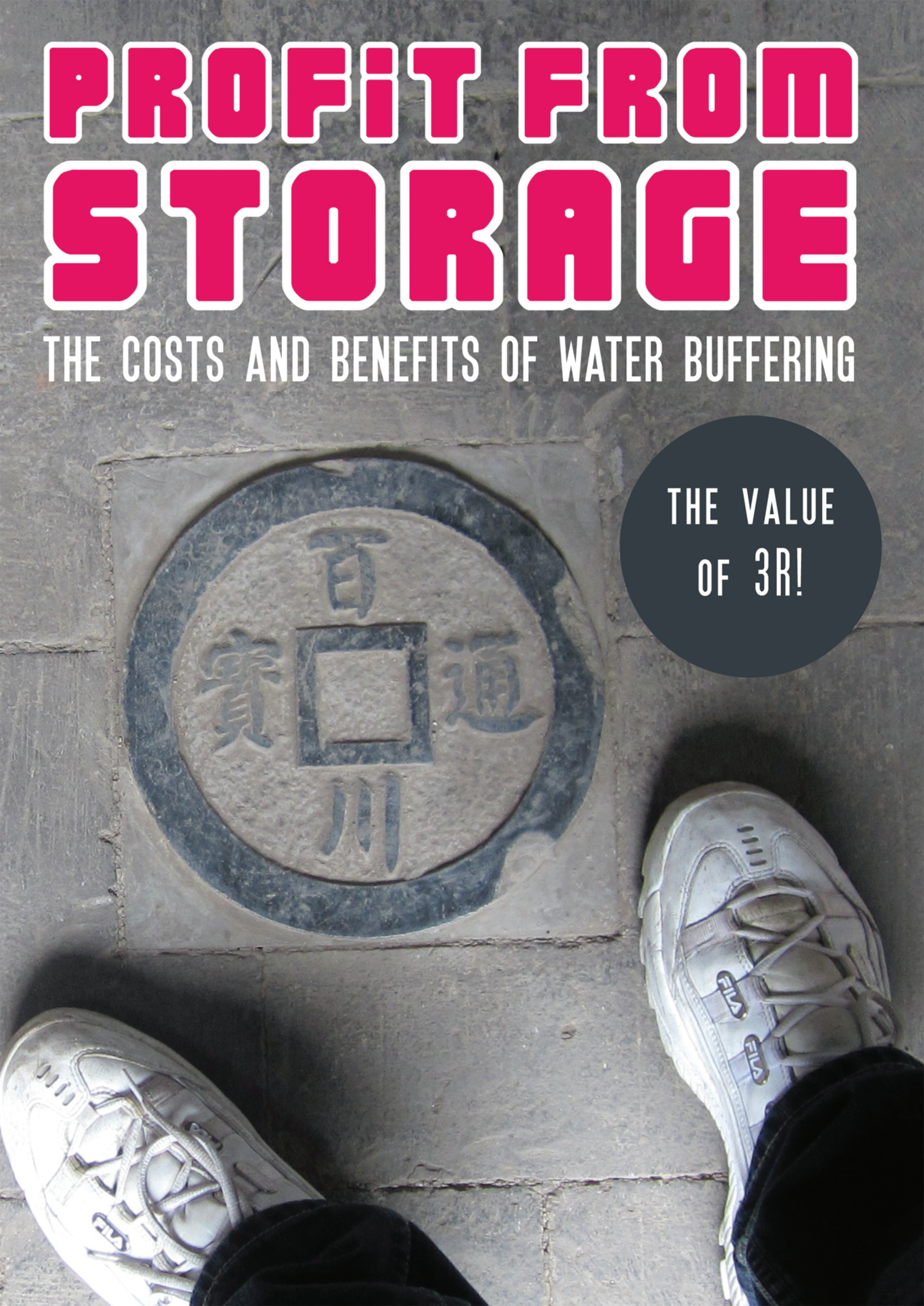
PROFIT FROM STORAGE

THE COSTS AND BENEFITS OF WATER BUFFERING

THE VALUE OF 3R!



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The cover photo is the floor of one of the earliest banks in China, in Pinghyao. The image in the floor is of an ancient coin with a square in the middle, as used from the Qin Dynasty onwards. Ancient Chinese believed that the sky was round and the earth square – hence the shape of the coin. The square in the middle also stands for a well, with water flowing from all directions from the boundary. The characters from top to bottom in this coin read 'hundred streams' and from right to left 'monetary value'. The entire piece is probably the cover of a well itself and symbolizes the profit from storage.

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Foreword

The Bonn2011 Conference “The Water, Energy and Food Security Nexus – Solutions for a Green Economy” introduced the nexus approach, for a better understanding of the inter-linkages between different sectors such as water, energy and food security. Even though progress has been made towards meeting the Millennium Development Goals (MDGs), many basic services have still not been secured for a large proportion of the world’s population. About 0.9 billion are still without adequate access to water for their basic needs. Many more do not have water that is safe for consumption. 2.6 billion lack access to safe sanitation, and close to 1 billion are still undernourished.

Our global water resources are affected by various drivers, including climate change. At the same time, an ever- growing population puts an enormous stress on these resources, particularly through agricultural demands. We are reaching, and in some cases have already exceeded, the sustainable limits of resource availability. Therefore, we need to develop more innovative solutions to achieve sustainable consumption and production patterns, and distribute natural resources in a fair manner.

Although concrete climate predictions are subject to uncertainty, we have to act now. Adaptation strategies are needed to avoid devastating consequences such as cyclical droughts and famines, particularly in the Horn of Africa and the Sahel region.

One of the answers is capture and storage of water during wet periods, to have enough during the dry seasons. As a part of the solution, storing water and using it as a buffer is particularly relevant given the increasing climate variability, especially more frequent extreme events like storms and droughts. Natural recharge happens by rainfall and infiltration through the soil. Water buffer management helps nature by increasing the natural recharge, by bringing the surplus surface water underground to store it in a place which is protected from evaporation and usually safer from pollution. From there, it can be pumped again during the dry seasons.

Thus, water buffer management can provide locally adjusted solutions that improve the resilience of people and their environments to food insecurity and climatic variability, both at the local and basin-wide levels. It is, therefore, complementary to the principles of Integrated Water Resources Management (IWRM) through the responsible management of both water and land resources. It also presents one concrete example of the “anthropocene” (Paul Crutzen). In a world that is heavily influenced by human activities, humans are both drivers of change and impacted by those changes. However, humans can – and increasingly have to become – part of the solution as well.

In a “world at risk”, local economies, often characterized by limited resilience, are particularly under stress. In this context, various cost-benefit analyses (CBA) of water buffer management in many parts of the world, in wet and dry countries, have shown that these solutions do not only have a positive impact on water-availability but have also lead to higher economic returns. Such pay-offs result from better access to safe water during dry periods, both for drinking purposes and, for example, irrigation. As a result, fewer people have to suffer from malnutrition and there is more time for income-generating activities. Thus, wise water buffer management keeps water in the cycle and plays an essential part for more sustainable land and water management. This contributes to food security, income generation and climatic change adaptation.

This publication presents CBA studies on water buffering, which is illustrated through cases across the world. They offer an easy-to-use method for making the case for wise water and land management.

Let us make use of existing solutions! Water buffer management should be included more precisely in water resource management in particular and in national adaptation strategies. The economic and social significance of good land and water management will become increasingly important for eradicating poverty, addressing climate change and improving water availability.

Prof. Dr. Klaus Töpfer

Former German Environment Minister, Former Executive-Director of United Nations Environment Programme (UNEP), currently Executive-Director of the Institute for Advanced Sustainability Studies (IASS), Potsdam, Germany.

Endorsement

I wholeheartedly endorse the message of this book. At the behest of the President the 3N "Nigeriens Feeding Nigeriens" initiative has been set up in Niger. The vision is in its title.

Niger, which lies almost entirely within the Sahel and Sahara climatic belts, about 5.5 million people are at risk of hunger this year. But, regardless the current situation, Niger has regularly suffered food crises, and sometimes severe famine. The northern half of the country is desert, while the south lies in the Sahelian belt, where rains fall for only a few months (3-4 months) each year and frequently fail. National production of essential food crops and livestock is inevitably subject to large fluctuations from year to year. With the population rising fast, food insecurity has become a fact of life, an estimated two million persons are chronically food insecure and unable to meet basic food requirements even under normal condition. The situation of children is of particular concern. One in five never reaches the age of five. Rates of acute malnutrition are consistently ranked above 10% and chronic malnutrition is also significantly above the 40% 'critical' threshold, affecting 51% of children nationwide, and exceeding 60% in some areas.

This is painful as in the past Niger was able to feed itself. Although Niger is a Sahelian country with average per capita income among the lowest in the world, we believe that Niger can achieve food security and eradicate malnutrition because Niger does have cards to play. Even now our potential to store and utilize our water resources is poorly mobilized. In Niger 1% of the surface water and 20% of the groundwater flow are used. The irrigation potential is also largely untapped and there are many opportunities to make better use of storing, retaining and using water in natural depression, ponds and by other means. This needs to change. The massive regreening initiated by farmers in large part of the country and the successful extensive use of zai planting pits and stone bunds emphasizes that change is possible. Our livestock represents formidable wealth – if the natural resource system that sustains it is taken care off. Niger has a diversity of bioclimatic and agro-ecological zones that are an important asset to be exploited, through an intelligent local planning. Last but not the least, Niger pending power is increasing, because of the rise in global demand for Niger's uranium and because it has now started commercial production of oil, serving national needs and West African markets.

The 3N initiative "Les Nigériens Nourrissent les Nigériens" launched this year by the democratically elected President Mr Issoufou Mahamadou, is a vision, a political will and a commitment to quickly reach sustainable food security for Niger and build its people's resilience to shocks and crisis. Under the 3N initiative the aim is to harness and use the local water resources – by developing a large number of irrigation systems and water harvesting structures, by developing better grain storage and develop slaughterhouses, by improve agricultural training and boosting agricultural credit (to give farmers and pastoralists a financial buffer), introducing new crops (with high nutritious value) and improving agricultural research. We hope for a larger role of the private sector and think that this is possible as there is enough business in better agriculture. A checklist of targets for development provision has been set at national level, but the underlying goal is to stimulate a pro-active local culture of development planning and implementation, in the belief that this will increase the chances that projects and initiatives will be sustained over the longer term. The 3N strategy aims to ensure there is a basic development "kit" or checklist of possessions, structures, equipment and services at every level of society locally.

We welcome this book, because water control (irrigation, water harvesting, in situ water management etc.) at the household and village levels is at the heart of 3N strategy. The many examples – such as the flood water spreading that is practised in Niger itself – show that there are still many things that can be done. The book also shows the sound financial case of developing small water resources. We support the message of the book that water buffering is a way out of food insecurity and into resilience in the face of dry and wet cycles.

Amadou Allahoury Diallo

Haut Commissaire à l'Initiative 3N

"Les Nigériens Nourrissent les Nigériens"

Présidence de la République du Niger

Profit from Storage
The costs and benefits of water buffering

1. Profit from storage: stronger reserves, values that last

1.1 Introduction

This book discusses the advances of local water storage for drinking water and food security, and the economic justification underlying it. A broad range of examples across the world show that wise land and water buffer management can pay off and that considerable profits can be realized from local water storage. In this book a number of these examples is given, together with an overview of the methodology, both technical and financial, for optimizing the use of water buffers.

