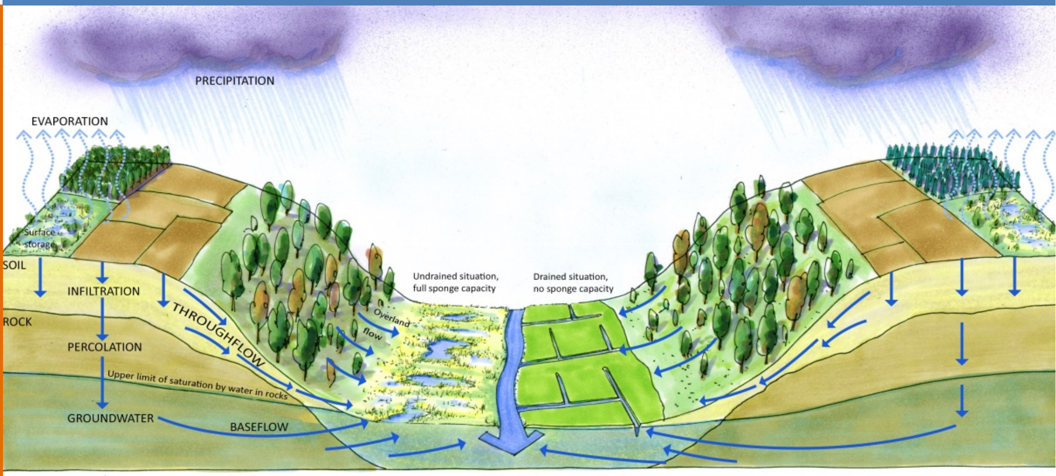

Possibilities for storage?

Stores of possibilities!

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INHOUD

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1. INTRODUCTION

Natural storage

Increasing the storage capacity within a water system is a promising measure to reduce flood peaks. An additional advantage of this approach is that the additional storage (e.g. in newly developed marshes) gradually but steadily releases its water and thus also contributes to tackling the problems of low discharges and drought. However, there have been on-going discussions for some time now about the potential of natural storage in the hydrological system (the system's natural "sponge capacity"), including questions on how much water can be stored and for how long. To contribute to this discussion Bureau Stroming, among others, has carried out a number of preliminary studies and developed project plans (see for example 'Storing near the Source', 2003).

For various reasons the public and policy makers have shown a great deal of interest in projects restoring the natural sponge capacity of water systems. However, water managers appear to be less enthusiastic and question how effective these natural buffers actually are. The question among water professionals is not so much *whether* natural buffers work – there is broad consensus that they do. The question is whether they are *sufficiently effective* to play a significant role in water management and for the moment an impasse between "believers" and "non-believers" seems to exist. **Particularly as there appears to be agreement on the principles, this impasse is unhelpful and is stopping projects from actually being carried out.**

This study

This study aims to create more clarity in the discussion on the functioning and potential of natural storage. It points out where we think there are misunderstandings and indicates how we think these could be resolved.

Natural storage and an increase in the sponge capacity of areas are often associated with "climate buffers". Climate buffers are areas that are managed with the aim to mitigate the consequences of climate change. Natural processes in particular are used to buffer climate effects. This enables climate buffers to grow in size and effectiveness, thus keeping up with the extent of the climate problem. Because climate buffers are multi-functional (they can be combined with the development of natural landscapes, recreation, restructuring of agriculture etc.) they also contribute to an improved quality of life. In short: natural sponges are climate buffers but climate buffers need not necessarily be natural sponges.

2. SPONGE CAPACITY AND CLIMATE BUFFERS

Modern water policy

The Dutch government's publication in 2001 of 'A Different Approach to Water, Water Management Policy in the 21st Century' (see Dutch government policy document: http//www.rijksoverheid.nl)[1] broke away from an age-old tradition. Traditional water policy involved discharge as much water as possible as quickly as possible. This traditional method resulted in a water system that needed a gradual increase in monitoring and regulation (see also Chapter 7). As a result of intensified land use, the pressure of urbanisation, climate change and the growing importance of recreation and natural landscape the traditional method no longer fully meets current needs.

Modern water policy still continues to focus on flood prevention. However, we are no longer trying to discharge the water as quickly as possible, but are in fact trying to retain it for longer periods. This new water policy has been detailed in the National Water Plan 2009-2015 and the National Administrative Agreement for Water.


RETAIN STORE DISCHARGE

Figure 1. New water policy: Retain-Store-Discharge water (source: www.ruimtexmilieu.nl)

An important component for the retention and storage of water is found in the sponge capacity of a river basin (see figure 1). This sponge capacity, the total active storage area for water, contributes to the retention of water and results in a slower discharge. This causes the discharge peaks to become longer and lower. When large additional storage capacity is created, which very gradually releases water (large, slow storage) this can also make a significant contribution in solving the problems of low water (drought).

Decline and rise of sponges

River basins naturally possess an enormous storage buffer which provides sponge capacity. Human intervention in the river basin can actively increase or reduce this buffer. In the past, traditional agricultural engineering methods focused on drainage has in effect reduced this buffer.

These methods were euphemistically referred to as 'normalisation of the water system' (construction of drains, channels and ditches and accelerated drainage by the straightening and widening of water courses).

But growing urbanisation and an increase in impermeable man-made surface area (particularly due to sewage systems and accelerated discharge of rain water) also contributed to a reduction in the sponge capacity. Current water policy is focused on reversing the decrease of buffer capacity and we should explore and use all options at our disposal: we need to reduce direct discharge by increasing infiltration, construct retention-basins and extend the use of the natural storage capacity within the system.

Natural storage

An unconventional way of creating increased storage capacity in a river basin is through the restoration of natural storage, i.e. the retention of water in the natural storage system itself. This means developing additional buffers by reintroducing more natural and extensive forms of land use in strategic parts of the river basin. Projects for water storage in the natural sponge system are often combined with projects to develop more natural landscapes. This creates a mutually beneficial situation, with water management measures contributing to environmental objectives and environmental objectives contributing to water management measures. It is crucial that we (re)develop forms of land use which are compatible with a termination of rapid water discharge.

Dutch engineering firms and research institutes involved in foreign water management problems often recommend the use of "natural sponge capacity" in such a way that it creates a more robust and resilient response to extreme hydrological events. Along with the strategic use of hard infrastructure this seems to be the hallmark of the Dutch approach towards water management. The results of large inter-disciplinary research programmes like 'Climate for Space' and 'Knowledge for Climate' underline the importance of solutions based on the principles of increasing natural buffers.

