Summary

Integrated ecological restoration in stream valleys

Development of diffuse drainage systems, lowering of discharge dynamics and stream profile recovery

Foreword

The object of the Knowledge Network for Restoration and Management of Nature (OBN) is to develop, distribute and utilize knowledge for the benefit of conservation site managers regarding the restoration of nature, Natura 2000, PAS, habitats and the development of new nature.

Thousands of kilometers of stream systems have been restored in the Netherlands in the period between 2000 and 2017 for the purpose of complying with the ecological goals and standards as put forward in the European Water Framework Directive (WFD) and the Dutch Water Policy 21st century (WB21). Many of these restoration measures are geared towards restoring physical aspects, such as re-meandering the course of streams, with no evident relationship with the hydrological, morphological and biological processes on a local scale or catchment area scale. The restoration mainly concerns changes to the stream profile and room for (limited) inundation. This sectoral approach considers the course of the stream itself and misses opportunities in terms of the integrated recovery of stream valleys; the stream and the valley with the semi-aquatic and terrestrial systems. These restoration measures do nothing in solving, for example, the groundwater depletion, which is one of the major bottlenecks with respect to complying with the Natura-2000 goals. And the same applies the other way round, as restoration measures are implemented for semi-aquatic and terrestrial systems in the valleys within the scope of nature policy (Natuurnetwerk Nederland) and Natura2000, whereby opportunities for the streams are missed. A measure from one of the two approaches to restoration (WFD + WB21 versus N2000) may be beneficial to one goal and disadvantageous to another.

The aim of the project ‘Integrated ecological restoration in stream valleys through the lowering of discharge dynamics, the development of diffuse drainage systems and differentiated stream profile restoration’ is to develop tools with which to come to well-considered choices regarding integrated restoration goals and measures with respect to the quality of streams and stream valleys.

Studies show that the best opportunities regarding the hydrological restoration of the drainage regime lie in retaining rainwater in the infiltration areas and the substrate. Preventing drainage and water depletion in these areas will prove a huge boost for the infiltration and will lead to an increase in the supply of rainwater to the aquifer, an increase of groundwater levels and less drainage. The greatest opportunities lie in locations where the dry soil can retain extra water and where surface water can remain behind in lower areas in the landscape. Improving the infiltration capacity contributes to strengthening water retainment.

It is important to point out in this respect that the future climate conditions will lead to an increase in the number of peak rain showers and more prolonged dry periods. It is essential that these prognoses are also considered when developing measures for adjusting the catchment area. It is likely that this change in the distribution of precipitation will make it even more relevant that measures be taken to lower the discharge dynamics.

Introduction

Much diversity has been lost in Dutch streams and stream valleys during the past century. Attempts to restore streams and their valleys often do not result in the desired improvement because 1) aquatic and terrestrial targets are seen as opposite and 2) much redevelopment is limited to the local scale, among other factors. Therefore, an integrated approach to stream valley recovery can provide a significant boost to enhancing biodiversity and performing successful improvement. An integrated stream valley restoration approach calls for catchment-wide hydrological measures in both the infiltration area and the stream valley. The three main hydrological measures that are central in this study are:

1. To restore heterogeneous and diffuse drainage systems.
2. To lower discharge dynamics by addressing the drainage hydrology.
3. To decrease the width and depth of stream profiles and to come to integrated stream valley restoration.

In addition, morphological measures (adapted to future discharge regimes) and eutrophication-reducing measures (such as buffering sub-surface and surface run-off and purifying in the hydrological veins) are necessary.

The main objective of the project 'Integrated ecological restoration in stream valleys' is to study the extent to which interventions in the water system, such as removal of drainage structures in infiltration areas, storage of water in the ground, reconstructing diffuse discharge areas and reducing the streambed profile contribute to a reduction in discharge dynamics. The theoretical building blocks behind the integrated approach consist of a number of concepts that are supported by international scientific literature.

The core is based on the 5-S-model (Verdonschot et al., 1998 and others). The 5-S-model stands for the processes of the ecosystem, how they function and the resulting patterns.
The model divides the catchment area into the conditioning prerequisites of the system (*S*ysteemrandvoorwaarden), the operational hydrological factors (*S*troming), the *S*tructures (morphology), the *S*ubstances (chemistry) and the response of the *S*pecies (species and ecological communities). The ecosystem approach in the 5-S-model is based on groups of key factors and key processes that are hierarchically categorized and the steering factors and processes that can be derived from these. Together, the key factors and the steering factors describe the water systems as coherent parts in areas that are defined in a hydro-ecological or spatial sense. The groups of key factors / processes and their mutual relationships are shown in Figure 1 below.