The benefits of storing water within a landscape are often overlooked. Nonetheless, a large range of relatively small measures exists, that when implemented at an integrated landscape scale can make the difference between an area that is vulnerable to drought, wash-outs and erosion or a highly productive landscape. Also at the scale of a household, the buffer concept can provide considerable profits. For example, if farmers and other land users have access to secure water reserves, they are less exposed to risk. With a safe deposit of water (see also the cover of this book), one also can afford to be more entrepreneurial and to make investments for improvements of their livelihood conditions.

This book tries to overcome the limited understanding of water buffering by discussing the costs and benefits of local water storage in particular. Water buffer management has a number of direct benefits, such as more production by securing soil moisture and water availability and easier access to drinking water. Additionally, it creates better resilience: i.e. the ability to deal with variability and uncertain circumstances. These may include droughts, unusually wet years, years with ill-timed rain or abnormal temperatures. The need for resilience is increasing with climatic changes, since this is predicted to cause more variability in the precipitation and longer and more pronounced dry periods. Some of the potential monetary costs of droughts are given in box 1.

Figure 1. Water buffering brings multiple benefits. In semi-arid Machakos in Kenya local fisheries are developed using the water retained in sand dams (Photo: Bancy Mati).

Box 1: Examples of economic cost of droughts *

- Farmers count the losses of the 2011 drought in Argentina at USD 2. 5 billion or USD 94 per ha for soya and USD 167 per ha for corn;
- The loss of crop and livestock during the recent drought in Texas is estimated at almost USD 8 billion for 2011;
- The direct and indirect cost of the 2007-2008 drought in Catalonia (Spain) were estimated at USD 1.6 billion for a one-year period;
- The 2006/2007 drought in Australia reduced the GDP by 1 % . The farm GDP fell by around 20 %;
- The 1999-2000 drought in Kenya affected almost all economic sectors. It resulted in a 1.4% drop in GDP in 1999 and 0.7% in 2000 pushing inflation up from 7.6% to 9.8%

Sources: A. Markandya and J. Mysiak: The economic costs of droughts in Options Méditerranéennes, A no. 95,2010 - Economics of drought and drought preparedness in a climate change context
http://blogs.ft..com/beyond-bricks/2012/01/23/argentinas-drought-counting-the-costs/#axzz21APS9Em7
Economic cost and consequence3s of drought. Basic Center for Clamate Change BC3
http://www.iamz.ciheam.org/nemedca/istanbul2010/presentations/S2-Markandya.pdf

Overall global trends are still towards the degradation of scarce land and the depletion of precious water resources. Nonetheless, there is also a large part of the world where the situation is improving[1]. There are numerous examples of successful transformations, which are triggered by land user initiatives, by local governments or by dedicated projects. A range of decentralized practices for local water storage can make a difference, and many of these techniques have the potential to be implemented in more places other than the regions where they are being applied now. Such techniques,that create better water buffers through Recharge, Retention and Reuse, are summarized under the heading 3R (box 2).

1.2 Set up of this book

This book stresses the need for more investments in 3R to contribute to drinking water and food security. This will especially benefit the poor, of whom a large percentage is engaged in rain-dependent agriculture, livestock production or fishery. This book is also written to convince bilateral and multilateral financiers to give a harder thought to the following idea: given the large potential economic benefits of water buffer management, there is a good case to mainstream investments

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1 The GLADIS survey by FAO and ISRIC (Bai et al., 2008) established that land degradation was still on the increase between 1991-2008, affecting almost a quarter of the global land area. However, the important message, from this global survey is that the picture is mixed. There are areas where land quality has been declining (24% of the global land surface), but also areas where land quality has improved (16%).

Box 2: 3R = Recharge, Retention and Reuse

With 3R the water buffer is managed through recharge, retention and reuse. The idea is to create strong buffers and extend the chain of water uses.

Recharge

Recharge adds water to the buffer and as such it adds water to the circulation. Recharge can be natural – the infiltration of rain and run-off water across the landscape - or it can be managed (artificial recharge) through special structures or by the considerate planning of roads and paved surfaces. Recharge can also be a welcome by-product of for instance inefficient irrigation or leakage in existing water systems.

Retention

Retention is the process in which the speed of the natural water cycle is reduced in order to create large wet buffers. This process can be increased artificially, for example by slowing down the (ground)water flow or by hindering the surface water runoff with dams and reservoirs. Therefore it extents the chain of water uses and can have a large impact on agricultural productivity.

Reuse

Reuse is the third element in buffer management. The big challenge of 3R is to make water circulate as much as possible. Scarcity is resolved not only by managing demand through reduction in use, but also by keeping water in active circulation. In managing reuse two processes are important. The first is to manage non-beneficial evaporation to the atmosphere. Water that evaporates 'leaves' the system and can no longer circulate in it. One should rather try the opposite and capture air moisture, such as dew where possible. Another process is the management of water quality – to make sure that water can move from one use to another, even as water quality changes along the chain of uses.

in resilient landscapes and better storage. This can also be a good alternative to the development of large surface water storage dams, that now are seen by some as the main answer to water shortage and climate effects.

We hope that by systematically discussing the benefits and costs of improved water buffers they can be better quantified and planned, and we argue that investments in 3R methods do not have to differ from investments in roads, harbours, or irrigation systems. Many examples show that they pay off economically and financially, though the opportunities for better water buffering vary from area to area. A number of such examples have been discussed in the preceding 3R books 'Managing the Water Buffer' and 'Transforming Landscapes, Transforming Lives' and more cases are added in this publication (Box 3).

The set up of this book is as follows. Chapter 2 discusses local storage, which is a central concept in water buffering. Different types of storage are discussed and linked with the cost, and the type of benefits and resilience they bring. Attention is paid to other benefits as well – for instance to biodiversity or sediment management.

Chapter 3 discusses implementation at scale. One central lesson from the different cases is that resilience and impact multiply when the different local storage measures are implemented at a high density in a landscape or sub-basin. This has a multiplier effect and achieves larger benefits, that are not possible with piecemeal interventions. If landscapes are transformed at scale, macro processes change as well as the hydrology, the micro-climate and also the economy. Chapter 3 discusses several ways of scaling up embedded in the support of local land users and other stakeholders, based on the local priorities and opportunities.

Chapter 4 works out an approach for calculating the costs and benefits for buffer management to set the stage for more intense financing. There are several benefits of better water buffers and more resilient landscapes. They bring on-field benefits (more production), basin-wide benefits (less erosion, regulated flows) and also off-stream benefits (carbon sequestration, better micro-climates). The larger resilience also reduces the costs of a drought or an unusually wet period. These costs are compared with the costs and benefits of undertaking the works – differentiating between economic costs (for the society as a whole) and financial cost (from the viewpoint of an investor).

The fifth chapter presents a large number of cases. They explain the cost and benefits of storage in specific situations. Each case describes the 3R techniques in a nutshell, their application in the particular local context, their costs and benefits and the financing modalities. They also discuss implementation modalities, success factors and challenges.

Finally, the last chapter 6 of this book gives some concluding remarks.

Box 3: The previous 3R books

The concept of managing the water buffer at scale was introduced in the book "Managing the Water Buffer - for Development and Climate Change Adaptation" (2009). This book gives a background to the 3R concept and is illustrated with 19 examples of the application of 3R techniques at different scales.

The theme of the second 3R book "Transforming Landscapes, Transforming Lives - the business of sustainable water buffer management" (2011) is that water storage is key to food security and food production. Achieving food security requires not only the availability of water, but also its integration with land management and agricultural practices. This book describes the linkages between land management and water buffer management and the underlying business case. Like the first 3R book, it also includes worldwide cases to illustrate the different scales of landscape and water buffer management and examples of wet and dry countries of innovative approaches.

2 Buffering

2.1 The 3R concept

*"Not even a little water that comes from the rain must flow into the ocean without being made useful to man" (*Paräkramabähu *I, ruler of Sri Lanka 1153-1186)*.

In many areas in the world, people experience periods of water scarcity even though there is enough rainfall and run-off on an annual basis. At moments when water is plentiful, often a large portion of it disappears unused through floods, surface runoff and evaporation. The essence of water buffering is to better manage natural recharge and to retain water longer. In this manner unused runoff and evapotranspiration can be reduced (figure 2). The larger idea is that tackling a local water crisis is not so much about reallocating scarce water, but to store water when it is plentiful and to make it available for the dry periods – and also to extend the chain of uses. Storage is, thus, the central concept.

Often storage is associated with large surface reservoirs and mega-dams. 3R presents an alternative concept – of using many smaller systems and storing water in the landscape. Much water storage is invisible: it takes place in the ground - in the upper part of the soil, the unsaturated zone, or below the water table (the saturated zone). In addition, water can be stored in many small surface systems (figure 2).

The advantages of decentralized storage compared to large dams are several. First and most importantly, the range of geographic and livelihood settings where 3R solutions can be applied is huge and is almost universal – in arid and in humid areas, in hilly topography but also in flat lowlands. Secondly, storage in the soil profile or in aquifers does not lose water to evaporation as large surface reservoirs do. Thirdly, many surface reservoirs are affected by sedimentation that

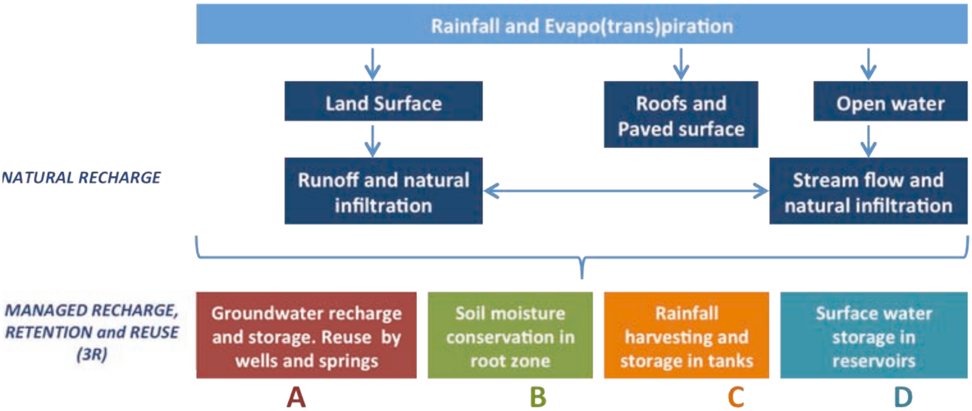

Figure 2. The 3R concept in a nutshell.

over time reduces their capacity. In contrast, when storing water in the soil or in small reservoirs sedimentation is usually not a problem and soil deposits may even be assets as they improve fertility. Finally – different from large reservoirs - many small decentralized storage systems do not disrupt life when introduced but add value to livelihoods already in the area. These four arguments are not to say that large dams are not required but that there is a powerful and universal alternative that needs much more attention than it receives now.