Natural storage for the Netherlands

However, while advising foreign water managers to increase natural buffer capacity, the Dutch themselves seem reluctant to implement this approach. This reluctance seems to be based on two underlying factors:

- Lack of confidence in the <u>actual effectiveness</u> of the (natural) sponge capacity in river basins. One of the concerns is that there will always be a point in time when a sponge will be completely filled so that potential problems are just postponed – not solved.
- Limited possibilities for <u>monitoring and managing</u>. The concern is here that an increase in sponge capacity does not facilitate effective high water management because it uses a natural system in which it is not possible to determine whether it is 'on' or 'off'. This makes it difficult to assess its effectiveness and hence the magnitude of its added value is. A related question is: who is accountable if the system fails?

Effectiveness

In this report we will discuss a number of concepts relating to the buffer capacities of (natural) systems. We will also elaborate on various aspects of the computer models generally used in discussions on storage because not all models are equally suitable for use in the issues of storage, or for the data used to enter into the models (is what is being measured and used as input going to allow the model to provide the answers needed?).

Manageability

We will also present some details relating to managing and monitoring of the system. Water is always a (semi) natural system that is subject to limited manipulation. The trend in water management is to control and manage water systems to the highest degree possible. However, confidence in storage within the natural system, demands an approach which accepts that the system contains various components which cannot be accurately managed or monitored, yet are effective and natural.

Turning the argument around

Although questions can be raised on the effectiveness of natural buffers, we also want to highlight the other side of the story. During the 1950s and 1960s extensive research showed that efficiency gains in the agricultural sector contributed to 'improved drainage' (i.e.: reduced buffer action). More recent research into municipal water management (among others by the Technical University in Delft) shows that the increase in impermeable man-made surfaces and the accelerated discharge of rain water via sewage systems definitely contribute to the reduction of storage and natural sponge capacity. This is why the Dutch Water Test (used in e.g. urbanisation projects) specifically refers the increase of impermeable man-made surfaces and requires a compensation for the loss of water storage capacity related to the project.

Since there is a clear link between human intervention in the system and the accelerated discharge from that system it is safe to assume that by reversing and reducing those interventions storage capacity will be increased and discharges slowed down.

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[1] http://www.rijksoverheid.nl/documenten-en-publicaties/brochures/2000/12/04/a-different -approach-to-water.html.

3. THE PRINCIPLES: HOW SHOULD IT WORK?

Buffers and storage in the river basin

Natural river basins provide huge storage capacity. This is found in the soil, lakes, marshes, ponds and depressions. Land use may enhance or reduce this storage capacity (for example deciduous afforestation) and also more artificial elements such as man-made reservoirs have an effect.By definition the volume stored in these various elements is the quantity of precipitation already fallen but not yet discharged. This can be represented using the familiar formula

$$\Delta S = I - O$$

with

ΔS = change in storage

I = input into the system (precipitation)

O = output from the system (evaporation and discharge)

When put into a graph, it becomes clear how large this storage actually is. In the first graph the precipitation and associated discharge has been plotted for a relatively small river basin in Limburg, the Netherlands (river basin of the Gulp, area of 28.5 m²). It relates to a relatively wet period with intensive rain showers. What is shown is a typical response for such river basins. and it is obvious (and very logical) that the peak in precipitation preceeds the peak in discharge.

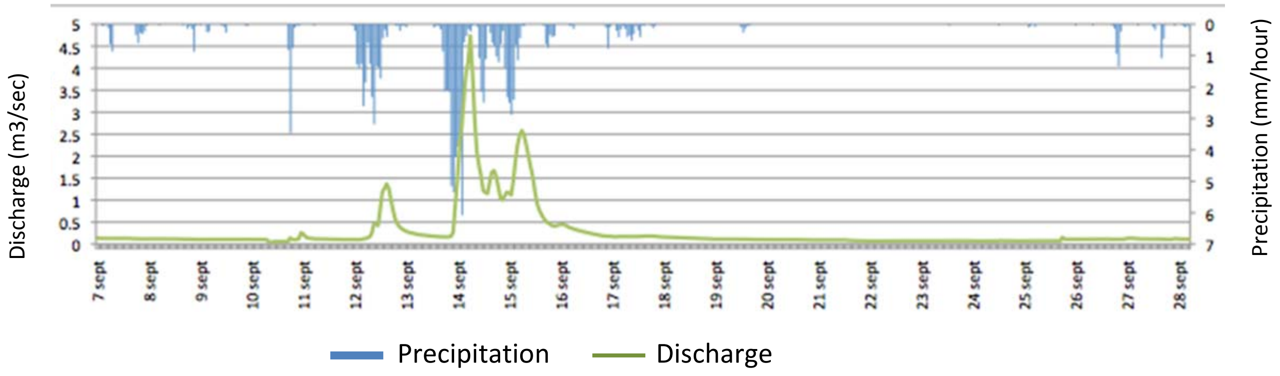

Figure 2. Precipitation and discharge during an rainy period in the river basin of the Gulp. The blue line (values on the right hand axis, reading from top to bottom) indicates the precipitation. The green line (values on the left hand axis) indicates the response of the river basin (discharge).

When we add the “change in storage” to the graph, the importance of the role storage plays becomes clear. Only a small proportion of the precipitation is discharged immediately, while the river basin as a whole stores an enormous quantity of water.

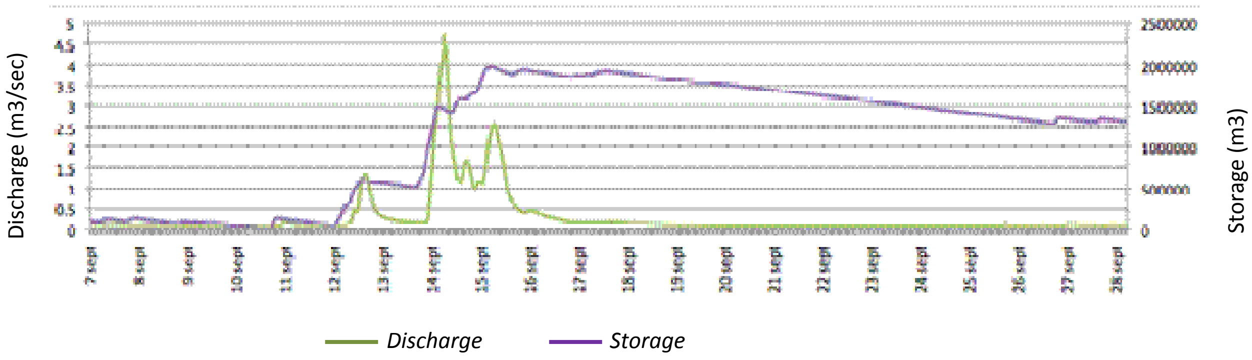

Figure 3. The storage of the river basin of the Gulp. The green line indicates the quantity of water which the river discharges (same as in figure 2) the purple line indicates the quantity of water stored by the river basin: the natural sponge capacity. Note that evaporation also extracts water from the storage, so although there is little discharge in this example, the stored volume still decreases.