The DPSIRR-model (Feld et al. 2011) was developed to structure the interactions between the human activities and the stream- and stream valley environment. DPSIRR stands for: Driving forces (=human activities) - Pressures (=pressure factors) – State (=state of the steering factors) - Impact (=consequence for the ecosystem) – Responses (=human reaction in the form of measures) – Recovery (=restoration of the ecosystem). It describes the chain between cause and effect of human activity on the ecosystem (Figure 2 below). It is essential that this chain is understood before opting for measures. This understanding opens up opportunities to implement measures at different places in the chain (ranging from measures at the source if the driver is to be tackled to effect-oriented measures). The DPSIRR chain relates directly to the 5-S-Model.

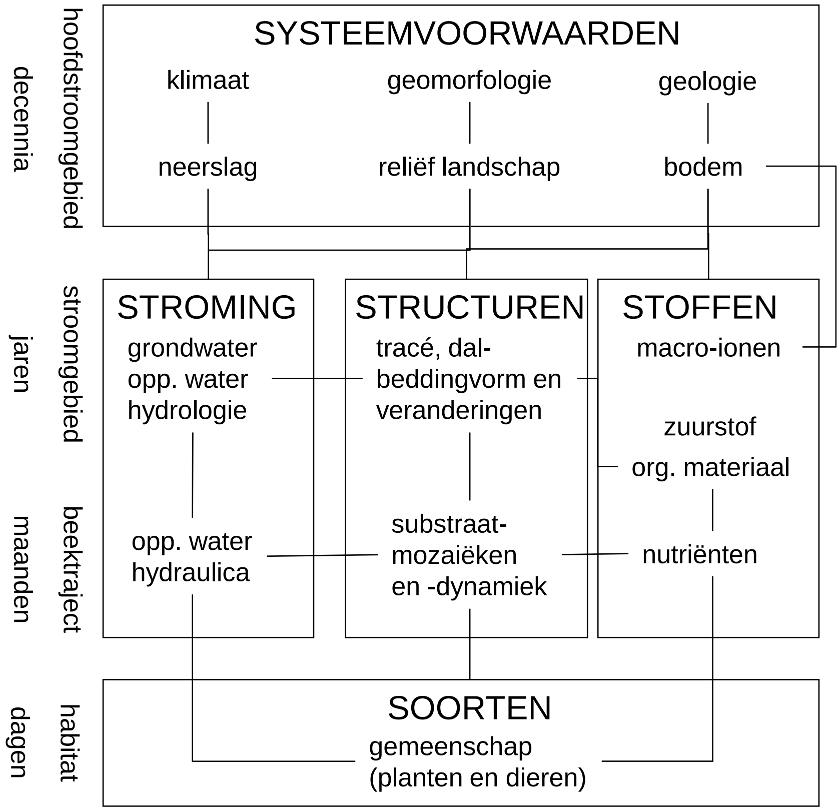

***Figure 1**: The 5-S model for running waters. The components in the 5-S model ae hierarchically ordered according to scale in space and time, with system conditions at the highest scale (large area, long time) and species lowest (habitat, days) (left column).*

