RIVER ECOSYSTEMS REHABILITATION

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Summary

Recently, physical stream rehabilitation/restoration in Europe has become a priority for local, regional, national and international authorities. The key to restoration is the understanding of the complex spatial and temporal interactions between physical, chemical and biological components on a whole catchment scale. The catchment comprises aspects of spatial and temporal scale and hierarchy. Thus, an effective decision support system should include the catchment approach in the restoration plan. Such a whole watershed approach can generate solutions which can be more effectively applied to sustainable management that includes water resources quality and quantity, and diversity and abundance of biota. The modern restoration approach should prioritize and reduce human impacts and develop management tools that increase system resilience to changing human impacts at local and global scales.

1. Introduction

After a very long period of adapting streams and rivers as well as their catchments to agricultural, domestic, drinking water and industrial needs amongst others, people became aware of the damage being caused by these alterations. In the Netherlands, only about 4% of the streams still have a natural morphology and a (more or less) natural hydrology. In Denmark only 2% is more or less natural and in Germany the respective value is between 2 and 5% (current results of the mapping of stream morphology in almost half of the country).
Environmental awareness, concern for the loss of stream and floodplain habitats and biodiversity provided the (political) route for stream rehabilitation and restoration. Recently, physical stream restoration has become a priority for local, regional, national and international authorities. Stream restoration is growing very fast in Europe. For example, in the Netherlands in 1991, 70 projects were performed, in 1993 this had risen to 170, and by 1998 it was up to 206, with a total cost of about 1.3 billion euro (Verdonschot and Nijboer, 2002). From the scientific and technical point of view, there are many possibilities for physical stream restoration, e.g. reforestation of the floodplain, restoration of meanders, removal of dams and bank fixation. New, innovative approaches include the adding of coarse woody debris, the removal of sediment deposits in floodplains (an approach described in) and various methods to combat the deep cutting of streams.

In order to make the proper choices in stream restoration, the complex spatial and temporal interactions between physical parameters, habitat diversity and biodiversity have to be understood. When a stream has been restored, the degree of success (increase in biodiversity) depends on the re-colonisation of the original (indicator) species. Whether these species will be able to re-colonise the restored stream depends on the distance to remaining populations, dispersal barriers between the remaining population and the restored stream, and the dispersal ability of the species. Establishment of an invasive or non-native species may also hinder re-colonisation, and biodiversity may in general be threatened by invasive species replacing the native ones.

2. Concepts in stream restoration ecology

The key to restoration is the understanding of the complex spatial and temporal interactions between physical, chemical and biological components. The success of restoration depends on steering the appropriate key factor(s). Which factor this is, differs for each stream and each site.

Like most ecosystems, lowland streams are composed of groups of interacting and interdependent parts (e.g. species, resources) linked to each other by the exchange of energy and matter. Linkage not only occurs between different parts in the transverse profile of a stream but also between upstream and downstream parts of a stream. For a long time, the longitudinal component of a stream was seen as a sequence of inter-linked zones or as a longitudinal continuum. But exchange of energy and matter is not limited to the stream itself. Hynes (1975) was the first to include the catchment. Stream ecosystems are considered to be complex because their functioning is not limited by the stream itself and the banks but it stretches out all over the catchment. Within the catchment as a whole, streams are characterised by strong interactions between components, feedback loops, significant interdependencies in time and space, discontinuities, thresholds, and limits. To untangle this complexity, Ward (1989) introduced the concept of the four dimensional nature of stream ecosystems with a longitudinal, lateral, vertical and temporal component (Figure 1). In addition to this theory about dimensions, a second theory is important. Frissell *et al* (1986) ordered the controlling factors from catchment to stream habitat in a hierarchical space and time framework. Processes in streams are important at different scales. The organisms in a stream are dependent on habitat characteristics. These characteristics are in their turn dependent on morphology and hydrology of a stream. Morphology and hydrology depend on geomorphologic structure and climate in the catchment. Knowledge of this hierarchy allows us to infer the direction and magnitude of potential changes (alteration as well as restoration) due to human activities.