From a graph representing cumulative precipitation (how much precipitation has fallen up to a given point) and cumulative discharge (how much water in total has been discharged from this river basin), it also becomes clear that the largest proportion of the precipitation is not discharged immediately but buffered somewhere within the basin.

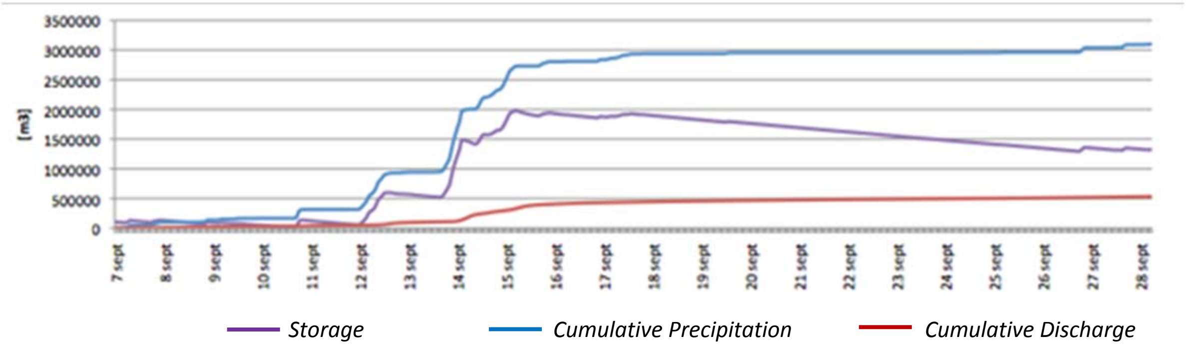

Figure 4. Precipitation, storage and discharge from the Gulp. The graph shows that on 15 September, when most of the precipitation had already fallen, only a very small proportion of this had been discharged. Most of the water was stored in the natural sponge and discharged later on (‘continued release of water’).

It must be noted that both natural and artificial components contribute to this storage capacity and that in most river basins the natural buffers are much larger than the artificial ones.

Structure of the slope

The functioning of river basins can often be described using a slope profile. This represents the river basin as having a plateau, a slope, the foot of the slope, the flood plain and the stream or river. Storage takes place in almost all parts of the river basin. We will describe the storage processes in low mountain ranges, at the foot of the slope and in the flood plain. Although we are using the concept of slope profiles in low mountain ranges, the concept is also applicable to moderately sloping landscapes, which can even be found in the Netherlands.

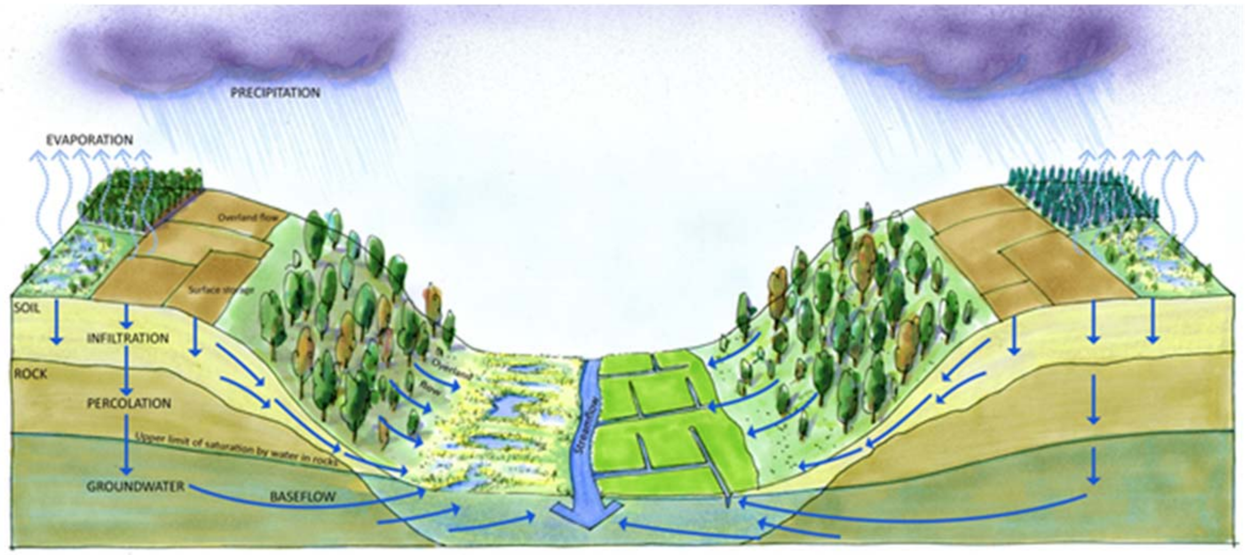

Figure 5. The various components of the water system. See the text for explanation.

Four transport components

In principle water transport in hilly areas consists of three components: overland flow, throughflow (also referred to as interflow) and baseflow (also referred to as groundwater flow). Of these, the overland flow is the fastest component and the base flow the slowest. Infiltration into the ground determines the distribution of precipitation among the components. Part of the water will penetrate the ground and be discharged through the soil and ground. The remainder will be discharged over the surface. Water always chooses the path of least resistance and in most cases this involves infiltration into the ground and transport through the ground in the form of throughflow. Only if infiltration does not take place quickly enough (‘there is more rain than the ground can absorb’), the ground is completely saturated, or if the easiest path for the water to flow is along the surface, the water will remain on the surface. In all other cases the water is discharged by the underground components (throughflow and baseflow: the slower components).

Eventually the water will reach a small stream, brook or river: the streamflow. From that moment onwards it flows rapidly downhill all the way.
The key for decelerating discharge is to decrease the intensity of the faster components and thus ensuring an increase in the intensity of the slower components.