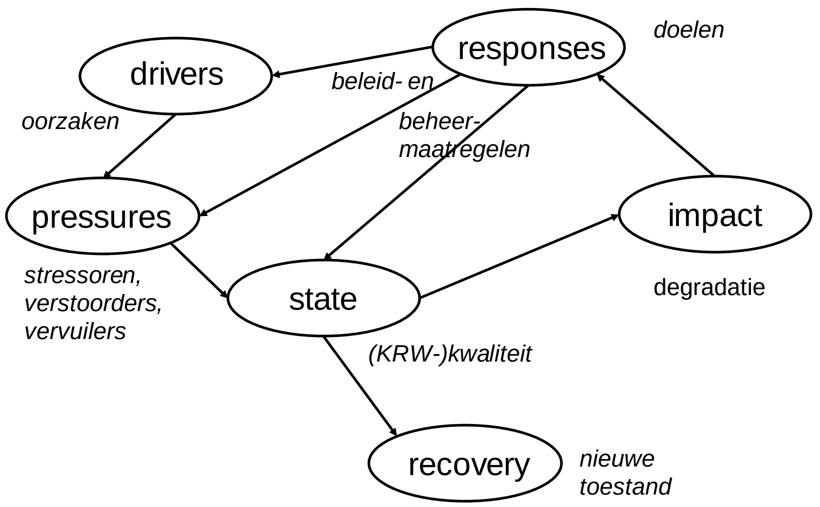

***Figure 2**: The DPSIRR-chain with mutual interactions (after EEA 1995).*

Just how species respond has to do with the strategies that the species pursue. These strategies depend up the life phase of the species and are related in terms of space and time to certain environmental circumstances (abiotic and biotic within the hydrological unit / catchment area, water body, water compartment and habitat/niche (Poff & Ward 1990, Poff 2002)).
These circumstances and the changes in that respect in the course of time make up 'habitat templates' for species and lead to the filtering out (the approach with landscape filters; Poff 1997; Figure 3 below) of species in the event of a mis-match between the characteristics of the species and the habitat or living environment that is available. The frequency, scale and predictability of this variation in environmental/habitat circumstances make up an important filter of the 'habitat template' (Southwood 1977 & 1988, Townsend & Hildrew 1994). And with that, habitat templates offer insight into the relationship between spatial and temporal variability (habitat stability) and the strategies of the species on the scales concerned (Townsend & Hildrew 1994).

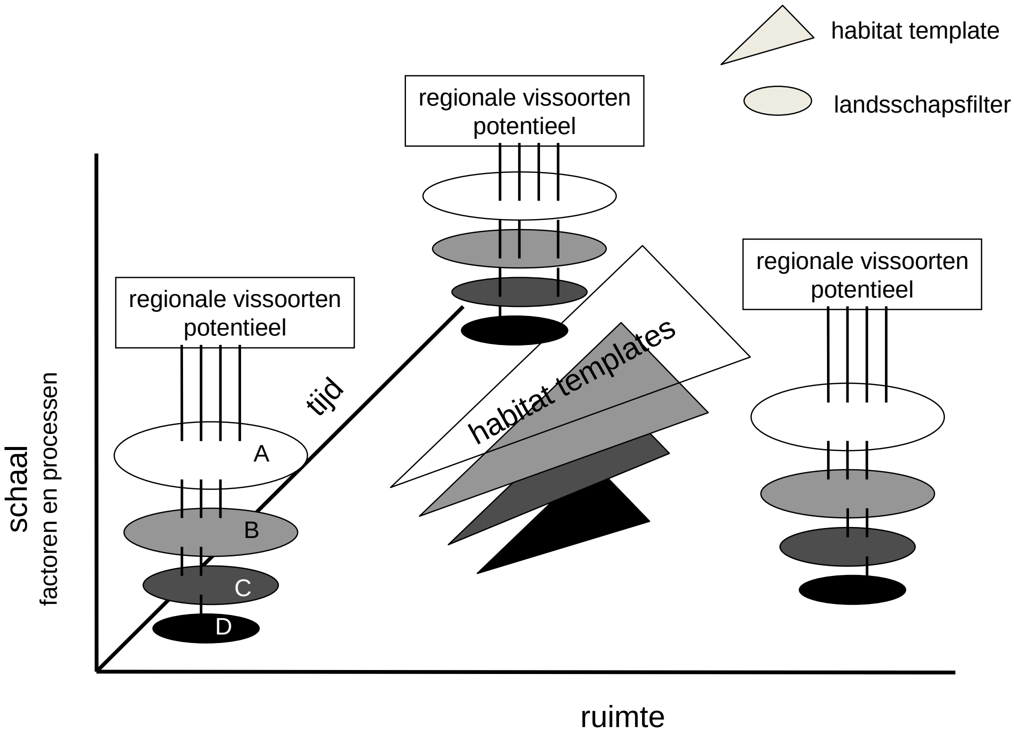

***Figure 3**: Filtering of species with certain traits on different hierarchical spatial scales with associated habitat templates (active environmental factors and processes). Habitat or landscape filters on the scale of the catchment area (A) limit the occurrence or abundance of species present on the scale of the stream valley landscape (B) and continuing on to the scale of the water body (C) and habitat scale (D), as indicated by the increasingly smaller size of the regional species 'pool' (size of the ellipse). Because conditions in surface waters are often dynamic, the operation of landscape filters varies in time and space. Based on Poff (1997), Wiens (2002) and Townsend & Hildrew (1994).*