2.2 Different methods of storage

Storage in 3R systems comes in many shapes and sizes. Benefits that can be created in the various types of storage systems differ, as do the costs. For example, the amount of rain, runoff or snow melt that can be intercepted, how long it is retained and what side benefits are created are system-dependent.

To provide an overview of the different techniques 3R solutions are classified based on the method of **retention** and the **recharge** – how water is intercepted and where it is conveyed to. In the method of retention four main categories of buffer options are distinguishable (see also figure 3):

Groundwater is a 'closed' storage, and therefore the amount of evaporation losses are much smaller than in open water storage. It can store large volumes of water; more than 90% of global fresh water (ice and snow excluded) is stored as groundwater. However, the water is not directly available and wells with or without pump are necessary to access the water. An advantage of groundwater storage is that it can filter the water, and may therefore improve its quality. The downside of this is a possible contamination risk of the water, if the ground contains polluting elements. Thus, good site selection is very important.

Soil moisture has advantages comparable to groundwater because it is a relatively 'closed' type of storage with less evaporation losses as compared to open water storage. Soil water is stored in the upper part of the soil, which coincides with the root zone. Therefore, the water stored as soil moisture is available at the location where it is used by the crops. It does not need transport for agricultural use and nature conservation. Part of this water may percolate deeper and provide local recharge to the groundwater.

Closed tank (or cistern) storage provides a method to store water in a very clean manner, close to the location where it is used as drinking water. However, often the volume of the tanks is limited and therefore the scale of use is relatively small, generally limited to providing drinking water or water for livestock. Moreover, there are potential health hazards related to still water that remains in a tank for too long. In larger tanks, the water can be used for supplementary irrigation.

Open surface water storage provides a method to store larger volumes, and can therefore be used for agricultural or industrial purposes. It has the advantage of being directly available. However, large open surfaces are prone to relatively large evaporation losses and have a relatively higher risk of contamination compared to the other systems listed above.

Each type of buffer has its own strengths and weaknesses. The time for which water is retained and stored differs across systems. In general the buffering capacity increases as one moves from small to large storage and from surface to soil/groundwater storage. Whereas small tanks and soil moisture will help to bridge a long dry season, large surface storage and particularly groundwater storage can help bridge even an unusually dry year or series thereof. Usually, different types of storage

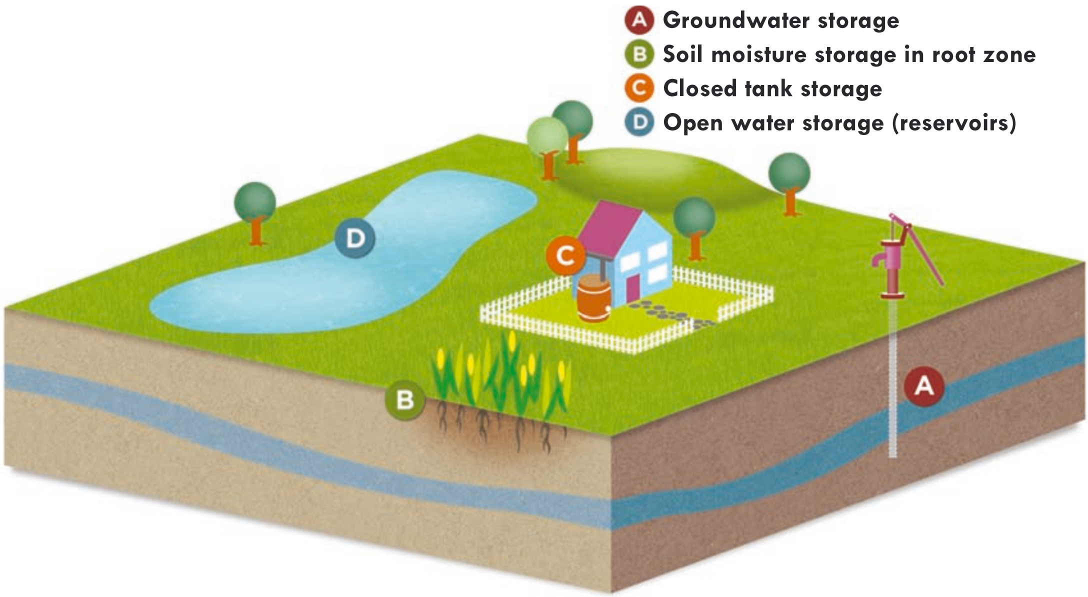

Figure 3. Infographic illustrating typical cases of storage.

GROUNDWATER STORAGE

Riverbed infiltration
- Gully plugging
- Sand dams
- Subsurface dams
- Retention weirs
- Controlling sand/ gravel mining

Land surface infiltration
- Infiltration ponds
- Trenches/ditches/ drains
- Floodwater spreading/spate irrigation
- Wetland protection

Direct infiltration
- Infiltration wells/ tube recharge
- Injection wells
- Riverbank infiltration
- Dune infiltration

A

SOIL MOISTURE STORAGE

Run off reduction
- Grass strips
- Bunds and ridges
- Terraces
- Planting pits

Land surface infiltration
- Deep ploughing
- Half moons
- Using invertebrates
- Intense controlled grazing

Evaporation reduction
- Use of compost/ biochar
- Mulching
- Conservation agriculture

B

CLOSED STORAGE TANKS

Rainwater harvesting
- Rooftop tanks
- Small tanks
- Underground cisterns

Fog harvesting
- Fog shield and tank

C

OPEN RESERVOIR STORAGE

In stream storage
- Small storage reservoirs

Off stream storage
- Off stream storage reservoirs
- Road water harvesting
- Trapezoidal bunds
- Rock outcrops/ hillside storage

D

Figure 4. Overview of 3R techniques.

complement each other in water buffering at landscape and basin level.

In figure 4 several examples of water buffering techniques are listed, ordered by retention and recharge method. The detailed classification is provided in Annex I. The advantage of this classification is that it is on the one hand system based, and on the other hand application oriented. The overview shows there are many options at hand – which might be used under different local conditions.

Many water storage methods are specifically designed to increase the water buffer capacity. It can also be enhanced as a complementary spin-off of land and water management activities that have different primary goals. Sometimes storage is a 'side product': for instance, farmer-driven regreening movements in some of the driest countries in West Africa developed much useful tree vegetation but also helped to raise groundwater levels.

In other cases buffer management objectives can be built into existing investments: for instance in the construction of roads and low causeways. Roads can be constructed to guide run off to storage ponds, cisterns or recharge zones. When roads in mountain section are constructed 'in cut' it often creates springs and these can be developed. In dry river beds low causeways (or Irish bridges) can retain subsurface flows and increase water levels in upstream wells. In terms of cost and benefits of storage, the use of such opportunities will reduce the cost of buffering. Table 1 gives some examples of interventions undertaken for other purposes (e.g. managing agriculture, rangeland or agroforestry), but which also enhance water buffer capacity.

Table 1. Intervention examples for different purposes also inducing water buffering capacity

	Management focus	Primary goal	Example measures
Water storage as complimentary spinoff	Managing the water source	• Improve water availability	• Protection and flood management • Conjunctive use, demand management
	Managing agricultural farming practices	• Increase production/ reduce erosion / reduce time or machine need	• Controlled / bio drainage • Contour farming, minimum tillage • Composting, nutrient management
	Managing agroforestry	• Increase production/ reduce erosion	• Farm forestry, controlled tree felling
	Managing rangelands	• Increase production/ reduce erosion	• Controlled intensive grazing
	Natural resource management		• Control mining (sand and gravel)
	Physical infrastructure management	• Transport • Create new land / reduce erosion • Improve water conveyance	• Road water harvesting / retention • Warping dams to create land • Improved karezes

The infographic on the next page illustrates a variety of 3R applications in a river basin. Box 4 descibes a special case and shows that creating storage is not only a man made effort.

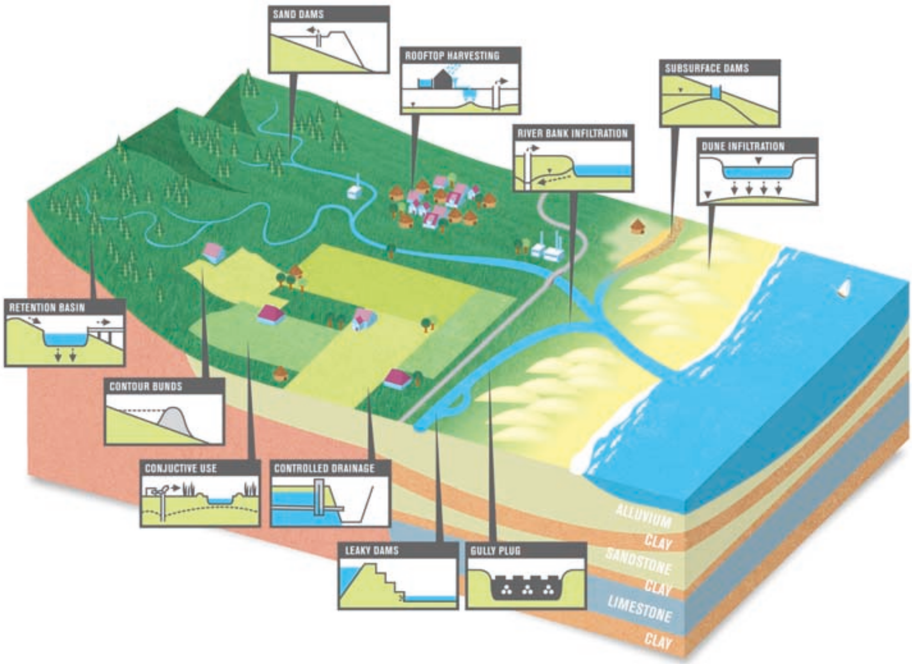

Figure 5. Infographic showing 3R applications in a river basin.

Box 4: Storage, biotic life and vegetation

Storage – particularly soil moisture and groundwater storage – is affected by vegetation and biotic life: small creatures, be it termites, sowbugs or earthworms may increase the porosity of the soil and its capacity to absorb moisture and recharge groundwater. There are several techniques to increase the presence of these invertebrates and insects. On the other hand mice and rats may cause the soils to dry up by creating large tunnels. Vegetation also has an important effect – consuming water but also affecting the micro-climate, run-off patterns, soil structure and permeability.

2.3 The practice of water buffer management

The next sections highlight the main categories of storage options and also typical costs of development and maintenance.

2.3.1 Recharging the groundwater

Technologies

Whereas the total effect of storage in tanks or cisterns is small in terms of water quantity, it is different as far as the storage in shallow aquifers is concerned. This is a major – though not often well understood - part of the hydro(geo)logy of an area. Shallow groundwater resources sustain major agricultural economies in Asia and North Africa and have the potential to do the same in large parts of Africa.

Recharge of the groundwater takes place under natural conditions (natural recharge) as is depicted in figure 2. Enhancing the recharge can be achieved in many ways: by a variety of methods usually referred to as managed aquifer recharge (MAR). In addition, recharge can take place incidentally, for instance through infiltration of excess irrigation water and leakage from water mains and sewers.