The role of land use on the plateau and the slope

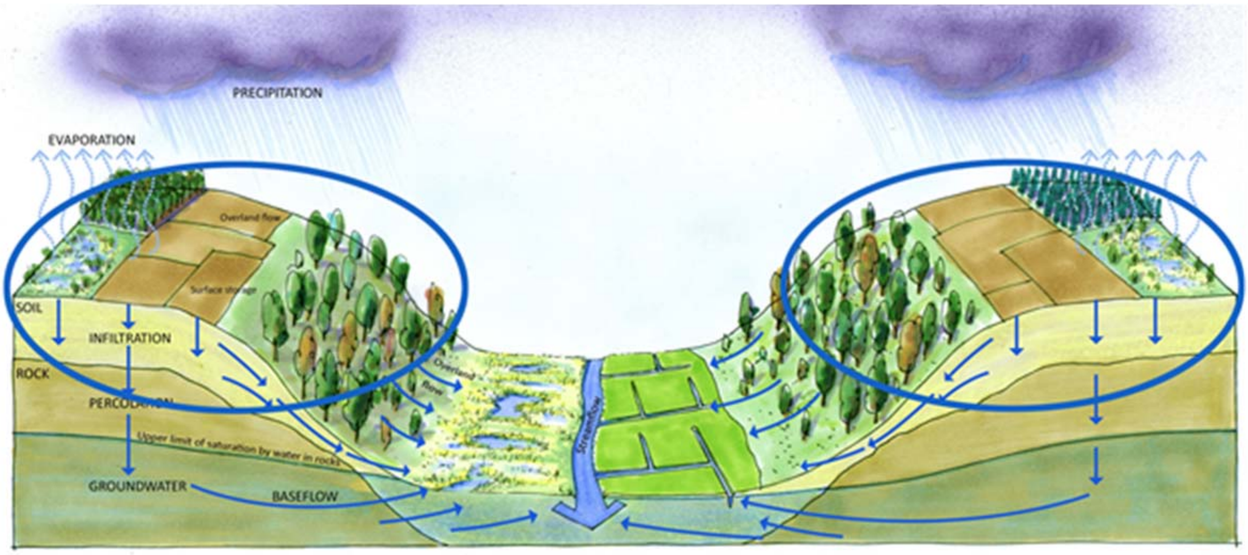

Figure 6. The plateau and the slope.

Land use greatly affects the infiltration capacity of the ground. Land use determines how much precipitation infiltrates the ground and how much water remains on and is drained over the surface. Grassland, shrubs, woods and other vegetation tend to increase infiltration because they slow down the surface water and because vegetation ensures a looser, more porous structure. In areas with those types of ground cover overland flow is a rare phenomenon. In these areas all the water infiltrates and throughflow and baseflow are the main transport components. Discharge peaks are thus modified and slowed down. On the other hand, fallow land and certainly impermeable man-made surfaces often produce a more limited infiltration speed which may result in overland flow. This causes a shift from the slower components to the faster ones, and thus higher peak discharges.

More important: the role of drainage on plateau and slope

However, the main player which influences the soil moisture component is not land use but artificial drainage. Artificial drainage, the use of drain pipes or channels, ensures that the water is tapped deeper within the profile (the channels and drain pipes drain water from the profile above) and subsequently discharged superficially. So in the diagram above, artificial drainage ensures that the soil moisture component (throughflow and baseflow) is converted into a streamflow component. Consequently, under the influence of artificial drainage and channel construction a shift takes place to a much faster component and to higher peaks.

Even more important: the role of drainage at the foot of the slope

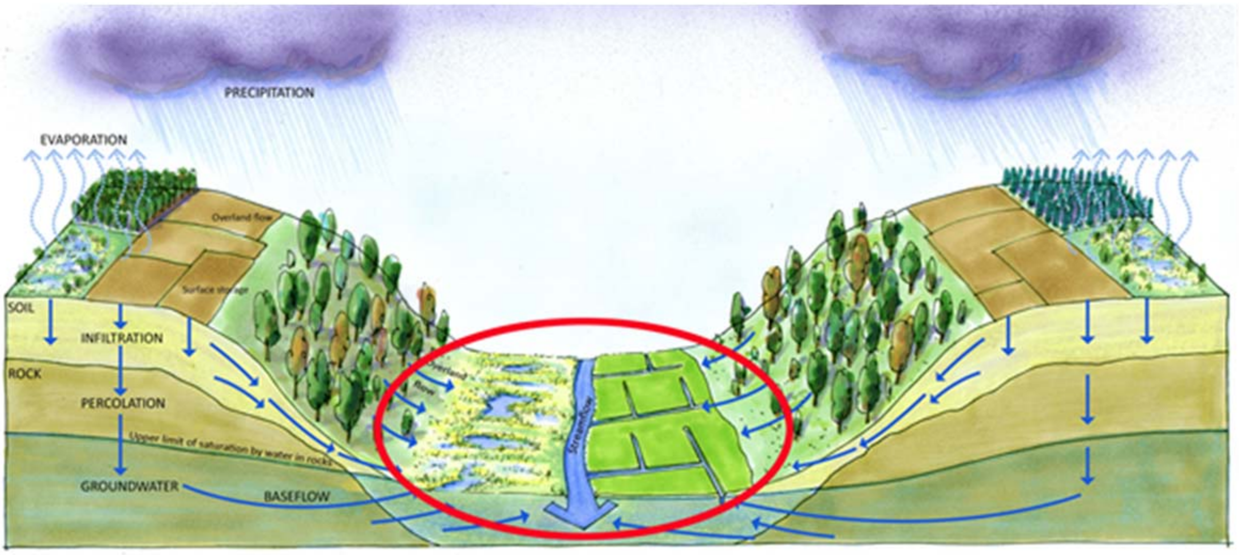

Figure 7. The role of drainage at the foot of the slope. On the right hand side the floodplain is drained by means of channels and on the left hand side an undrained situation.

Drainage (both drain pipes and channels) has yet another effect at the foot of the slope. As a result of (artificial) drainage, the throughflow component is intercepted and discharged into the streamflow at an accelerated rate. In addition, at the foot of the slope, where the ground water is close to the surface, drainage can also draw off the ground water. As a result also the slow baseflow is (partially) converted into the faster overland flow and streamflow, adding to a more rapid discharge and higher peaks.

Because of the above, the removal of channels and drainpipes from the foot of the slope plays a significant role in reducing the speed of discharge of water from the entire slope. In fact, all water falling on the plateau and the slope passes along here. As can be seen in the left hand part of the figure, by making changes in a relatively small area a deceleration of the discharge of the entire slope is achieved. Even if the channels and drainpipes are removed, it is still possible that water at the bottom of the slope will become surfaceflow (saturation overland flow). However, as the surface will be rough because of the natural vergetation which either is already present or will soon develop. The roughness of the terrain will decrease the velocity of the surface water.

In planning for the expansion of the sponge capacity in the low mountain regions, areas at the bottom of the slope have been specifically selected as the most promising areas for intervention. From the slope analysis above it is clear why: the effectiveness of sponges can be considerably increased by addressing the drainage situation in areas at the foot of the slope. Projects here – and in de floodplain – should focus on the restoration of more natural vegetation combined with the removal of existing drainage channels and pipes.