Achieving the goal of the project involves an integration of the 5-S model, the DPSIRR concept, the operation of landscape filters and the habitat templates. The practical steps are:

- Performing an integrated ecological system analysis of processes in the catchment area, according to the 5-S model methodology.
- Understanding all disturbances in a catchment area, analysed according to the DPSIRR chain methodology.
- Setting realistic / appropriate development goals for the whole catchment area and for individual stream valley trajectories within that fit both scales and species-environment relations (using landscape filters).
- Selecting cost-effective measures.
- Monitoring the effects and adjusting them (implementing adaptive monitoring).

Method

The study began with exploring current projects that could serve as pilot studies. A potential pilot study should already be based on an integrated approach in stream valley restoration and have a running monitoring program. Such studies would be sufficiently interesting for additional, more detailed monitoring and for an evaluation of hydrological and ecological effects. A large number of stream (valley) restoration projects were considered and only a few turned out to focus on hydrological recovery. From the long list of restoration projects, Peizerdiep, Holmers, Geeserstroom and Strijper Aa were eventually chosen as pilot projects for this study.

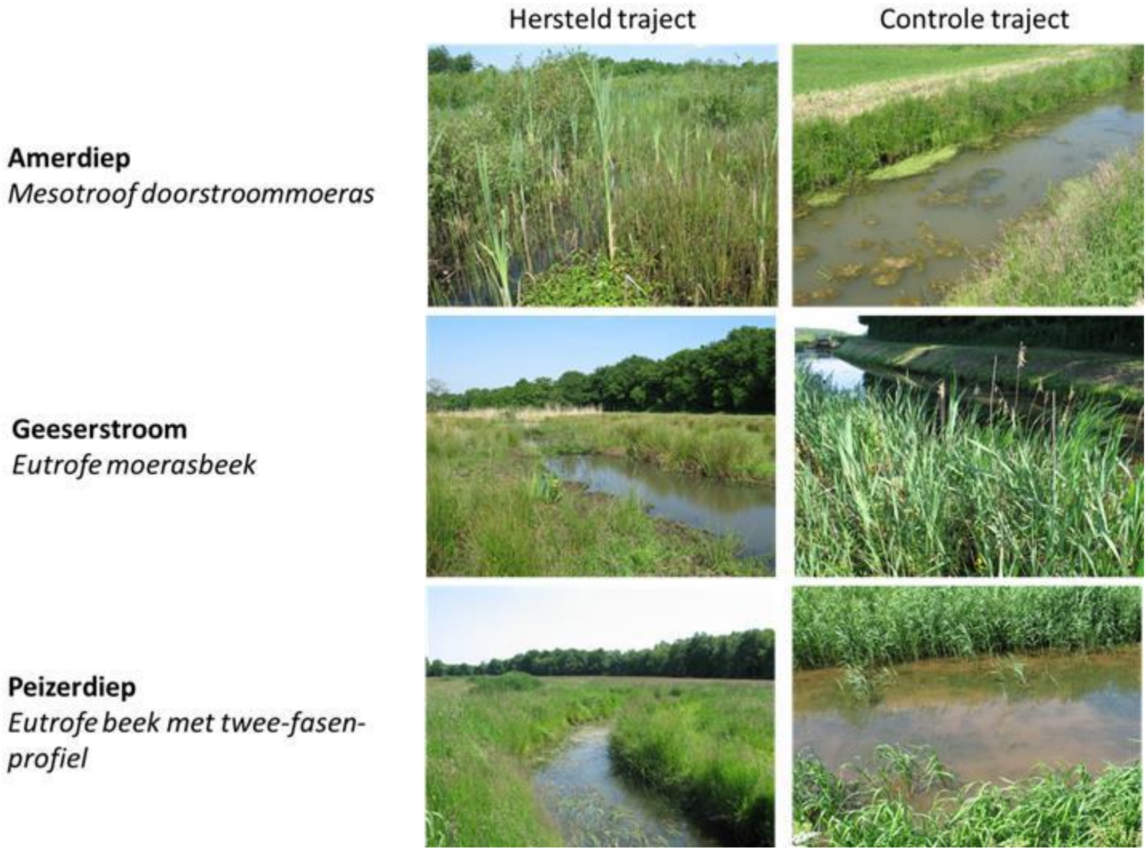

Figure 4*: Overview of the study sites. In each watershed paired restored (left) and non-restored control sections (right) were selected.*