Three basic methods of recharge are interception in the river bed (figure 6a and case 5.1 and 5.7), infiltration from the land surface (figure 6b and case 5.6) and direct infiltration through wells (figure 6c and case 5.4 and 5.5). The water source can be rainwater, river water, surface water, storm water runoff or treated waste water. In all cases, the primary goal is to increase the recharge of groundwater (saturated zone) where it can safely be stored even for a relatively long period.

Figure 6 a, b, c., d, e. Different types of recharge (Photos: Acacia Water).

A slightly different 3R technology under this category is riverbank infiltration, where use is made of the natural storage of groundwater around the riverbed, by inducing the infiltration through continued abstraction along the river bank. (Figure 6d: Barichoo riverbank infiltration system Kenya Coastal Region; and figure 6e: arsenic-free well in Chapai Nawabganj, Bangladesh.)

Box 5: Hydrofracturing – increasing the storage capacity of the aquifer

A special technique to increase the effective yield from particularly hard rock aquifers is hydrofracturing. Hydrofracturing involves injecting water under high pressure into a bedrock formation via the well. This is intended to increase the size and extent of existing bedrock fractures. It is done by pumping water at high flow rates into those fractures at pressures as high as 3000 ps. This opens up the fractures and allows them to interconnect with water bearing fractures nearby. Water can then flow back through these fractures and into the well at a faster rate than before. Hydrofracturing is not common yet and needs more research to avoid potential environmental risks.

Where to apply?

All these groundwater recharge techniques require a suitable aquifer to store the water. The aquifer may be shallow or deep. Shallow aquifers which are not covered by a clay layer (like dunes and alluvial sands) are particularly suitable for land surface infiltration like basin infiltration, ditches or furrows. Where aquifers are covered by clay or in the case of deep aquifers, usually a well injection system is needed to infiltrate the water – which adds considerably to the costs. River bank infiltration systems are either at perennial rivers with adjacent sand layers or in dry rivers through subsurface dams or sand dams.

The scale of systems may vary widely: Most recharge techniques for rural water supply are small scale, such as shallow well infiltration, and sand dams or sub surface dams. Medium scale systems include recharge dams and aquifer storage systems. These systems are generally well described, like the recharge dams in the Middle East and the Aquifer Storage Recovery (ASR/AS(TR) systems in the USA and Australia.

Large scale systems include bank infiltration systems and spreading basins for large cities (Netherlands, Berlin, Budapest) and large (often multi-purpose) recharge dams and large conjunctive use systems for infiltration of irrigation water.

Also, one can see a wide range of technical complexity: from single sand storage dams (case 5.1) via infiltration ponds (Ahwat) in Sudan, to the deep aquifer storage and recovery injection systems (case 5.4).

Costs and benefits

The economics of any recharge scheme will be governed largely by the infrastructure as well as operational and maintenance requirements. These will vary significantly between schemes, not only in the scale and cost of each component, but also because some components, such as water treatment and infiltration pond maintenance, may be required for some schemes but not for others.

Many different types and technologies of small scale recharge are found in many countries, some of them dating back to ancient times. Typically, the cost of such systems is in the order of USD 0.5-2 /m^3.

In India the investment costs for artificial recharge range from USD 1 per 1000 m^3 for a percolation pond (alluvial area) to USD 551 per 1000 m^3 for an injection well, while the operational costs however range from 1 USD per 1000 m^3/year for a check dam, a percolation pond or tank (alluvial area) to USD 21 per 1000 m^3/year for an injection well. The cost of constructing a sand dam in Kenya is USD 5000 per 1000 m^3 and for shallow aquifer injection in Bangladesh USD 10,000 per 1000 m^3. Therefore, in general, the costs of construction and of operation of the recharge structures, except in the case of injection wells in alluvial areas, are reasonable; the comparative costs of recharged water per 1000 m^3 in such cases work out to USD 1 – USD 3. On the other hand, USD 0.05 - USD 0.15/person/year is very reasonable as the cost of using recharged groundwater for domestic water supply purposes.

Studies that focus on the financial and economic benefits of aquifer recharge are rare. There is a study on the national costs and benefits of reusing wastewater in agriculture in Israel[2]. It was calculated that the use of wastewater discharge in irrigation in the central and southern Israel would lead to an additional agricultural output worth USD 0.14/m^3, the benefits of recharge was USD 0.70/m^3 and the damage to the aquifer because of seepage was USD 0.10/m^3. All of this works out to a net national benefit of USD 0.11 /m^3, which is a cost-effective option compared to, for example, river disposal which has a net cost of USD 0.40/m^3.

Managed recharge schemes provide a range of benefits. This includes the protection of water resources from pollution and evaporation and the distribution of water within the aquifer using the aquifer as an alternative to surface channels. There are also many environmental benefits related to enhance groundwater levels subsequently maintaining dependent ecosystems and biodiversity. This is preventing saline groundwater intrusion.

Benefits of the various recharge schemes also depend on their type and scale. Table 2 gives a summary of typical benefits and constraints of MAR schemes.

Financing mechanisms

The financing mechanism is dependent on the typical size of the system, financial benefits to be captured, the socio-economic setting and who is extracting these benefits.

If the benefits are mainly economic benefits, it will be hard to convince individual households to engage in financing recharge schemes. In case there are indeed considerable financial benefits in rural settings in developing nations, smaller schemes can be financed either through microfinancing schemes or savings. Bigger recharge schemes will have to be financed and also managed and maintained at the community level. Financing the maintenance and operations costs could take place through tariffs or fees in cases where financial benefits are made. Meanwhile, the investment costs may be financed through government budgets or external sources. If the financial returns are not adequate, budgetary allocation at municipality level will also have to be utilised for operating and maintaining these recharge schemes. The same goes for typical larger recharge schemes which will have to be financed and operated at the basin level. External support might be required in case there is a lack of available budgetary means.

2 Agricultural reuse of wastewater: nation-wide cost-benefit Analysis, Nava Haruvy, Agriculture, Ecosystems and Environment 66 (1997) 113-119

Table 2. Summary of typical benefits and constraints of managed aquifer recharge schemes

Technology	Main advantages	Main constraints
River bed modification	• Drinking spots for cattle, irrigation, washing and cleaning • Increased infiltration in shallow waters • Increased percolation	• Relatively high levels of evaporation, water pollution
Sand storage dams / sub surface	• Low cost structures, community based, low maintenance, structures are installed in streambeds and therefore do not interfere	• Potential ownership issues, potential for water pollution, infiltration of relatively small quantities of water, quality control
Recharge dams	• Structures are installed in streambeds and therefore do not interfere with land use	• Breached structures may result in significant damage downstream • Recharge maybe limited due to siltation
Infiltration ponds and basins	• Infiltration of large quantities of water at relatively low cost • Maintenance and anti-clogging procedures are relatively simple • Organic	• Requires large flat permeable surface area • Potential for surface water related breading of disease vectors • Potential for water pollution
Flooding	• Infiltration of large quantities of water at relatively low cost	• Potential for high evaporation
Ditch, furrow, drains	• In case of reversed drainage, structures can be installed underground and therefore do not interfere with land use	• Requires large permeable surface area • Potential for surface water related breading of disease vectors
Deep infiltration wells: ASR	• Clogging partially removed during recovery cycle • Infiltration of large quantities of water at relatively low cost	• Complex design, complex construction, complex operation and maintenance • Intensive monitoring required • High quality requirements
Shallow well / shaft / pit infiltration	• Use of existing facilities reduces costs • Recovery from same structure reduces clogging	• High quality requirements of source water
Induced bank infiltration	• Large quantities of good quality water can be withdrawn • Organic contaminants in source water are filtered out in soil	• Complex design, complex construction, complex operation and maintenance • Intensive monitoring required • High potential for well

Source: Artificial Recharge Around the World; IGRAC and Acacia Water, 2003

Implementation

Small MAR systems are usually designed, constructed and managed with a high degree of community participation. The site selection and design usually needs the input of a specialist but the implementation can largely be covered by local manpower (contractor, local administration, community) and with maximum use of locally available materials.

Medium and large size systems are usually characterized by a higher degree of technical complexity and a need for more professional expertise in design, construction and management. Usually, construction is done by contractors and the management responsibility is assigned to (municipal) authorities or agencies.

2.3.2 Improving soil moisture storage

Technologies

Retention (regreening) can be accomplished either by

- increasing the amount of water that is added to the soil by slowing down surface runoff (example in case 5.1),
- increasing the amount of water that can be stored in the soil by increasing its water holding capacity (example in case 5.9), or
- by reducing the water that escapes from the soil by evaporation (example in case 5.10).

Increasing the amount of water added to the soil can be accomplished by reducing run-off and thus increasing the amount of time for which water is retained on top of the soil and allowed to infiltrate. Options for run-off reduction include terracing, which locally reduces the slope of the hill. Another less costly option is to construct contour bunds, which provides obstacles to the water that runs downhill, so that it accumulates behind them and the run-off velocity is decreased. They can be applied in various shapes along hillsides over the length of the field or more locally. Additionally they can be combined with planting pits to create a micro-environment for plants or specific trees. Also, the amount of water added to the soil can be increased by spate irrigation, a technique in which water from a river is diverted to flow over the land during peak flows, thus increasing the amount of water that infiltrates in the soil and increases thereby soil fertility (see www.spate-irrigation.org).

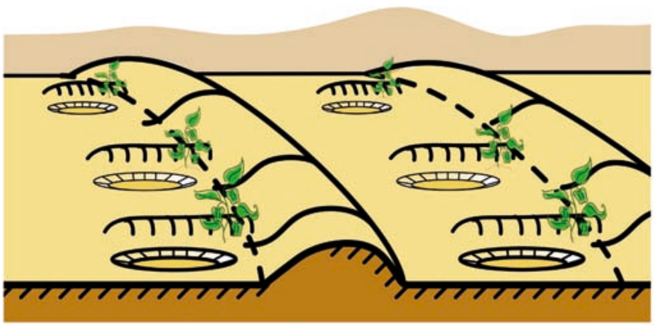

Figure 7. Earth bunds with pits (Goltzback, 2011; Critchley, 1991a).

Figure 8. Making of compost in Burkina Faso (Goltzback, 2011).

The amount of water that infiltrates the soil depends on the soil conditions. These vary naturally, but can be managed to optimize the amount of water that is able to infiltrate. Mismanagement, or over-exploitation can reduce the infiltration capacity of the soil, and thus its fertility. By maintaining more water in the soil, its water holding capacity can be increased as well. This can be done by increasing the amount of organic matter in the soil, for example, by composting, adding fertilizer or conservation tillage (in which more of crop residues are left on the field). Roots and litter from plants also increase the infiltration capacity of the soil. This is used when reduced or zero tillage is applied, where part or all of the vegetation is maintained, and can be strengthened by the planting of trees. With the latter methods a possible increase in evapotranspiration should be taken in account.

Evapotranspiration losses from the soil and crops can be reduced by mulching. In this practice the soil is covered by natural or plastic materials. Since the coverage material may be scarce, often only the soil around individual plants is covered. Traditionally, organic mulch is used. Plastic mulch can give better results, but there is also a risk that non-degradable parts of plastic may be left behind in the soil.

Where to apply?