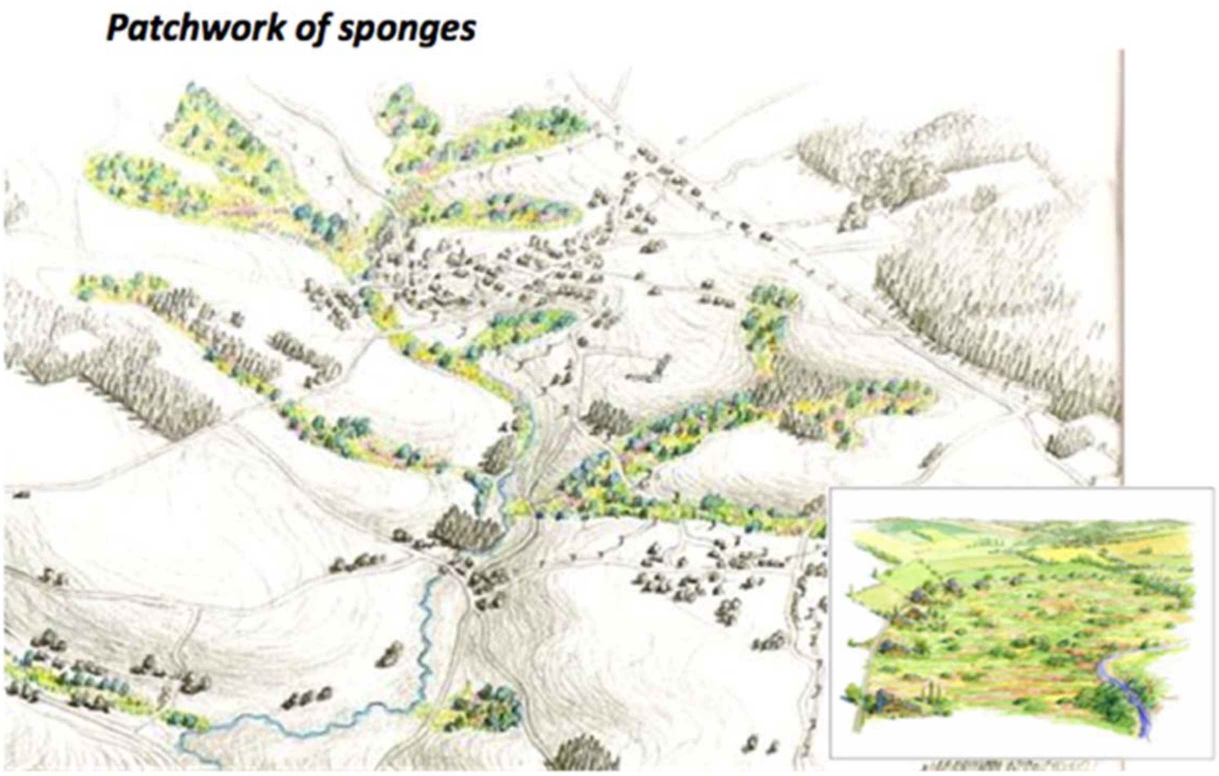

Figure 8. A patchwork of sponges as an example of a plan aiming to change the drainage situation and restore natural vegetation.

From the above it should be clear that measures, which are limited to change of land use in the stream valleys or in the flood plain (from intensive agriculture to extensive agriculture) or restoration of natural vegetation, will produce unsatisfactory results if the drainage channels and pipes are left untouched. For optimal results, the drainage situation should be addressed as well.

4. THE MODELS: HOW EASILY CAN WE SIMULATE THIS?

Introduction

In hydrology, and in almost any science, simulation models are used to increase our understanding of processes and systems. Simulation models are gradually replacing practical research and fieldwork. A shift is thus taking place from an empirical approach to a more theoretical approach.

We do not want to question the use of models as an important tool, but we wish to add a number of comments to the discussion. These comments relate to:

- Model design;
- Data Used and
- The question whether our measurements and models are actually answering the questions that are being asked.

Model design

The most popular model design for simulations in river basins links a hydrological rainfall-runoff model (in many cases the HBV model) with a hydraulic wave propagation model (often the Sobek model). In this design, the effects of creating additional buffers in the system is simulated by changes in land use.

Simulations with this model design show very limited effects when buffer capacity is added to the system. This, however, is a direct consequence of the design. After all, as argued above, impact should not be expected from changes in land use alone, but impact should be expected from changes in land use combined with changes in the drainage situation. Therefore we should develop models in such a way that they show the combined effect of changed land use and changed drainage situations. If the change in the drainage situation is not included in the calculation, the effectiveness of such measures is indeed small. Though the model probably works correctly, the measure has not been properly incorporated into the model concept and hence the model we created does not describe the processes we intended to describe. Simulation models which only consider the infiltration process, and adjust the infiltration coefficient based on changes in land use, show significant but predictable underestimation of the actual changes.

In addition to the problem above, the concepts used to simulate changes in land use are often too simple. This is particularly the case if the model has been based on a modification of the Curve Number Approach. This Curve Number Approach is frequently used because it is simple and can be easily applied.

However, it should be noted that this method (which is very conceptual and lacking a physical basis) is in fact a crude simplification which was developed many years ago for use in the United States. When applying this approach (and particularly in this kind of studies) one should be aware of its limitations. One of these limitations is that the foot of the slope is often not very well covered by the compounding sub-models. The foot falls just outside the reach of the hydraulic model, which only describes the water channels. And the hydrological precipitation-discharge model does not describe this part of the cycle satisfactorily either. Although the foot of the slope plays a crucial role in the transport of water from the slope to the river, it does not actually feature in either of the sub-models referred to above. Therefore, when applying models in studying the effects of additional storage, we strongly recommend careful examination of the sub-models to ensure they accurately describe the essential key processes. In the model structure referred to above this is not the case.

The use of hydrological precipitation-discharge models can also easily yield the conclusion that high waters develop as a consequence of complete saturation of existing storage capacity. When the storage is “full” as a result of prolonged and intensive precipitation, it will spill over and generate a flood peak. Discharge decelerating measures such as those described in this report would therefore not be relevant because ‘just when it’s needed the sponge would already be full to its maximum capacity’. Again, the reason for this premature conclusion is very likely an unsuitable model design. Since we can not know the total storage capacity of a river basin, we cannot determine whether the storage area is full. Moreover, in reality every time an ‘even more extreme’ event occurs in the river basin, it appears to store even more water. So there obviously is no absolute, clearly defined limit to the basin’s storage capacity and thus it seems unlikely that one could assign it a meaningful value. So, the idea of the ‘full sponge’ is mainly based on theory, not supported by empirical studies or fieldwork.