Central theme in the catchment area of Peizerdiep is the reduction of the dynamics in the discharge regime. This study added a modelling approach to all activities of the regional water authority. Restoring the (geo-)hydrological situation of a catchment area cannot be based on reversing one or a few of all the changes that took place in the past. In many cases, a partial solution of that kind does not provide the desired effect on the discharge regime and can even cause undesirable effects. For example, increasing groundwater levels can lead to higher peak flows if the surface water drainage infrastructure and the total surface area of erosive terrain and paved surfaces are not reduced. The storage capacity must be increased in every part of the water system (below and above ground) so that the peak flows will decrease and base flows will increase. Peak discharges can be further reduced by taking measures to adapt the morphology and the vegetation development in the watercourses. It is important to combine different measures that combined result in a more equally divided flow of all available water over the year.

Stream valley recovery with the aim to reducing the dynamics in flow regime must be approached from a catchment-wide angle. An ecological system analysis of a catchment area can identify those processes that pose the greatest stress on the flow regime. In addition, processes related to conditions instream, such as stream morphology, effects of weirs, vegetation development in the wet profile and land use types (e.g. evaporation of crops, erosion-sensitive management, (semi-) paved surfaces, drainage density) and also conditions relating to the groundwater system (e.g. regional geohydrology, groundwater extraction), must be taken into account. Based on an ecological system analysis of that kind – possibly supported by a model study - a strategy can be determined to take effective restoration measures. In most cases, this strategy will require a catchment-wide approach.

The catchment area of the Holmers-Halkenbroek (upper course of the stream Amerdiep) was used as a pilot to restore a diffuse drainage system. Most diffuse drainage systems were lost due to their high susceptibility to dewatering. The restoration of large-scale diffuse drainage systems is therefore not very realistic due to the needs regarding other human uses. There are, however, still good opportunities to restore such systems in the upper courses of lowland streams, especially where it concerns streams that were dug in the past to drain groundwater-fed swamps. The most important criterion for a successful restoration is the occurrence of a continuous ground water recharge that is either still present or can be activated.
The restoration of a diffuse system with optimal hydrological conditions for the formation of peat will often not be possible. Still, the extensive use of large areas in the province of Drenthe has undoubtedly contributed to the success of the Holmers restoration project. The inventory of potential restoration projects showed that it will be difficult in many other parts of the Netherlands to take similar measures to develop well-functioning diffuse drainage systems. On a smaller scale, however, there seem to be several sub-catchment areas to restore or to develop as small groundwater-fed diffuse drainage systems.

In the Geeserstroom catchment area, the restoration exemplified a reduced streambed profile with the development of a flow-through swamp. Here, the effects of stream re-profiling (with a strong reduction of the wet streambed) were initiated and studied. The image of the natural Dutch lowland stream valley consists of a pattern of diffuse drainage systems in the upper part of the catchment area and a chain of stream sections that connect diffuse flow-through areas or swamps in a downstream direction. The discharge is fairly constant, with seasonal fluctuations, due to inundation that reduces peak flows and feeds the streams during low flows. There still is a lot of spatial flow variation instream, resulting in a high biodiversity. The streambed morphology is heterogeneous. The substrate consists of 50% sand and the remaining 50% is mostly dead wood and organic material. The streambed is shallow but wide, yet still much narrower than in the current situation.

Based on the climatological, geomorphological and hydrological conditions, Dutch lowland streams lie between 200 m and 2000 m apart from each other. Our analysis of North Brabant streams showed that under natural conditions these streams lie 700 m apart on average.