Soil moisture is available where crops need their water: in the root zone. Therefore, increasing the amount of soil moisture can be very beneficial for agriculture. However, the water captured in the soil and is not freely available for other purposes or locations, as the water cannot easily be abstracted from the soil. Therefore, soil moisture retention is best used in agricultural areas.

General guidelines for application of these techniques are:

- Terraces and bunds are suited for areas with hill slopes (e.g. slopes > 0.5% with bunds);
- Spate irrigation, mulching and soil improvement can be combined with terraces or bunds;
- Mulching and soil improvement techniques are applicable either on flat terrain or on slopes;
- Regular topography is not required (e.g. semi circular bunds);
- The techniques are useful even with very low rainfall (150 mm; bunds);
- Most options employed for increasing soil moisture are easy to construct;
- Because of the ease of construction, they are suitable for remote areas.

Costs and benefits

The costs reported here are taken from the report “water harvesting potential for Africa, an assessment of costs and impacts”, by N. Goltzback et al (2011). The report describes various soil moisture enhancement techniques. Some of the techniques are low-cost, as is outlined below. Because the water retained is not available freely, but is available for the crops, the costs are expressed in ha instead of per m^3.

Low-cost material that can be used for mulching are agricultural residues, cut weeds and straws. The costs including labour and operation costs for mulching are USD 40 - USD 120/ha. Composting associated with planting pits may be as cheap as USD 8/ha, with the cost covering the digging, fertilization of manure and composting. Tillage (zero, chemical, or reduced) and adapted ploughing costs are in the order of USD 40 - USD 120/ha. Loss of area to grow crops is also a cost that is mentioned in many publications, and should be included.

For bunds, the price depends on the available earth or stone material and on the price of labour. Construction costs USD 8- USD 350/ha and maintenance USD 10 - USD 35/ha or 10 to 20 days/ha.

Terraces are more expensive at USD 275 - USD 1840/ha. Labour is the main component of this cost. Maintenance of the terraces costs about USD 45 -USD 365/ha/year.

The benefits include increased crop yield and support to a wider range of crops, water saving, as well as the protection of fertile soil on the land that leads to reduced fertilizer costs.

Financing mechanisms

These measures are typically taken at the community level. The measures could be implemented and financed through, for example, user associations, community groups or farmers associations. There will be sufficient interest for these measures to be financed and implemented, if there are sufficient financial returns in terms of increased agricultural production. In that case, the financing could take place through tariffs or levying fees with (pre)financing through (communal) loans or funds from the government budget. Due to the proven benefits of plastic mulch, subsidy programs (upto 50% of the cost) are in place in many countries to promote its use, especially in the Asian continent.

Implementation

Soil moisture conservation practice can be applied independently, or in combination with other techniques. For example, within the category of soil moisture storage, spate irrigation can be combined with contour bunds or terraces hence the spate water remains longer in the fields and can infiltrate. Soil moisture conservation methods can also be successfully combined with methods of other water retention categories. Irrigation water storage can be optimized when combined with soil water retention methods. For example, less irrigation water will be lost when the soil’s water holding capacity is improved, or when mulching is applied. Terraces may make efficient irrigation possible at locations that were previously to steep. For efficient agricultural practice, soil moisture optimization techniques often form a relatively cost effective basis.

2.3.3 Storing in closed tanks and cisterns

Technologies

The classic example of this category of 3R technology is the collection of rainfall from roofs and its storage in a tank. Alternatively runoff water can be harvested from prepared surfaces (including storm water runoff in urban areas, roads) and stored in underground reservoirs and cisterns.

A rainwater harvesting system usually consists of three basic elements: the catchment system, the conveyance system, and the storage system. Catchment systems can vary from the rooftop of a domestic household to a large ground surface catchment area that recharges an impounding reservoir. The most widely used storage devices are tanks (or cisterns), with sizes typically ranging from 5-10 m^3 when used for drinking water purposes or 300 m^3 for supplementary irrigation. Small tanks are made of polyethylene, ferro-cement, corrugated steel, plastered brick, concrete. Their use is typically complementary: water from the tanks may be used when collecting water from elsewhere is not an option. Larger tanks may consist of excavated faults or natural depressions.

The classification of rainwater harvesting systems depends on factors like the size and nature of the catchment areas and whether the systems are in urban or rural settings.

The appropriate storage capacity of a rainwater harvesting system is related to the amount and distribution of rainfall. For example, in a region with abundant, steady rainfall year round, a small tank sufficient to hold a few days of rainwater will be enough to meet the demands for most of the year. On the other hand, drought-prone regions will need a significantly larger catchment area and storage tank to meet the water demand. Calculations take into account design parameters, based on a series of monthly rainfall data and sometimes supported by simple models for the dimensions of a system.

A point of attention in small tanks systems is the quality of the water. Common measures are avoiding the first foul flush to enter the tank, installing filters and screens, and regular cleaning.

Figure 9 a,b,c. Closed storage options (Photos: Acacia Water and MetaMeta).

Where to apply?

Rainwater harvesting and tank storage can be applied where small catchment areas – including roofs - are available, and the rainfall patterns are such that the cost of storage remains within acceptable limits. Such systems are generally expensive. They should be employed in areas where (IFAD, 2012):

- Annual rainfall is between 200 mm and 1 500 mm;
- There is no or insufficient perennial water source – either surface or groundwater;
- Existing water sources are insufficient to meet multiple water needs;
- Groundwater potential is low (low yield) and/or of poor quality (e.g. high levels of arsenic or fluoride, agricultural or industrial pollution), and is too expensive to treat;
- Surface water is seasonal or unavailable and/or of poor quality, which is too expensive to treat;
- Remoteness makes it difficult for households to access water sources;
- Water collection drudgery is severe, due to distance and/or elevation;
- Appropriate alternative community managed technologies (boreholes, protected wells, protected springs, etc.) are not available, affordable, and/or manageable; and
- There is no severe air pollution[3].

Cost and benefits

The costs of small rainwater harvesting systems[4] can be divided into investment costs, the costs of maintaining the systems (including management) and other costs (IFAD, 2002; IRC, 2011). The benefits are multiple and both direct and indirect. The investment costs of a rainwater harvesting system includes the planning and -implementation cost, tools and materials used to construct the system, and education materials on proper maintenance and health information (Huffon 2004). The maintenance costs include the materials needed to maintain and repair the components, the replacement of carbon in the filter, the washing of storage tank and the time of controlling the first flush system. An important category of the other costs is the costs of capital, which can be substantial, especially in situations where the banking sector is immature and there are high levels of inflation and uncertainty. The financing costs, i.e. the interest costs and the loan repayments, are generally included in the costs calculations. However, there are also costs attached to tying up capital, which are less obvious and are often forgotten. So, even in cases when investments are financed from own sources, there are costs of capital that have to be considered, especially the so-called opportunity costs of capital. It is important to consider all costs over the whole live time of the project[5].

The cost mainly depends on the size of the storage tank which for a household is usually between 5-10 m^3. For school roofs or other larger roof catchments, the tank size may increase to 20-50 m^3. Depending on the material (ferro-cement, masonry, concrete) the typical capital costs of a rainwater harvesting system is between USD 40 - USD 200/m^3 (2011)[6]. For larger structures, they add up to around USD 20 - USD 40/m^3.

Direct benefits of roof top water harvesting are the reduced cost of water for instance where water

3 Precipitation is known to wash away pollutants. These could include micro-organisms and chemical contaminants and can affect the quality of harvested rainwater.

4 IFAD (2012) "Technical, financial and economic tool on roof rainwater harvesting" (IFAD, 2012) and IRC (2011), "Life cycle cost of rainwater harvesting systems (IRC, 2011).

5 One of the methods that considers all costs is the Life-Cycle Cost Approach (LCC)

6 Life-cycle costs of rainwater harvesting systems, IRC, May 2011

was obtained from water vendors. Other direct benefits may occur if sufficient water is stored for small livestock water supply or backyard gardening. Indirect benefits can be categorized into health benefits and non-health benefits. Cost savings in health care are mainly related to improved water quality and the reduced number of diarrheal cases or other water-induced diseases, which can be monetized in terms of the averted costs of medical treatments and hospitalization days. Non-health benefits may include the income saved from payment to private vendors, time cost saved from fetching water, income gained from increased number of productive days/ more school days/ more days of child care due to fewer incidents of disease.

Box 6 hints that rainwater harvesting could be economically and financially feasible, i.e. the benefits could indeed outbalance the costs in particular situations.

Box 6: Economic advantages of rainwater harvesting

A rainwater harvesting project in Kattanad, India - investment costs for a 6,000 litres system would cost about Rs 13,500 (USD 40/m^3). The WHO's study estimates that the operation, surveillance, and maintenance cost for rainwater harvesting to be about 10% of the investment costs.

An important non-health benefit is the income saved from buying water from private vendors. These figures are based on interviews. As for health benefits, the WHO assumes that a diarrheal case visits a health facility once, with a range of 0.5 to 1.5 visits. Once hospitalized, the length of stay is assumed to be 5 days on average. Based on the WHO report, the annual patient treatment costs saved from providing access to water and sanitation services is USD 134 per capita. The report for India assumed that the averted patient treatment costs to be 1/3 of the WHO figure. In addition to the health benefits and lower medical costs associated with averted cases of disease, an extra benefit is the gaining of income that was otherwise forgone due to lost working days. Also, the minimum wage is used to monetize the extra days available for schooling and childcare. The WHO's study reasons that the impact of illness is school absenteeism, which has a negative impact on the children's future human capital. For this reason, time not spent at school by children of school age can also valued on the basis of the minimum wage. The study monetizes the days gained for child care (due to averted illnesses) at 50% of the minimum wage.

The expected net benefits of the investments in rainwater harvesting in Kattanad range from Rs 384 million (USD 7 million, at a discount rate of 0%) to Rs 13.5 million (USD 245,000, at a discount rate of 30%).

Source: Water Quality Study and Cost-Benefit Analysis of Rainwater Harvesting in Kuttanad, India, Christina Tang, 2009 Center of Environmental Studies at Brown University

Financing mechanisms

Rainwater harvesting typically takes place at individual households and at the village level. If the financial returns are sufficient, there will be an interest of households to finance it themselves. Besides, financial assistance could be made available via micro credit schemes at village or district levels. In other cases, the installation of rainwater harvesting systems will have to be subsidised from other sources, such as the government, NGOs and donors.

Implementation

Rainwater harvesting systems are sometimes a fully local initiative, but in most cases they are part of rainwater harvesting projects with funding and implementation support from NGOs or other development agencies at the international, national or local level. Some international development agencies cited to implement rainwater harvesting systems in multiple countries in Asia and Africa are Adventist Development and Relief Agency (ADRA), WaterAid, World Vision or international development organisations such as UNDP and UNICEF.

2.3.4 Surface water reservoirs

Technologies

Surface water reservoirs are also characterized by a large variety in size and scale. Small reservoirs (defined as reservoir behind dams less than 15 meters high and of a volume less than 0.75 km^3) usually meet the demands within a period of a few months. The aggregate capacity of the 17,000 small dams in Sri Lanka is 0.25% of the storage capacity of the High Aswan Dam in Egypt. In this book, we focus on small dams, surface reservoirs like small tanks and other micro-storage facilities such as dug cisterns and farm ponds. Case 5.12 and 5.13 give some typical examples.