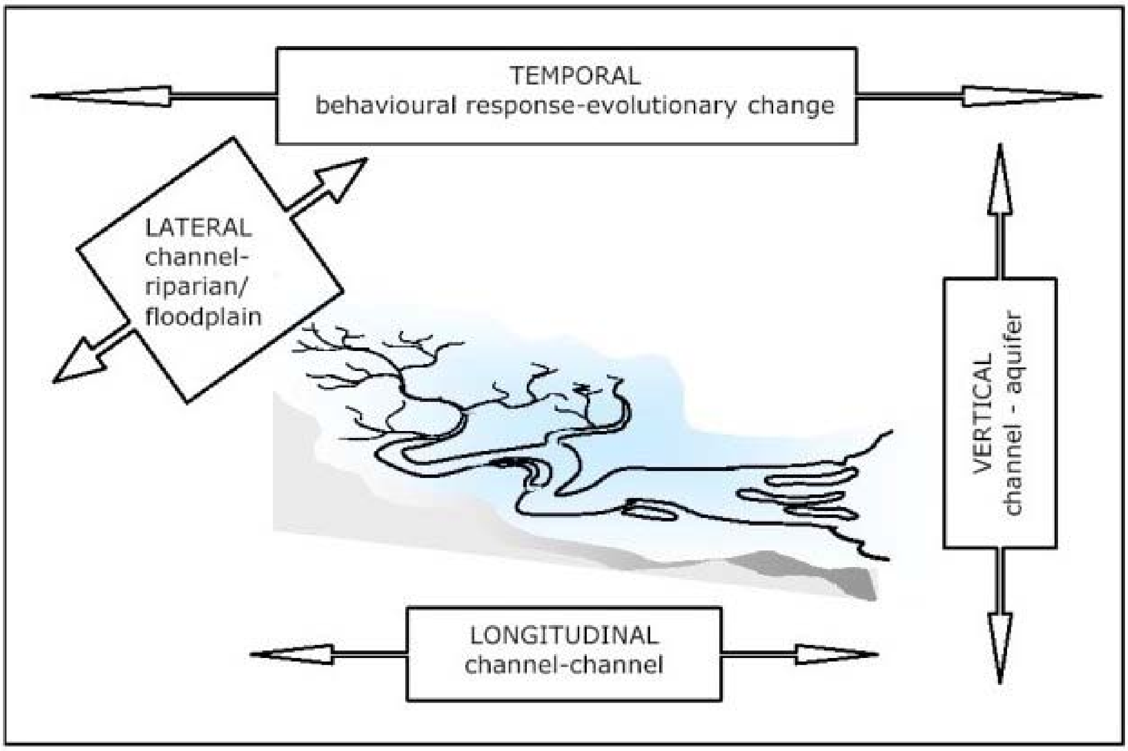

Figure. 1. The four-dimensional nature of river ecosystem (after Ward 1989, changed).

2.1. The catchment as backbone in restoration

Stream restoration can only become successful through an integrated catchment approach. The transport property of a stream is the most important process and directly depends on the catchment (spatial component). Because of the open character of the stream, it reflects the past and present structure and functioning of the whole catchment and thus includes the temporal component. Water that infiltrates in the catchment can have a long retention time before it enters the stream. In a catchment approach the longitudinal and transversal components also include the 'dry' floodplain and the (infiltration) areas at a higher altitude in the catchment. In fact, infiltration areas affect the stream water quality and land use in these areas influences, amongst others, transport of substances towards the stream. The deep groundwater flow, which connects infiltration areas to the streams, is important in lowland streams and differs in the different reaches. Upper courses often only receive subsurface and less deep flow; middle reaches can receive subsurface flow but are also often infiltrating, and lower reaches almost always receive deep, old groundwater. The water enters the stream in a more vertical direction as seepage. In conclusion, a stream is part of its catchment and cannot be studied without looking along all dimensions.

Large catchments are comprised of tributaries and their sub-catchments. Tributaries contain multiple stream reaches, each reach of which potentially includes different habitats, and these habitats each contain multiple microhabitats (Frissell *et al*, 1986). The multitude of processes that form stream systems exist within a hierarchical framework . The catchment comprises aspects of spatial and temporal scale and hierarchy (Figure 2). The temporal component is not always independent from the spatial ones and can be added to each of them.