The above is all the more reason for practical studies and field tests. Nothing describes the natural flow of water better than actually measured values. Any model trying to replace these empirical studies becomes trapped in its own assumptions and concepts, and the outcomes will therefore reflect these underlying concepts and assumptions. Only comparison of modelling results with the processes that have actually taken place, can show whether the models accurately describe the relevant factors. We will examine this matter more closely in Chapter 6.

5. THE DISCUSSION: CLAIMS, HYPOTHESES AND ASSUMPTIONS ABOUT THE EFFECTIVENESS OF STORAGE.

In this chapter a number of claims are presented – and investigated – which are often forcefully advanced in the discussions on the storage of water in the natural system.

Claim: By decelerating discharge waves discharge peaks will actually start coinciding.

This claim is frequently used in the discussion about natural storage in large river basins (particularly in the river basin of the Meuse). The argument runs as follows. In recent situations of high water, the peaks originating from the downstream tributaries mostly seemed to precede those in the main river. So in the downstream section of the Meuse, the peaks from the tributaries comes first, followed by the peak from the main river. If we start attenuating the flood peaks from the tributaries, they will add up to the peak in the main flow and the downstream tributaries. So decelerating water in the tributaries produces a situation in which peaks from tributaries and main river coincide which leads to an even higher peak.

Probing the claim: This argument is based on the assumption that flood peaks are always caused by similar weather patterns. In specific weather patterns, deceleration of the peak in the downstream tributaries may indeed lead to a situation in which two peaks coincide. However, high water is caused by a large number of different weather patterns with different timings of precipitation. So in certain cases, deceleration of waves in the tributaries can lead to a more favourable situation, while in other cases it can lead to a less favourable situation. In general, we cannot predict whether a deceleration of a wave in one of the tributaries makes it more likely for peaks to coincide. In general, however, we can say that deceleration of waves always leads to longer, lower waves and that this positive effect always occurs irrespective of the weather pattern.

Claim: The complex composition of flood peaks makes buffer efficiency unpredictable.

The composition of flood peaks originating from various sub basins is so complex and varied, that it is impossible to provide meaningful suggestions as to where one should or should not retain water.

Probing the claim: This contradicts the first claim relating to the potential problem of coinciding peaks. We cannot claim to be sure that peaks will coincide if we introduce deceleration into the system and, on the other hand, claim that we are unable to evaluate the way wave deceleration works due to the complex build up of flood peaks. It is not possible to find convincing evidence for either of these claims. However, we do know that decelerated waves are *always* lower and longer than non-decelerated waves.

Claim: Change in land use has a limited effect on the rate of the discharge process.

This claim is largely underpinned by the relationship between change in land use and the corresponding change in infiltration capacity. These arguments are often based on simple model studies as we have shown above.

Probing the claim. Changes in land use where one particular type of vegetation is replaced by another type, do indeed not have much effect on infiltration capacity. However, this ignores an important factor, namely the relationship between change in land use, position on the slope and the (artificial) drainage situation. Simple model conceps often do not go beyond the mere description of the infiltration capacity and as a result will underestimate the significant effect of the associated changes of the drainage situation and the position on the slope.

Claim: Storage does not work on slopes.

Descriptions of the discharge process are dominated by the visual observation of surface runoff: when it rains in the Ardennes and other low mountain ranges, the water there just runs off the slopes (i.e.: is unstoppable).

Probing the claim: Even during extremely heavy showers the visible surface runoff is only a fraction of the precipitation. Only a very small proportion of the discharge process is determined by surface runoff. Most of the water discharges through the groundwater streams (throughflow and baseflow). In contrast to the overland flow you cannot see this part (which causes the confusion) but it is definitely there and many times greater. We do not intend to claim that additional storage capacity on the slope is hugely important (as most of the steeper slopes are covered in woods anyway, and large scale overland flow only takes place on these slopes under exceptional circumstances). We do claim however that slowing down the process at the bottom of the slope has a significant effect on the water flowing from the entire slope.

Claim: In the low mountain ranges there is not enough space as the slopes are steep and the valleys narrow.

Probing the claim: This image of low mountain ranges with exceedingly steep slopes and extremely narrow valleys does not correspond to the actual situation in large parts of the low mountain ranges in North-West Europe (Ardennes, Eifel, German and French low mountain ranges in the river basins of the Rhine and Meuse). Large parts of these areas consist of relatively flat plateaus and most of the river valleys are relatively wide. There is definitely space, at least at a local level, to increase the sponge capacity and to introduce other measures to ensure the deceleration of the discharge.

Claim: The construction of climate buffers and other means of storage will take up too much space.

This claim is based on the principle of proportion. So, if you want to retain 10-20% of the water, this means reorganising land use in a corresponding surface area of the river basin. This would involve a huge loss of agricultural land.

Probing the claim: In this paper we argue that different sections of the slope each play their own part in the process of decelerating the precipitation-discharge process. We also argue that changes in the drained locations at the bottom of the slope can be particularly effective in decelerating the discharge process. So making changes where they are most effective can considerably reduce space requirements. Introducing changes which can be combined with other objectives will greatly reduce the need for space. As an example, by turning inefficient agricultural land in the river valleys and at the foot of the slope into undrained natural landscapes it is possible to make substantial progress without requiring large areas of land.

Claim: Flood peaks occur as a result of extreme circumstances

All the sponges will already be at capacity when we need them most. The idea behind this claim is that the situation which occurs during extreme flooding is so extreme that the sponges will be full and unable to absorb any more water. ‘No use when you need them most’.

Probing the claim: Although the sponges in the river basins will obviously become fuller when showers are more prolonged and intense, there is absolutely no reason to assume that all the sponges will be full. Calculations of volumes of precipitation and discharge show that during extreme events a river basin stores enormous quantities of water, which it also discharges in the course of that same event. However, it cannot be shown that there is a maximum volume of water that can be stored and that it is possible to reach this maximum. Nor can it be shown that flood peaks are caused by the storage area “spilling over” because its maximum storage capacity has been reached. This is not an adequate representation of the processes taking place. The actual process is better described as a slope process in which increasingly full storage components provide a gradually increasing contribution to the discharge.

Claim: We are dealing with very large areas which will make implementation of the approach unaffordable.