Many surface reservoirs also provide recharge to the groundwater underneath the reservoir and into the banks. Where this is part of the design of the dam, we speak of recharge dams. Recharge dams range in size and are well known in arid regions like Oman, UAE and Yemen.

Large numbers of small reservoirs can be found throughout semi-arid areas. While the hydrological impact of small reservoirs is individually quite small, the existence of several hundreds of such structures may have a notable impact on a regional scale. On a local scale, the hydrological impact of small reservoirs is relatively small as they only capture parts of the total runoff at the head of a watershed. In terms of food security, economic development, and income diversification, small

Figure 10. Open water storage behind a check dam (a) and in a plastic lined pond (b) in the Andes, Peru (Photo: Acacia Water).

reservoirs have a significant impact on rural communities[7]. On a regional scale such structures can alter hydrology (eg. base flows, basin water yields, regulation of flows etc).

Where to apply?

Reservoirs can be constructed in intermittent rivers where the soils, topography and geology allow for safe dams and for the creation of the reservoir. For large dams, the feasibility study and design is the specialized work of engineering firms and includes a thorough assessment of the environmental, financial, economic, social and hydrological impact. Small dams are less complex, but also need engineering inputs for design, siting and construction supervision. Small tanks and farmer ponds are usually constructed in local depressions, by the owner or the community.

Costs and benefits

A handbook on small dams in Kenya, produced for DANIDA[8], presents typical costs of constructing different types of water storage reservoirs of volumes ranging from from 100 m^3 - 5000 m^3. It shows a range from 20 Ksh[9] per m^3 (USD 0.27), for a reservoir volume of 5000 m^3 (a valley dam constructed by oxen), to 100 Ksh per m^3 (1.37 USD), for a reservoir storage volume of 100 m^3. The handbook concludes that the construction of valley dams is much cheaper than the construction of excavated tanks and ponds. The reason is that for a valley dam the least amount of material has to be moved compared to its capacity. The most expensive option is the manual excavation of tanks and ponds, because only one cubic metre of water storage capacity is created for each cubic metre of soil excavated. The cheapest construction method is to use oxen, with the cost being as low as Ksh 20 per cubic metre of storage capacity created, in the case of valley dams. This type of dam is, however, the most difficult for a community, farmer and/or water technician to construct.

The economic benefits include the value of labour and time saved in fetching water and watering livestock. Benefits may also result from improvements in the condition of livestock and small stock, cash from the sale of irrigated farm produce and value of food grown for the household. The handbook calculates the total value of these benefits for a 500 m^3 storage to be 10,000 Ksh (USD 137). This includes 3,000 Ksh for time saving to fetch water and watering livestock and 7,000 Ksh of increased income because of additional yield due to better water availability, which would allow for a payback period of less than two years on a small hill-site dam. The handbook acknowledges that there are environmental benefits and costs to the construction of reservoirs and admits that these effects can be substantial, especially for larger reservoirs or a large number of smaller reservoirs. However, it only provides a checklist of potential effects, without further quantification or monetisation.

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7 The Small Reservoirs Project: Research to Improve Water Availability and Economic Development in Rural Semi-arid Areas, Jens Liebe, Marc Andreini, Nick van de Giesen and Tammo Steenhuis, resp Cornell University, Ithaca, New York, USA, International Water Management Institute (IWMI), Washington, D.C., USA, Delft University of Technology, Delft, The Netherlands.

8 Water from Small Dams, Erik Nissen-Petersen, Danish International Development Assistance (Danida), 2006

9 USD 1.00 = Ksh 73 (August 2006)

Financing mechanisms

The choice of financing mechanism very much depends on the size of the water reservoir system. If it involves a large-scale storage dam, the financing mechanism will most likely go through the national government and a dedicated authority will be established to manage and operate this dam and reservoir. Net economic benefits very much depend on whether the local population has to be resettled. Environmental loss due to loss of natural habitat and/or environmental downstream damage should also be taken into account[10]. For large-scale dams, the reason for construction is that there will be substantial financial benefits in terms of increased agricultural production[11]. Investments in the construction are generally financed by government budget or from external sources, while maintenance and operations costs could be financed through user contributions.

If it is a small-scale dam, the system will be managed and operated at a more local level. For example in Sri Lanka and in South-East India, farmers organisations are responsible for operating and maintaining tank systems. These organisations charge fees for their services. The investments will come from government or external sources. There are, however, some cases in Sri Lanka, where farmers take care of the construction themselves.

Box 7: Retaining water by reintroducing beavers

While beaver numbers in North America once amounted to hundreds of millions, the hunt for their pelt and ecological change has reduced their numbers to 6-12 million. In the past, there would be a beaver dam on every stream every 500-1000 meters. These dams created ponds and wetlands retaining water and snow melt. While beaver ponds were relatively small , they helped recharge groundwater, intercept sediment, allow trees and vegetation to flourish and increase biodiversity and buffer the area in general. The amount of water that a single beaver colony adds to the local ecosystems is the equivalent of a once-in-200-years flood event. In Washington state they have been proposed as an alternative to flood storage dams. Repopulating the areas with beavers is an attractive but not an easy proposition: forests are less dense and reintroduced beaver families have fewer options for their habitat.

Source: D. Ferry (2012), Leave it to beavers: can they help us adapt to climate change? The Atlantic, June 2012, 24-25.

Implementation

Like for financing mechanisms also the implementation of dams is largely dependent on the scale. Large dams are generally designed and constructed by consultancy firms and contractors, while for smaller dams there is an increasing input of local manpower and use of locally available materials.

10 The social and environmental costs for large-scale dams were considered to be very high which was the reason why the World Bank was, after the critique on the 'Three Gorges Dam' in China, very hesitant to get involved or to finance in very large scale kind of dams. Smaller-scale dams are less critique prone as the potential social and ecological damage is considered much lower.

11 We do not consider hydro-power dams here as these have different purposes

3 Reaching scale

3.1 Different routes of reaching scale

Where possible, buffer management should be done at scale, with a high density of measures covering a large part of the area[12]. This will make it possible to reach a tipping point so that entire landscapes and economies are transformed. When 3R is implemented at high intensity and regreening reaches a certain scale, many processes will change with it: the hydrology, the sedimentation processes, the micro-climate, the soil chemistry and nutrient cycle and the regeneration of vegetation cover. This multiplies benefits.

By now there are impressive examples of such systemic landscape changes, like the watershed movement in Tigray in Ethiopia (see case 5.11.), that is now replicated elsewhere in the country. Other examples are the systematic regreening of a number of catchments in China and watershed programs in several states in India. Some of these large scale buffer management practices are externally supported, while others are primarily driven by farmers' initiatives, like the recharge movement in Saurahstra in Gujarat (India) and the managed regeneration of natural vegetation in Niger and Mali – all cases involve upward of 1,000,000 hectares[13].

In chapter 2 an overview of 3R techniques was introduced. Which combination of techniques can be successfully applied in which area depends on local preference, the source of water and other specific local conditions (climate, topography, soils, geology, land use). It also depends on the specific purpose of water buffering and the scale of use (table 3 and 4). All these measures individually contribute to increase the water retention capacity of a landscape.

If these techniques are scaled up and/or combined, their benefits will significantly increase. Upscaling can be supported by systematic planning within a landscape or sub-basin, scanning a range of technologies that provide the best value for money. With reference to the cases in chapter 5 this can be applied in different manners (figure 11):

- **Replication** of a single scheme. This can be beneficial in areas where one particularly useful technique is applied in large numbers. Examples of this are a cascade of sand dams in riverbeds (case 5.1), a large number of shallow groundwater injection schemes in a coastal plain (case 5.5), or a multitude of rooftop rainwater harvesting systems (case 5.14).
- **A variety** of 3R applications in one area - which are selected, planned and designed as a package. This is very promising in areas with various water uses/users and a variety of physical characteristics or where water resources' protection and development is combined. Examples include the modernization of the ancient groundwater harvesting technique, Karez system, in

12 It is important to work and manage in particular the hydrological interaction within a landscape – the link between surface flow and groundwater; the large scale conservation of soil moisture; the management of run-off in local drains.

13 See: Shah, T. 2000. Mobilising social energy against environmental challenge: understanding the groundwater recharge movement in Western India. Natural Resources Forum 24: 197–209; Zhu Qianag, Li Yuanhong, John Gould (2012) Every last drop: rainwater harvesting and sustainable technologies in rural China. London: Practical Action Publishing and:. Reij, C., G. Tappan, and M. Smale. 2009. Agroenvironmental transformation in the Sahel: Another kind of "Green Revolution." IFPRI Discussion Paper. Washington, D.C.: International Food Policy Research Institute.

Table 3. 3R solutions: physical parameters

Retention method	Recharge method	Requirements (Y should be present, N should be absent)					Recharge source			
		Slope	River / stream	Aqfuifer	Covering soil layer	Buildings	Rain	Surface runoff	Stream flow	Other
A. Groundwater storage	1. Runoff reduction: riverbed	Y	Y	Y	N				X	
	2. Land surface infiltration			Y	N			X		
	3. Direct aquifer infiltration			Y	Y/N		X	X	X	X
B. Soil moisture storage	1. Runoff reduction	Y							X	
	2. Land surface infiltration				N			X		
	3. Evaporation reduction									
C. Closed tank storage	1. Rainwater interception					Y	X			
	2. Fog harvesting									X
D. Open water storage	1. In the riverbed	Y	Y		Y				X	
	2. Outside the riverbed		Y		Y/N			X	X	

Table 4. 3R solutions: use and scale

Retention method	Recharge method	Primary use				Scale			
		Drinking	Agriculture	Livestock	Other	Household community	Village / cooperative	Small town	Urban regional
A. Groundwater storage	1. Runoff reduction: riverbed	X	X	X		X	X	X	
	2. Land surface infiltration	X	X			X	X	X	X
	3. Direct aquifer infiltration	X		X			X	X	X
B. Soil moisture storage	1. Runoff reduction		X			X	X		
	2. Land surface infiltration		X			X	X		
	3. Evaporation reduction		X			X	X		
C. Closed tank storage	1. Rainwater interception	X				X			
	2. Fog harvesting	X				X			
D. Open water storage	1. In the riverbed	X	X	X	X	X	X	X	X
	2. Outside the riverbed	X	X	X	X	X	X	X	X

Pakistan (case 5.3) or watershed activities in India (case 5.8) and Tigray (case 5.11).

- Managing the entire landscape **at one go** with one or two large interventions that have a major impact – for instance a large dam or a stringent ban on sand and gravel mining in a river to ensure it keeps performing its functions of flood water storage and groundwater recharge.

Figure 11. Several routes of reaching scale

3.2 Working systematically

There are several ways to promote and introduce water buffering at scale. Sometimes, initiatives spread spontaneously. For instance, the recharge movement in Gujarat (see box 8) as well as the regreening through managed regeneration in Niger and Burkina Faso'[14]. Also, it could be the initiative of the local government (as in Ethiopia), associations of land and water resource users (such as Water Resources Users Associations in Kenya) or special programs (such as the watershed programs in South India) – to introduce new techniques, build capacity, organize local planning and support part of the investments.

