involving invasive species removal and reintroduction of native species, improves terrestrial habitat conditions. This can attract butterflies, birds, and other wildlife species. A greater area on the river side of the levee allows for more room for meandering and development of wetlands and forests.
Recreational, aesthetic value[9]	Creation of a more pleasant environment and opportunities for recreation.
Other beneficial uses (in case of flood bypasses)[7]	As flood bypasses are only inundated during floods they can be used for a variety of economic activities, such as agriculture, with land use varying with inundation frequency.

LINKAGES TO CLIMATE CHANGE

Mitigation: Carbon is stored in above-ground biomass, dead organic matter on the ground surface, as well as in the soil profile through C-burial.[9] At the same time, the case-specific effects of water level fluctuation on GHG emissions during cycles of drying and rewetting need to be well-understood to balance environmental benefits of floodplain restoration.[14]

Adaptation: Floodplain restoration contributes to climate adaptation through its significant attenuation of peak flows and, thus, flood risk. Increased presence of vegetation mitigates temperature increases through enhanced transpiration and provision of shade.

DESIGN-ENABLING CONDITIONS AND TYPICAL CONSTRAINTS

- Catchments need to be of sufficient size to allow for formation of river floodplains. As a consequence, floodplain restoration is more applicable to downstream sections of river basins.
- Budgetary constraints can arise if artificial/built-up features are present in the floodplain, which need to be removed.[2]
- Land may need to be acquired to proceed with the implementation of restoration measures, potentially from a large amount of (agricultural) land owners, or other ways need to be found to work with farmers to allow for temporary inundation of farmland.[10]
- The slope of the river and of the floodplains is one of the most important variables when evaluating the floodplain retention potential[11]
- Connecting floodplains on small-order streams may not provide enough retention time for impactful nutrient removal.[8]
- The potential for denitrification in floodplains is related to flood frequency, with a demonstrated higher potential in areas that are more frequently flooded.[8]
- From an ecological perspective, the management and maintenance activities must be kept minimal to enable the long-term natural development and succession. Depending on the context, the following maintenance activities may be relevant[12]: invasive species removal, renewed excavation or dredging of excess sediments, or grazing management.

RELATION TO GREY INFRASTRUCTURE

INFRASTRUCTURE?	SERVICE PROVIDED BY GREY SOLUTIONS	TYPE OF RELATION
Embankments[7]	Flood control	Complementary (effectiveness of natural floodplains can influence required dimensions of flood control structures), Alternative
Sluice gates[7]	Existing small sluices can be used to prolong inundation duration of floodplains	Complementary
Water treatment plants[3]	Water purification	Complementary, Alternative

COMMON RISKS AND TRADE-OFFS

- Rapid growth of invasive species in the nutrient-rich habitats, e.g. caused by seeds contained by flood waters[13]