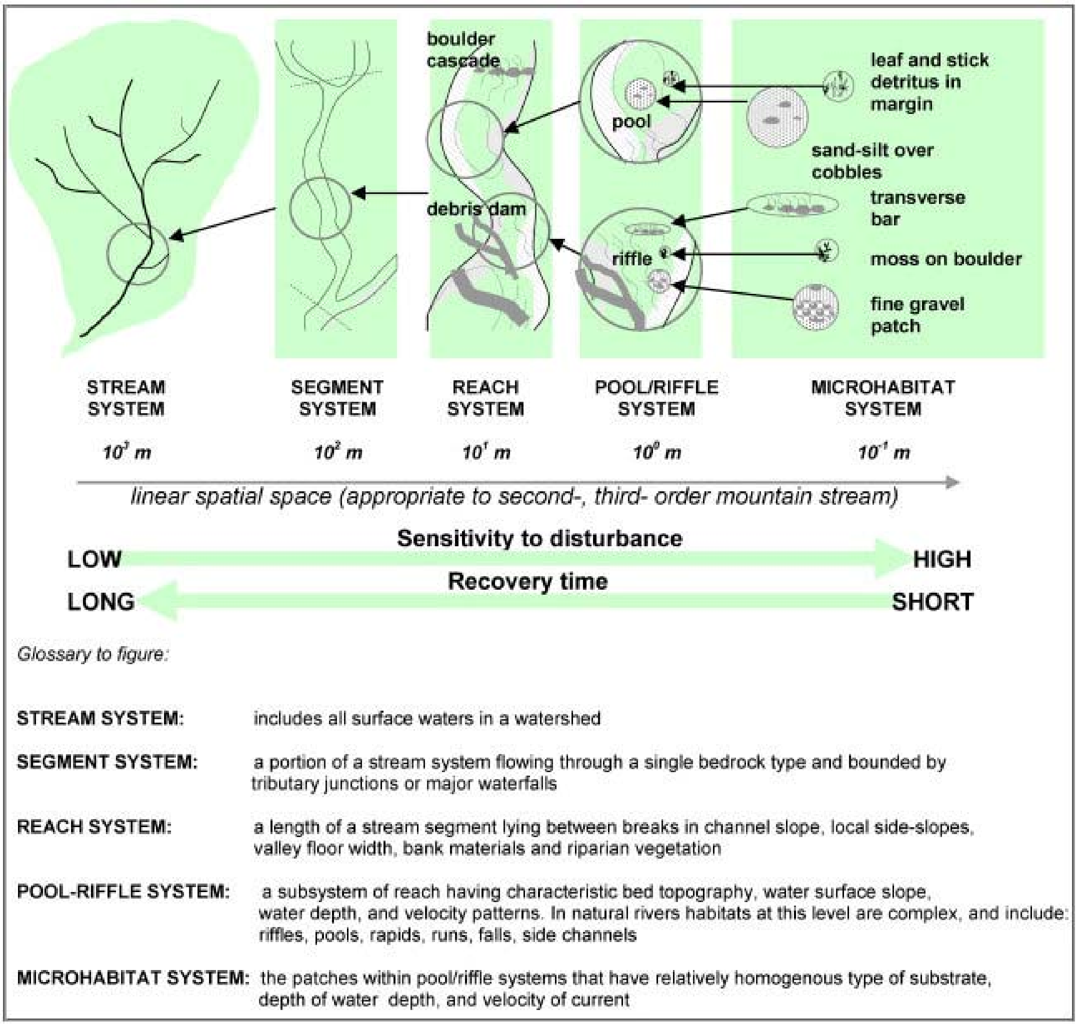

Figure. 2. Hierarchical organization of a stream system and its habitat subsystems (after Frissell *et al* 1986, changed).

The longitudinal component stretches out over the whole spatial area of the catchment. It more often concerns processes acting over a long-term period, such as deep groundwater flow and processes of longitudinal meandering. But there are also examples of shorter term processes like nutrient spiralling and fish migration. The longitudinal component can be related to a coarse spatial and a different temporal scales.
The lateral component interacts at the spatial scale of the flood plain and concerns processes like inundation and (sub-) surface runoff. These interactions more often act over a shorter time period. The lateral components also include the creation and evolution of oxbows or marshes; they act over a long term. Thus, the lateral component can be related to an intermediate spatial and again different temporal scale.

The vertical component includes the riparian zone or the wooded bank as well as the thin more or less oxygenated substrate layer on the stream bottom. Its interactions more often cover a short time period such as the exchange of gases between atmosphere and water column, the emergence and reproduction of adult insects in the overhanging trees or the (bio-)turbation of the stream bottom substrate. On the other hand the vertical component is highly influenced by processes that operate at a long temporal scale, such as erosion and deposition resulting from stream incision. The vertical component can be related to fine spatial and different temporal scales.