The implementation process can be a phased activity which helps to fine tune the 3R needs to areas where there is sufficient priority to make the investment most successful. A good starting point is to understand what is going on already and to understand the natural recharge and storage processes. Also, in many areas there are good practices around that can be promoted more widely.

Planning can start with a quick scan of a larger area and observation what is already there or not, and what works well and what does not. A quick scan would involve systematic mapping of the area to delineate where water buffering is needed and by whom, and what the physical conditions are. There are several general global data sets that can be of help: on population density, land use, rainfall/aridity, soil types and topography. They can lead to the selection of specific areas (sub basins) and the specific needs to be addressed.

In the next phase one can zoom into areas with large scope and potential, using secondary information that is available (there is often a wealth of unused information) and field visits. This should set the basis for detailed discussions with local and regional stakeholders on how to improve water buffering. To stimulate and open the debate, there are many interactive tools and methods available, which have proven their effectiveness in such projects.

Once the options have been discussed, the planning process focuses on operational issues – who can do what, what can be catalyzed and what needs to be financed. There is often a large potential for learning by observing other areas, and through exchange visits between local organizations – be it NGOs, the private sector (SMEs), local institutions and the land users. This will generate the implementation capacity at the local level. Further feasibility assessment in the selected areas

14 See also van Steenbergen et al. (2011), Transforming landscapes, transforming lives. Rome: IFAD.

Box 8: Self financed recharge movement in Saurashtra, Gujarat, India

Recharge, retention and reuse can, in many cases, be self-financed as several regreening movements demonstrate – such as the recharge movement in Saurastra in Gujarat. In 1978 a charismatic religious leader called Pandurang Shastri Athawale spoke at the inauguration of a common property forest and said: 'If you quench the thirst of Mother Earth, she will quench yours...' After three years of drought between 1985 and 1987, farmers were acutely aware of what was meant by this. Water harvesting had been promoted previously by several civil society organizations and the techniques were known. Pandurang Athawale asked his followers to adopt these techniques on a large scale. Whereas previously water recharge and retention was applied sporadically, it was now done at village level by a large number of people and the impact in terms of stabilized and increased groundwater levels became quite visible in several villages. Success bred success and the activities turned into a 'movement,' with farmers building close to 100,000 recharge structures in a few years. Having invested so much in groundwater recharge systems, water users in many areas imposed restrictions on the development of new wells.

will lead to the selection of the type of intervention that provides the best value for money and is appreciated by the stakeholders, and the proposed phasing.

Before implementation can start, the financing of the project (and its different phases) has to be in place. This is further elaborated in the next section. In the implementation phase the schemes are designed, constructed and handed over to the users for operation, maintenance and monitoring. Implementation will usually start with a pilot project during which the design, construction, operation and maintenance of a few systems is tested. The pilot phase will also generate a lot of information needed for the full implementation phase. Finally, a basin plan is realized with full scale implementation and embedding in the national-level planning. Annex II gives an example of the phased approach which was applied in the recent study in Nepal.

Another example where this approach was put into practice is shown in a recent 3R project (part of the Kenya Arid Lands Disaster Risk Reduction program- KALDRR). The map in figure 12 was produced as a sub result. In this program a regional assessment was carried out using the 3R approach in combination with a Multiple Use Services (MUS) inventory. Available data sets (through a desk quickscan) with field information were combined. This way opportunities for intervention were identified and the effectiveness of different 3R techniques analysed, within the geo-hydrological landscape. An overview of low-tech interventions were provided that have the highest potential to effectively provide the water required for different uses. All information was summarized in a comprehensive map (see figure 12). Simultaneously an identification of community water needs was assessed using the Multiple Use Service (MUS) framework.

In a participatory process, a set of actions were chosen by the community that matched the potential of water buffering measures with the local needs and context.

As a result, a 3R/MUS model for the region was generated. This knowledge can be used for the planning of feasible low-cost water storage infrastructure at a given location. Next to that the knowledge can be made practical at institutional level, e.g. the local government.

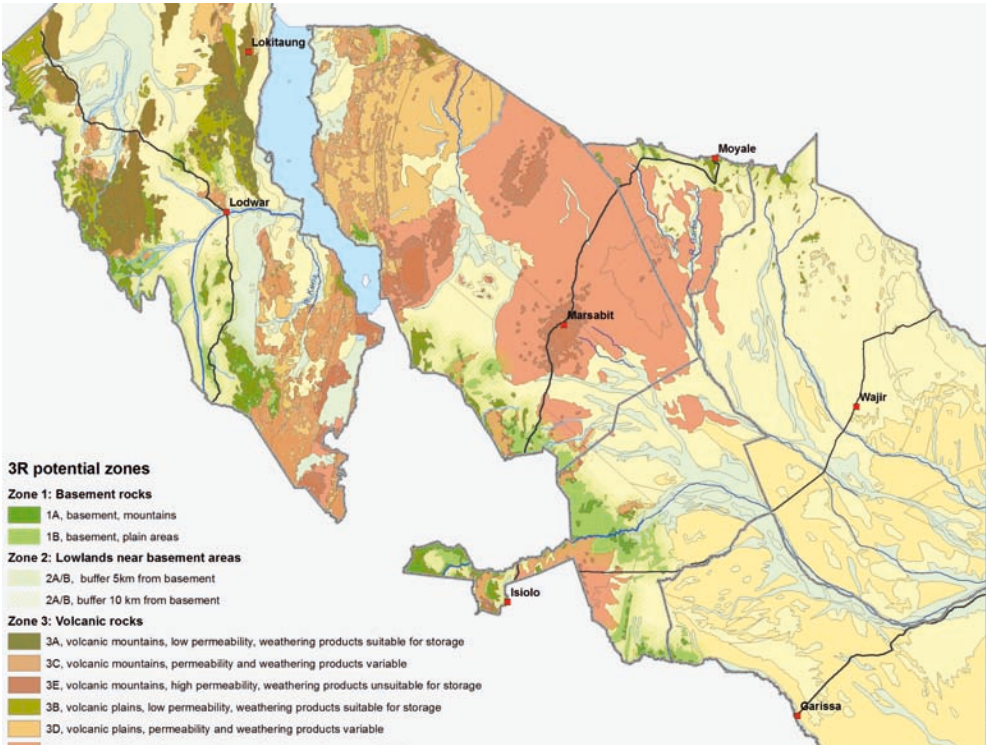
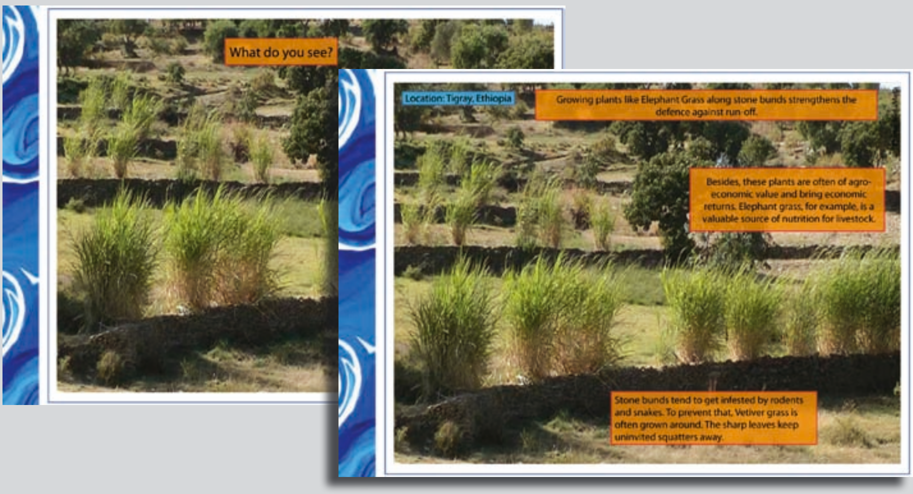


Figure 12. Example of a 3R potential map for the (semi-) arid lands in Northern Kenya.

Box 9: Visuals

Visual aids can be particularly useful in interactive planning, such as maps or images of the area printed on panaflex. Panaflex is durable but also allows one to use erasable markers, so as to aid the planning process. Other useful aids include flashcards showing different 3R techniques – especially those that are not yet common in the area.



4 Calculating the costs and benefits of water buffering at scale

This chapter further develops/explores an approach for calculating the cost and benefits for buffer management. It looks at valuing and quantifying the immediate benefits – on site, on stream or off stream – as well as at valuing the cost of resilience: the ability to overcome drought and to manage periods with high rainfall or floods.

This chapter is meant to be a guide for economic and financial planners – looking at investment in buffer management in a way similar to how one looks at investments in other infrastructure. We aim that this not only contributes to make the economic case for buffer management but also to maximize the cost-effectiveness of programs of interventions[15] and to think through the financing arrangements[16]. Moreover, it is important not to think in terms of planning and investment decisions alone, but also to recognize possible support through self-financed local land users initiatives for regreening, moisture conservation and small scale water conservation.

4.1 Basic principles

In order to judge whether an investment or policy measure is worth the effort, the cost and benefits of the planned measures and the consequences of those measures should be compared. There are the costs and benefits of the measures themselves and there are costs and benefits associated with the expected impact of the measures and the enhanced resilience that comes with them. Figure 13 is an overview of the costs and benefits at different levels.

Costs and benefits of implementation

Costs associated with water buffering and regreening measures are the costs of development and the costs of upkeep, incurred to keep the buffer management measures in tact. Chapter 2 has indicated the range of such costs for different 3R solutions. The costs come in monetary terms or in labour contribution. There are not only costs: the sheer fact of doing the work creates benefits too. It creates employment and activity and this will flow directly into the economy. How much buffer management programs contribute to the local economy depends on the nature of the investments. If – in case of external financing - most is spent on local labour the contribution to the local economy is high. Particularly where labour is paid in cash (rather than in food) this can 'fuel' local

15 A very useful reference for instance is Lasage, R and H. Verburg (forthcoming), Evaluation of small scale water harvesting techniques for semi-arid environments. To be published in Agricultural Water Management.

16 Following Winpenny, J. , I. Heinz and S. Koo-Oshima (2010), The wealth of waste: the economics of waste water use in agriculture.Water Report 34, Rome: FAO (pg 47).