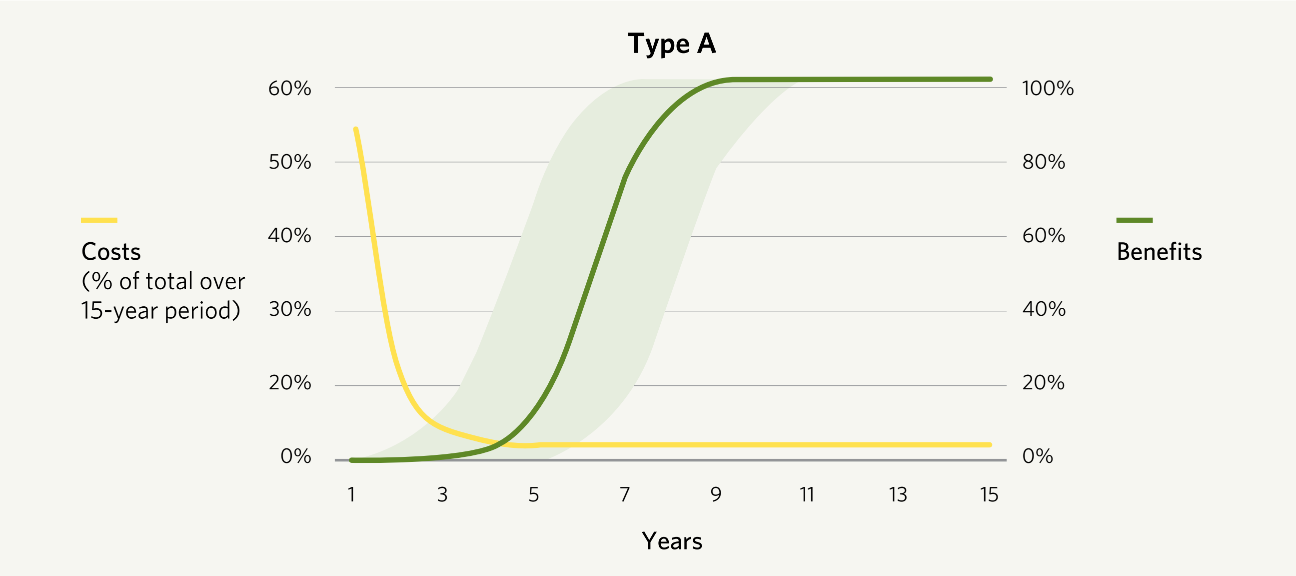
MONITORING OPPORTUNITIES

- A comprehensive review of different methods for monitoring effectiveness of floodplain restoration is available.[15] Suitability of different techniques (field surveys, UAVs, LiDAR[16], satellite remote sensing) is found to vary with spatial extent of the restoration project.
- Key physical parameters that need to be monitored with these techniques, from a WSC perspective, include channel and floodplain morphology, sediment concentration and deposition, water quality, and riparian vegetation.[15]
- Downstream discharge can be monitored with flow gauges to evaluate impact of floodplain restoration measures.

IMPLEMENTATION COSTS AND TIMING OF BENEFITS

The primary **capital costs** for levee setbacks are the removal and construction of levees. Costs of establishing a flood bypass at any location consists of the investment needed in construction works, as well as any costs associated with easements or title for land to ensure access to the floodplains.[3] Floodplain restoration costs are highly variable with e.g. land prices. Across Europe, a cost range from approximately $10,000 to $800,000 per hectare is reported.[17] In the Sigmaplan floodplain restoration project (Scheldt Estuary, Belgium and The Netherlands), land acquisition costs were €700,000/ha for residential areas, €24,000/ha for industrial areas, €12,000/ha for recreational area, and €10,000/ha for high-value crops. Other capital costs included dike heightening and other engineering costs, amounting to 10% of total investment**. Recurring costs** from maintenance were only 0.5-1.5% of investment costs.[2]

Although overall costs can be substantial, they are often counterbalanced by **benefits** from avoided grey infrastructure investments.[6] The floodplains store flood waters and lower flood levels, thus potentially lowering the cost and/or improving the resilience of built solutions, such as flood control embankments, sluice gates, and pumping stations.[7] Avoided economical damage from floods can be many times higher than overall investment, particularly in economically active urban areas.[3] Even if only nutrient retention effects are considered, these may economically justify required dike realignment investments in many cases.[18]



Lower Dungeness River floodplain Restoration, before and after (source: Clallam County, Washington)

EXAMPLES

Well-documented floodplain restoration projects, often implemented on large scales, are especially available from the United States and Europe. Some examples are given below:

Lake Champlain Basin, Vermont and New York, United States[19]

Brief description: The costs and benefits of floodplain protection were evaluated based on ecosystem service valuation, buildout/conservation analysis, hydrologic calculations of current existing peak flows and predicted future peak flows, hydraulic modeling of floodplains, building damage simulations due to flooding, and a cost-benefit accounting to determine what form of flood risk reduction makes sound economic sense.

Lessons learnt:

- Each of the Towns in this study has a large base value of ecosystem services delivered from floodplains over a 50-year timeframe: $38.1 million to $216.3 million in Waterbury, Vermont and $4.5 million to $37.0 million in Willsboro, New York. These benefits are especially provided by addressing WSCs through erosion control and flood mitigation.
- Floodplain restoration in strategic locations reduces damages and allows flood mitigation activities to work more effectively. The proposed floodplain restoration in Waterbury decreases existing annual building

damages by ~20%, leading to an overall reduction of $2.6 million dollars of simulated damage for a single modeled heavy tropical storm flood event.

- All considered mitigation activities reduced building damages for both today's floodplains as well as those predicted in 2065. The more naturally functioning floodplain that exists, the lower the damages to buildings in the floodplain due to enhanced flood mitigation.