Findings

Two measures have potential where it concerns reducing the size of the streambed wet profile. The first option concerns digging a new streambed profile, which implies that the desired conditions are quickly met. However, once the re-profiling is completed, erosion-sedimentation processes will temporarily occur and change the conditions, which goes hand in hand with a larger degree of sand transport. Furthermore, the newly dug profile is virgin and colonization processes will occur that, among other things, can result in a dense vegetation mat that in turn can lead to a stagnation in flow. The alternative is to place wood packages in the streambed and subsequently add sand to the stream. After a few months, the adverse effects of the addition of sand addition will be overcome by the stream community and an even more diverse community will develop through re-colonisation. The main objective, however, is the re-connection of the stream and its valley. And frequent occurring inundations will result in gradual gradients between the wet streambed and the dry surroundings. Of course, inundation requires space in a transversal direction in the valley. Because the addition of sand is preferable to active digging and inundation is desired at the landscape level, the most promising restoration projects are those that allow for the connection of stream and valley, i.e. where the stream can be rapidly brought to the level of the mowing field.

Dutch lowlands do not actively meander. Active meandering appears only to occur during the initial phase after a recovery project in which a bare bank was created. The Dutch natural lowland streams show a meandering longitudinal profile due to passive meandering processes that are initiated by external factors, such as seepage areas that weaken stream banks or trees that act as obstacles.
As previously indicated, stream restoration goes hand in hand with valley inundations. In fact, an important goal of stream restoration is to re-establish the land-water transition or wet cross-gradient through the stream valley. The gradual transition from stream to dry valley supports a high biodiversity and is important for various ecosystem functions, such as water safety.

Substrate variation or habitat heterogeneity contribute significantly to lowland stream biodiversity. Fine-scale hydro-morphological dynamics around plants and wood packages lead to a significant biological diversity.

Figure 5: Overview of the stream valleys of the Geeserstroom (top) and the Amerdiep (bottom).

It is generally assumed that the inundation of streams results in the eutrophication of the valley floor, because the most frequently inundated areas host mostly eutrophic vegetation. However, it appears that such is not always the case. Inundations during wet periods scarcely contribute nutrients to the valley, especially when the groundwater levels are high and seepage occurs.

Each restoration project starts with a catchment-wide ecological system analysis (CESA) that identifies all the major processes in and the functioning of this catchment area. The CESA answers the following questions:
1. What would be the situation here (on a generic catchment level) without human activity?
2. What is here?
3. What could be here?
4. Which stressors are acting here?
5. What are the possible solutions?
6. What is achievable?
7. What are the alternatives?

Restoring stream valley systems also means restoring ecosystem services and functioning, often on a larger scale.

Stream valley recovery also results in positive effects for the fauna, both on the scale of micro-habitat as well as on a landscape scale. For example, wolf spiders and ground beetles were used to evaluate the micro-scale and birds were used to evaluate the landscape scale. Habitat specialists in both the groups of ground beetles and wolf spiders increased in restoration projects that were examined, with the Amerdiep (the Holmers) showing a distinct different direction of development regarding the faunal community (swamps of small sedges) in comparison to the Geeserstroom and Peizerdiep. This difference in the direction of development in the Holmers is in line with the development of a diffuse drainage system that is poor in nutrients, instead of a nutrient rich swamp system. The breeding birds in the Holmers/Amerdiep and Geeserstroom stream valleys differed, but the species composition in the Holmers/Amerdiep was clearly a poorer subset in comparison to the Geeserstroom. This difference was especially evident from the number of waterfowl and birds of wet grasslands, and to a lesser extent also in the number of species of marshes. Various factors may be the cause of this. Habitat types (particularly vegetation and open water in the Geeserstroom), but also the extent of the restored stream valley, may play a role.

Recommendations

The effects of large scale hydrological measures are still relatively unknown. The evaluation of ongoing projects showed that monitoring is still lagging behind. Water and nature management authorities should be more aware of the value of the results of monitoring. To promote knowledge development, a generic approach to monitor restoration projects was included. A proposed protocol for monitoring should include the following items and can provide answers to the following questions:

- Reason: Why this protocol?
- Problem statement: What problem is addressed?
- Conceptual design: Which processes are related to the problem and the solution, and how do they relate conceptually?
- Purpose: Which testable goal is defined?
- Questions: Which questions are answered with the intended measurements?
- Demarcation: What is being measured and what not?
- Measurement design: How, when, and what will be measured (including design (BACI, CI, ...), parameters, methods, frequency, time planning, finances)?
- Quality: How is the quality of the entire campaign guaranteed?