2.2. A catchment approach acts at different scales and includes hierarchy

There is a hierarchy between the three components in space and time whereby the longitudinal component (coarser scale) bounds the range of ecological features of the lateral and vertical ones (finer scales), but also the vertical one (finer scales) affects the lateral and longitudinal components (coarser ones). Stream functioning acts at multiple spatial and temporal scales with ‘top down’ and ‘bottom up’ controls often termed dominance and feedback.

An integrated ecological approach in stream restoration should include more than one spatial scale (including at least one lower scale) and temporal scale (to include system dynamics) dependent on the objective which is addressed. Looking at stream functioning always should cover a fine, intermediate and coarse scale in space and time.
Including the whole catchment in stream ecology and restoration of streams implies working in hierarchical order. It is no use to start at a small scale (certain habitat in a stream) if there are problems on the large scale (in the infiltration area of the catchment). In a catchment approach processes at different scales in the catchment varying from microhabitat to catchment are included.

2.3. Solutions

Stream managers need a simple decision support system to handle the ecological complexity for an effective restoration plan at a site. It provides the opportunity to go through the most important steps in stream restoration and to extract the factors in the catchment that should be tackled. Each site and each stream is different. But the approach in planning a successful restoration should be the same. Such decision support systems should be based on the theories of dimensions, scale and hierarchy and force a water manager to include the catchment in the restoration plan. An example what should be considered in such a plan presents Figure. 3.

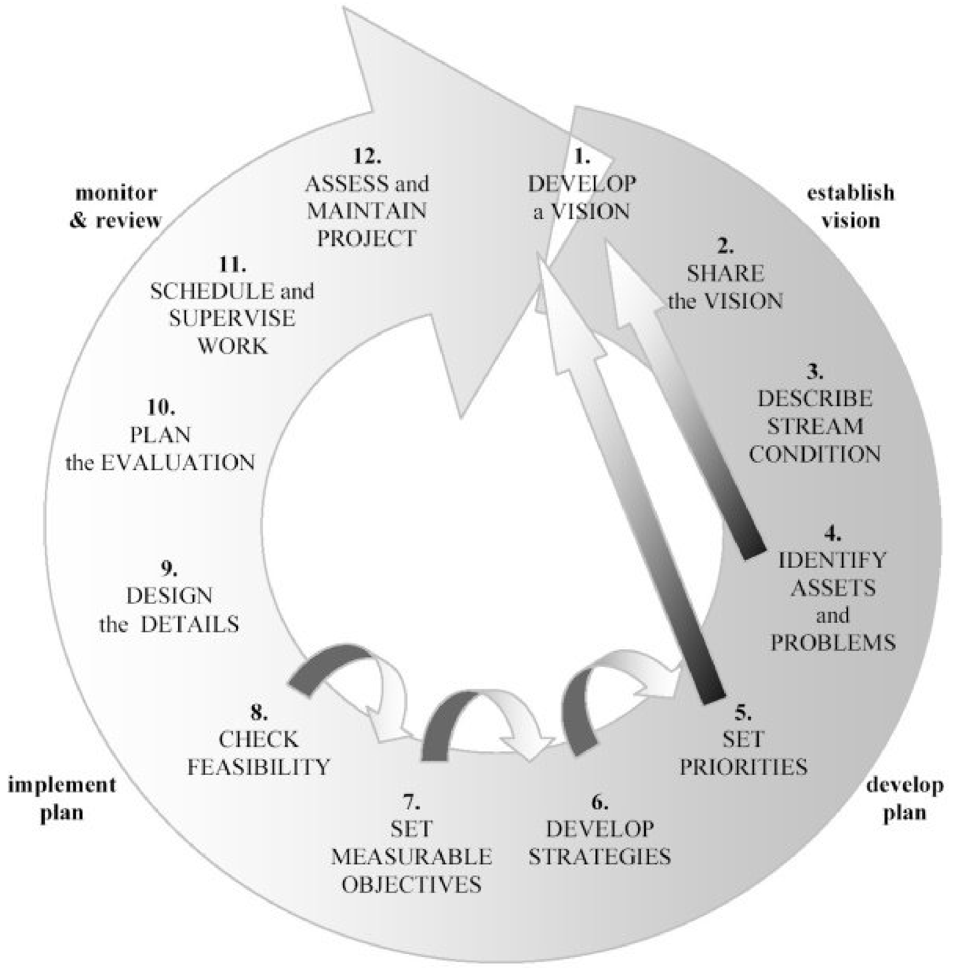

Figure 3. 12-steps stream rehabilitation procedure (after Rutherfurd *et al* 1999, changed).

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