Danube River Basin, Serbia, Slovenia, Slovakia[9]

Brief description: The benefits of floodplain restoration in terms of monetized ecosystem services (ES) in three study areas of the Danube catchment were estimated. Activities considered include cleaning and widening connecting channels between the river and lakes, deepening existing oxbows and channels, excavating new channels, and riverbed deepening. A total net gain was found of approximately 1.5 million USD/yr in Begecka Jama, 237,000 USD/yr in Krka, and 3.1 million USD/yr in Morava.

Lessons learnt:

- Important benefits that are relatively consistent through the three areas include carbon sequestration and water-based recreation.
- The different configuration of measures across the three catchment yields very different results regarding benefits from flood risk reduction and nutrient filtering. This shows that the case-specific situation needs to be well-analyzed in the design of floodplain restoration projects to address WSCs.

REFERENCES

1. Costanza, R. et al. Changes in the global value of ecosystem services. *Glob. Environ. Chang.* **26**, 152–158 (2014).
2. EU-NWRM. *Individual NWRM Floodplain restoration and management.* (2013).
3. UNEP-DHI. *Green Infrastructure: Guide for Water Management.* (2014) doi:10.1177/073346488800700208.
4. IOWA DNR. *River Restoration Toolbox Practice Guide 4: Floodplain Restoration.* https://pubs.acs.org/doi/10.1021/acsami.9b03822 (2018).
5. Opperman, J. J., Luster, R., McKenney, B. A., Roberts, M. & Meadows, A. W. Ecologically functional floodplains: Connectivity, flow regime, and scale. *J. Am. Water Resour. Assoc.* **46**, 211–226 (2010).
6. Opperman, J. J. A Flood of Benefits: Using Green Infrastructure to Reduce Flood Risks. *Nat. Conserv.* 1–27 (2014).
7. Browder, G., Ozment, S., Bescos, I. R. & Gartner, T. *Integrating Green and Gray: Creating Next Generation Infrastructure.* (2019).
8. Gordon, B. A., Dorothy, O. & Lenhart, C. F. Nutrient retention in ecologically functional floodplains: *A review. Water* (*Switzerland*) **12**, 15–17 (2020).
9. Perosa, F. et al. Integrated valuation of nature-based solutions using tessa: Three floodplain restoration studies in the Danube catchment. *Sustain.* **13**, 1–22 (2021).
10. Roth, D. & Winnubst, M. Reconstructing the polder: Negotiating property rights and 'blue' functions for land. *Int. J. Agric. Resour. Gov. Ecol.* **8**, 37–56 (2009).
11. Habersack, H. *et al. Risk Assessment and Risk Management: Effectiveness and Efficiency of Non-structural Flood Risk Management Measures – Flood risk reduction by PReserving and restOring river Floodplains* (*PRO_Floodplain*). (2008).
12. Wolters, H. A. & Platteeuw, M. GUIDELINES FOR REHABILITATION AND MANAGEMENT OF FLOODPLAINS ecology and safety combined Guidelines for rehabilitation and. *Water Manag.* (2001).
13. Wetland Science Institute. *Wetland Restoration, Enhancement, and Management. Natural Resources Conservation Service* http://www.restorenhwetlands.com/pdf/wrem.pdf (2003).
14. Machado dos Santos Pinto, R. et al. River-floodplain restoration and hydrological effects on GHG emissions: Biogeochemical dynamics in the parafluvial zone. Sci. Total Environ. 715, 136980 (2020).
15. Roni, P., Hall, J. E., Drenner, S. M. & Arterburn, D. Monitoring the effectiveness of floodplain habitat restoration: A review of methods and recommendations for future monitoring. *WIREs Water* **6**, 1–30 (2019).
16. Fuller, I. C. et al. An index to assess the extent and success of river and floodplain restoration: Recognising dynamic response trajectories and applying a process-based approach to managing river recovery. *River Res. Appl.* **37**, 163–175 (2021).
17. European Environment Agency. *Green Infrastructure and Flood Management: Promoting cost-efficient flood risk reduction via green infrastructure solutions. Publications Office of the European Union, Luxembourg.* (2017).
18. Grossmann, M. Economic value of the nutrient retention function of restored floodplain wetlands in the Elbe River basin. *Ecol. Econ.* **83**, 108–117 (2012).
19. Schiff, R., S. Bighinatti, E. Fitzgerald, N. Wahlund, D. Carlton, A. Church, J. Louisos, B. C. *Evaluating the Costs and Benefits of Floodplain Protection Activities in Waterbury, Vermont and Willsboro, New York, Lake Champlain Basin, U.S.A.* (2015).