- Execution: Add comments on sampling, field visits, laboratory analyses, etc.
- Data: How will the collected data be stored?
- Analysis: How will the data be analysed so that the questions can be answered?
- Reporting: How will the results be communicated and what is the follow-up?

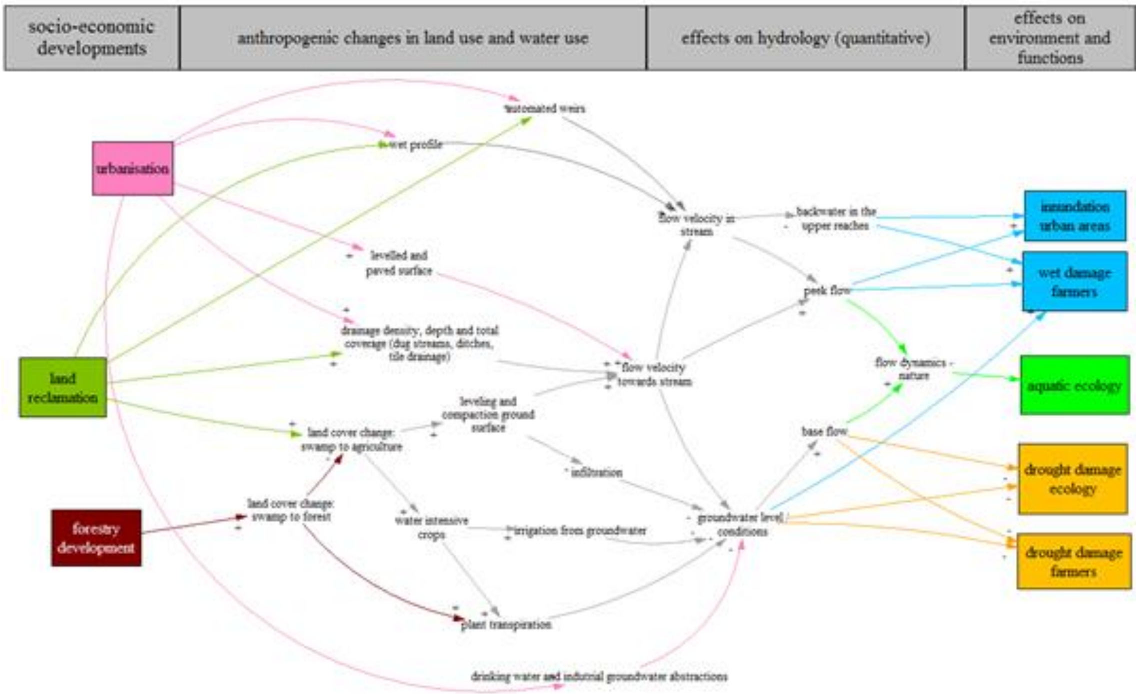

***Figure 6**: Schematic overview of the network of factors that influence the discharge dynamics of streams. The effects of changes in these dynamics are also shown.*

The research showed that the chances of hydrological recovery of catchment-wide flow regimes are most promising when effort is put into storing rainwater in infiltration areas. The removal of drainage structures in these areas – both in and above round - will strongly enhance infiltration and will increase groundwater levels. The promising areas for storing water are those areas where the dry soil can store extra water and the depressions in the landscape where water can be retained. In addition, the improvement of the soil infiltration capacity can contribute to strengthening water retention, in agricultural areas as well. Increasing the longitudinal length of the stream and decreasing the transversal wet profile further contributes to a reduction in discharge dynamics. Such wet profile adjustments can only be used if inundations are allowed for in the stream valley concerned.

An important consideration in stream valley restoration is the inclusion of the future climate conditions with heavier rainfalls and longer dry periods in design procedures. Climate forecasts must become part of stream valley restoration plans. Furthermore, the expected climate conditions are an extra argument in favour of taking measures to reduce dynamics in flow regimes.

Literature

Feld et al. 2011
Poff & Ward 1990
Poff 1997
Poff 2002
Southwood 1977 & 1988
Townsend & Hildrew 1994
Verdonschot et al. 1998 and others
Wiens 2002

Rapport nr. 2017/215-BE:
Integraal natuurherstel in beekdalen Ontwikkeling van diffuse afvoersystemen, gedempte afvoerdynamiek en beekprofielherstel