Probing the claim: The river basin of the Rhine measures 185,000km². Within that area, , peaks ending up in the Netherlands mainly originate from the low mountain ranges (flood peaks are not caused by melting glaciers but by precipitation, including melting snow). During the extrem flood peaks in 1993 and 1995 approximately 13,000m³/s entered the Netherlands at the Dutch/German border (Lobith)

Up until the mid-1990s the Netherlands felt it should be able to safely discharge 15,000m^3/s at Lobith. After the peaks in 1993 and 1995 the decision was taken that the discharge and storage capacity needed to be increased to 16,000m^3/s. The Dutch 'Room for the River' Programme is taking care of this and costs €2.3 billion. So accommodating 6.66% of additional water (1000/15000) comes at a cost of €2.3 billion.

What could have been achieved with that amount of money if one had not attempted to accommodate that 1000m^3/s in the Netherlands (by creating more space in the river forelands, raising dykes, and accelerated discharge of water) but had invested it in interventions in the Rhine in the German low mountain ranges where high waters in the Netherlands originate? It is hard to tell but here follows a rough calculation.

Preventing that additional 1000 m^3/s from coming into the country at Lobith means holding back 7% of the precipitation which falls in a 'critical period' for a couple of days so that this only reaches the Netherlands after the (rest of the) peak has passed. Initially one might assume that this meant that 7% of the river basin should be turned into sponge area, approximately is 12,500 km^2. However, in the low mountain ranges at least 50% more precipitation occurs than in the rest of the river basin so if we concentrated measures in that area we would not require 7% but (100%/150%)*7%=4.5% of the area as a sponge. However, there is an even more efficient solution: all the water falling on the slope itself and the plateau above has to pass along the foot of the slope and is discharged through the ground to the valley. By placing sponges in that area (at the foot of the slope) we could intercept the water which has fallen on high plateaus and slopes. From a research in the Ardennes we find that the ratio between 'foot of the slope' and 'plateau + slope' is approximately 1 in 8. This means that on average one hectare of sponge can intercept and decelerate the water flowing from eight hectares on the plateau. So as a result of this intelligent choice of location the area required can then be reduced to 1/8 of 4.5%=0.5% of the river basin or just over 1000km^2. (2)

If that €2.3 billion had been used to acquire 1000km^2 it would have enough to acquire that land for a cost of €23,000 per hectare. In Germany the average price for a hectare of agricultural land in 2010 was €11,900 per hectare. [3] Moreover, we must bear in mind that the following:

- the areas most suitable for the development of sponges is low quality agricultural land. Its price will certainly be below average and because this land has often already been abandoned or barely yields returns, this will involve little or no additional costs to compensate for loss of income;
- the next round of river safety measures (an increase of discharge capacity from 16,000m^3/s at Lobith up to 17,000 or 18,000 m^3/ s) will definitely be much more expensive than the current increase from 15,000 to 16,000m^3/s) because the 'cheapest' measures are already implemented within the framework of 'Room for the River';
- retaining water does not only reduce the flood peaks, but also, to some extent, drought problems. Admittedly, the retained water will not be released during the driest months[4] but it will be released in moderately dry periods and that is an advantage;

- the natural environment also benefits from retaining water upstream as do related functions such as recreation, attractive living conditions etc.;
- not only the Netherlands would benefit from the retention of water but all the inhabitants of the river valleys upstream from the Netherlands. So the Netherlands would not have to bear all the costs itself (although even if it did it could still prove to be a cost-effective measure).

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[1] ‘Storing near the Source’, 2003, Stroming. A statement of affairs drawn up relating to the Ardennes but the assumption is that the situation in the German low mountain ranges is comparable.

[2] Such a limited area of sponge would mean that there were decimetres of water in/on the sponge if 1000m^3/s had to be retained for several days. An optimum between number of hectares required and a realistic ‘water target’ should be sought.

[3] http://agriholland.nl/dossiers/landbouwgrond/home.html

[4] Because it would then have to be retained for six to eight months and that is not possible in sponges located on the surface; in that case the water would have to be retained underground.

6. SO HOW EFFECTIVE IS IT?

The simple answer to this question should be sought in measuring the effects. This would involve designing an experiment and carrying out field work to determine what the actual effect of the artificial drainage is on the flood plains. Empirical research should be carried out to monitor the actual situation.

Currently not enough empirical studies have been carried out to enable us to accurately determine the effect of the restoration of natural storage. This problem, however, should not stand in the way of introducing this type of measure. On theoretical grounds (described in this paper) we have concluded that such measures definitely do contribute, we just cannot quantify exactly to what extent. Just as in fitness training and working out: even though one cannot accurately assess how much fitness training and working out contribute to the quality of your life and health, one cannot use this as an excuse to do nothing about one's physical health. In general, the benefits of working out is so evident and generally accepted that it does not make sense to refrain from it just because one cannot exactly quantify its benefits.

On the basis of the concepts and principles described above it can be concluded that measures introduced at the foot of the slope have the potential to be extremely effective. Measures introduced in relatively small sections of the river basin could have a disproportionately great effect.

In order to gain more experience we strongly advocate the implementation of pilot projects. There are two reasons for this. Firstly, we expect these projects to provide a positive contribution to a more natural form of water management. Secondly, by carrying out such projects we can also start the necessary monitoring, which will allow us to provide quantitative underpinning.

We need to be aware that these projects and studies need to be carried out over a longer periode of time. In order to determine actual effectiveness a number of events should be measured and compared. The studies should extend over a period which includes the situation before and after the restoration measures have been introduced. Such requirements are not easy to fulfil but essential for field studies.

Research focused on the effects of change in storage as a result of changes in land use and drainage situation broadly consists of four parts:

1. The choice of a suitable river basin:
Which stream/river should be studied and where does its water originate? (It is probably most practical to start with an upper reach because it does not have tributaries, no glacier influence and a small catchment area). The area chosen should be nominated to undergo changes in land use and drainage situation. The preferred option would be to collect data in areas at the foot of the slope with and planned measures including the removal of drainage channels.

2. Setting up a model:
Using measurements of precipitation and discharge (taking a number of occasions and events) BEFORE the measures are introduced to design a calibrated and validated model which accurately describes the hydrological response of the river basin or slope, particularly in terms of height and timing of the discharge waves.
3. The data collection programme:
Precipitation measurements should be focused on the amount and intensity of the precipitation within the river basin and the time and duration as well as the locations and areas.
Discharge measurements should be focused on discharge of the stream, starting from before the shower, noting when it started to increase, peak volume and level and how long the “tail end” lasted.
4. Processing the data:
Model design aimed at: which part of the precipitation was discharged and when, how long was part of it stored and which part is not being discharged.
Description aimed at: what is the land use and the drainage situation in the river basin.

These steps are carried out before and after the storage capacity in the area has been restored, in order to be able to determine its effects. Subsequently, an analysis can be carried out of the changes in the response.

The restoration of natural sponge capacity is a no-regret measure. It does not rule out introducing other measures but it does reduce flood peaks, continues to release water during drier periods, provides a natural environment and provides money for the restructuring of agriculture in the lower mountain ranges.

7. MANAGEABLE RIVER BASINS?

NATURAL VERSUS REGULATED STORAGE

Over the past decades water management increasingly seems to be a fight against the natural system. Water naturally finds its own way through the river basin and humans try to control this process, to manipulate and adjust it. People seem to believe that leaving the water system to natural processes is not an option. They do not want to entrust the responsibility of water management to the natural system: there is a preference for intervention and regulation.

The idea is that the more control water managers can exert over rivers the better they are able to anticipate extreme events. The more regulation can be built into the water system, the easier it is to take control of all the possible negative effects of the natural processes which take place in rivers and the easier it is to further optimize the water system. These ideas have typified traditional Dutch water management. This mentality is seen in the growing standardization of all the regulations concerning the system and an increased regulation and manipulation of water flow through the system.

Typically water systems are (even under current conditions) still largely determined by natural components and events with limited possibilities for measuring and managing. The more of these components we are able to include in the man-made (manageable, measurable) system, the better we believe our control over the system is and the more soundly we sleep at night.

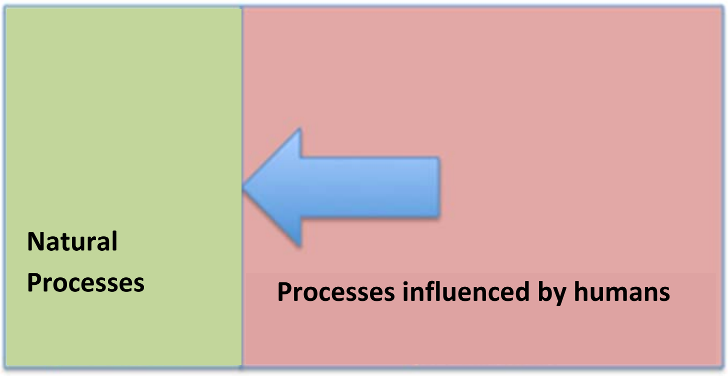

Figure 9. Traditional water management and the ever increasing influence of man on the natural system.

In this trend of ever increasing control, the introduction of storage in the natural system is a somewhat counter-intuitive move: in order to prevent flooding we are going to make ourselves more dependent on natural systems, which are not easily regulated and whose functioning we can neither completely determine nor standardize? Many water managers are not comfortable with the idea of introducing further uncertainty into the water system.

However, trust in the natural storage system requires accepting that the system will always, to a certain extent, contain components which are impossible to manage or monitor yet are definitely effective. The fact that we don't fully understand these components and cannot manipulate them accurately, does not rule out the fact that they definitely contribute to the increase of the storage capacity within the area and hence the reduction of flood risks.

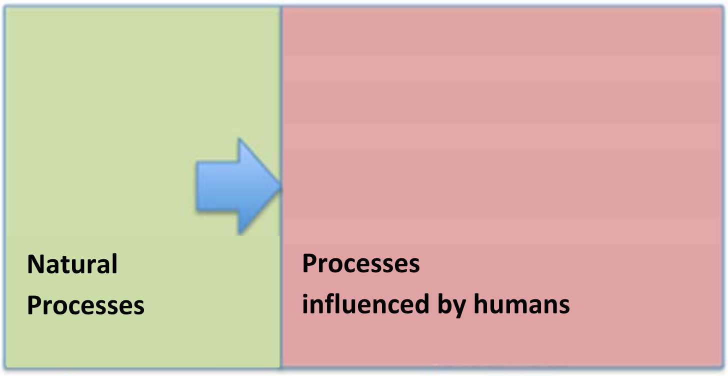

Figure 10. Natural storage. Greater trust in the natural processes within the water system.

In spite of this gut reaction, the application of storage in the natural system corresponds with initiatives such as 'water drives', the concept of 'The Netherlands living with water' and projects such as 'Room for the River'. When turning that policy into practice (and while accepting the responsibility that comes with it) there is undoubtedly some concern caused by a lack of familiarity and experience with the functioning of increased natural storage or (climate) buffers in general. It would be beneficial to deal with these concerns by setting up a number of pilot projects and a number of field studies in order to increase, within a wider circle, understanding of storage in the natural system. This is extremely important as the potential of the approach described above applies to a large number of issues and is far reaching.

8. THE MAIN CONCLUSIONS

This paper aims to present a number of important issues on the effectiveness and desirability of (more natural) storage and buffers for the prevention of flood risks. Additional storage and buffers can also play a positive part in low water situations. Although, in general, people support the concept of storage and buffer action, it seems there is a lack of belief in actual effectiveness of such measures as well as concerns with regard to management and monitoring of increased "sponge capacity".

These scepticisms and concerns are often expressed by advancing claims "proving" that (climate) buffers, additional storage and increased sponge capacity can never make a meaningful contribution to the reduction of flood peaks. This paper weighs up the known pros and cons and examines the strength of such arguments.

It should be clear that this paper does not argue for water management based solely on the use of natural storage and (climate) buffers. However, progress in water management can certainly be made by using these buffers and storage mechanisms, particularly if used in combination with changes in the use of poor agricultural land, development of the natural environment and other land-use decisions. When exploring and implementing this approach, it is crucially important to not just examine the land cover and the choice of vegetation (i.e. agricultural crops versus more natural vegetation and land use). Also the drainage situation of the area must be considered and adapted. Artificial drainage systems, when not removed, will continue to contribute to accelerated drainage and hence largely undo any progress resulting from other means of retaining water.

Particularly when dealing with hilly areas and low mountain ranges it is important to pay attention to the drainage situation at the foot of the slope. Relatively small interventions in relatively limited areas can make a large positive contribution to the natural storage of the area and the deceleration and lowering of discharge peaks from that area.

Currently we are not able to quantify claims about the exact effectiveness of the increased storage. Our recommendation is to set up pilot projects in order to obtain data and experience with the restoration of storage capacity. We anticipate positive effects from these pilots in three ways:

- they will generate a direct positive "storage" contribution;
- they can be used for the collection of data needed to quantify the contribution increased natural storage can make in flood (and drought) control.
- they can help in building up trust in natural systems and reduce concerns with regard to the "unpredictability and unmanageability" of natural buffers.

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Possibilities for storage? Stores of possibilities!