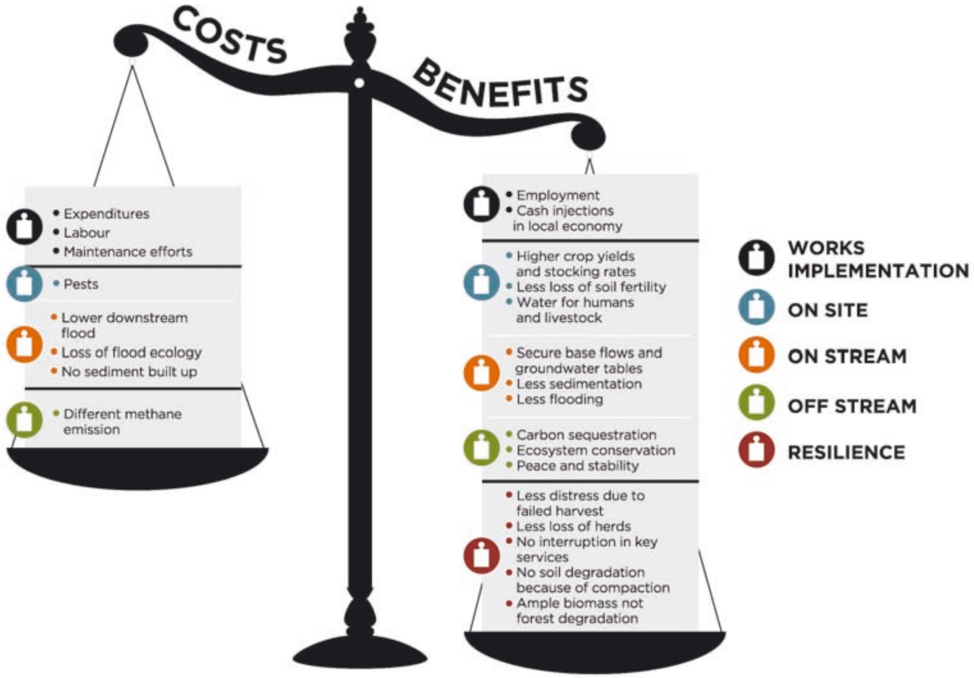


Figure 13. Overview of costs and benefits at different levels

money circulation especially in poor rural areas that are cash-starved and undercapitalized.

This local multiplier effect will not occur if most expenditures are made on items imported from elsewhere - for instance poly-ethylene sheets for plastic mulching or geo-textile for lining water ponds. Though the measures are useful they do not contribute to the local economy in the same way as the paid deployment of labour does. Providing income opportunities in safety net programmes has often been an argument for water buffering – but it has also been the trap. In some cases the opportunities for short-term employment became more important than the result of the works: interventions were not based on local planning or understanding what is most appropriate. Clearly in such contexts water buffer programs are likely to fail.

The cost of a 3R measure is best calculated using a life cycle approach. A life cycle approach does not just look at the initial efforts and investment but also takes into account costs of replacing and maintenance.

Costs and benefits: on-site, on-stream and off-stream

Not only the measures themselves, but also their consequences can be expressed in costs and benefits. The benefits are obvious – these are the reason to start the work. There can however be negative effects as well and these need to be taken into account.

Cost and benefits of water buffering come through as different types of services. Following the

Box 10: Life-cycle costs of rainwater harvesting systems

Life-cycle costs refer to the total costs over the lifetime of an asset, from “cradle to grave”. They are important for comparing the suitability of different hardware solutions. Life-cycle costs for cheap hardware may turn out to be more expensive over a lifetime than for more costly hardware solutions, because of high operation and maintenance costs.

RAIN and IRC calculated that the capital and operational expenditures of rainwater harvesting through storage in sand dams for water supply is relatively low compared with boreholes and piped schemes. Annual operational expenditures are typically within a range of 0-20% of the construction costs.

Source: Batchelor, C., Fonseca, C. and Smits, S., 2011. Life-cycle costs of rainwater harvesting systems. (Occasional Paper 46) [online] The Hague, The Netherlands: IRC International Water and Sanitation Centre, WASHCost and RAIN (Published October 2011). Available at: http://www.irc.nl/op46.

framework developed by TEEB[17] these services are: provisioning services (like soil moisture for crop growth or drinking water for humans and livestock), regulatory services (maintaining the micro-climate, reducing soil erosion, keeping the river system intact), support services (for instance carbon sequestration, increasing groundwater levels) and cultural services (such as well-being, religious uses).

The costs and benefits occur at different levels and this is important to connect the benefit stream with the financing modality. Some cost and benefits are direct in-field, others concern the stream or the basin and a third category of benefits is off-stream. Figure 14 presents an overview of the different types of benefits and different financing modalities that may apply.

On-site benefits from many of the better buffer management techniques, if done well, can be substantial. They often concern provisioning services - such as better soil moisture or the availability of safe water. Terracing, contour bunds, mulching and other improved field management techniques can cause crop yields or animal stocking rates to increase dramatically. Moreover, better water buffers reduce the crop risk of failure and allow the cultivation of new crops that are more sensitive to stress – such as fruit trees – or the start of new economic activities.

Apart from the on-site benefits - that directly benefit the land users applying improved techniques – there are other benefits. First are **‘on-stream’ benefits** that accrue to people and organizations elsewhere in the landscape: less disruptive sedimentation and more reliable base flows and higher groundwater tables, prevention of soil erosion, prevention of sedimentation and siltation, flood protection, improved drainage and run-off, controlled nutrients discharge and fisheries protection. In addition, there are biodiversity and aesthetics-related benefits attached to a watershed.

17 TEEB (2010) The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB.

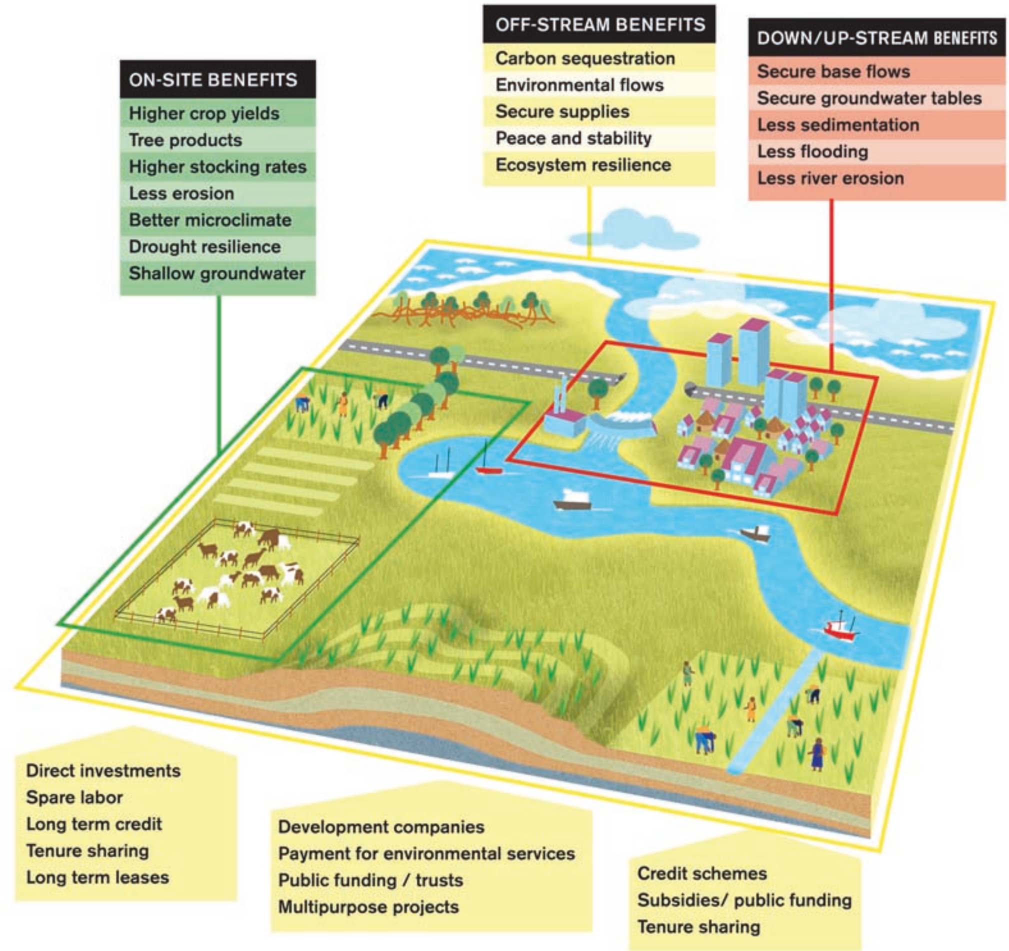


Figure 14. Most important benefits from buffer management and financing modalities

The total benefits of a buffered landscape are very much related to the agro-climatic zones of which they are a part. Benefits of watershed protection are for example perceived to be more than 15 times higher for tropical forests than for temperate forests[18]. This is because of the high biodiversity and biomass production in tropical landscapes. Then there is also the economy factor. The benefits are very much a function of the local economy. Hence the benefits of protecting a catchment close to a metropolitan area are several times higher than protecting a similar catchment in a remote rural area.

The final category comprise of the **off-stream benefits** that may occur at global or national levels: they concern the maintenance of ecosystems and environmental flows, the sequestration of carbon and keeping peace and stability in the region.

Different buffer management programmes score differently in terms of benefits at different levels. This is also illustrated by the different cases in this book (chapter 5, Annex III). The implementation

18 Secretariat of the Convention on Biological Diversity (2001), The Value of Forest Ecosystems: table 17.

of a large number of roof top water harvesting structures in Nepal for instance has many on-site benefits, but does not stabilize river flows or safeguards environmental flows. The implementation of an intense soil water conservation programme as, for example, in Tigray in Ethiopia affects many types of benefits: it improves (more than doubled) food production, it reduces downstream flooding and sedimentation and stabilizes the micro-climate. It also contributes to resilience – i.e. the capacity to overcome an unusual year – which a roof top water harvesting program does not.

Costs and benefits: resilience

Better buffered systems at landscape scale are more resilient: recharging groundwater and creating storage makes it easier to overcome a year with unusual weather – either excessive rainfall, drought or unusual temperatures. The costs of non-resilience is best measured against the risk and impact of droughts. Annex IV presents a sample of the droughts devastating impact on Kenya in 2000. As described in chapter 2 different 3R techniques have a different impact on resilience: some techniques create only short term seasonal storage (cisterns, roof top systems), whereas in other cases the storage lasts several years.

Shallow aquifers[19] have two broad functions. The first is the storage of a water reserve or stock. Ground water stored in an aquifer provides a reserve of water with a given quantity and quality dimensions which can be directly used to generate services, such as the supply of drinking water, irrigation, water for livestock and food production.

The second function is to discharge to surface water (streams, lakes, and wetlands), given the larger predictability of the services generated by surface waters and wetland ecosystems[20].
In the terminology of the TEEB team (The Economics of Ecosystems and Biodiversity)[21], buffer management adds to the natural capital stock, i.e the ability to provide services even in times of variability.

There is a range of values that builds up to the total economic value of landscapes, such as:

- direct use value (e.g. increased agricultural or industrial production);
- indirect use value (e.g. improved carbon storage);
- option value (value of conserving a 'good' or service in order that they may make some use of it in the future), or
- non-use values such as bequest value (value to conserve a 'good' or service –such as a tropical forest- even though people make no use of it, nor do they intend to.

The motive may be threefold: (i) the wish that next generations are able to use it, (ii) the existence value (the value that a 'good' service has because people simply wish that it exists) and (iii) the land conversion value (the value of its alternative use)[22].

The resilience factor adds predictability to these values and reduces the impacts of the losses of

19 Bergstrom, J.C., K.J. Boyle, C. Job, and M.J. Kealy. (1996) "Assessing the Economic Benefits of Ground Water for Environmental Policy Decisions." Water Resources Bulletin, 32, 279-291.

20 Of course the other way may be also true: surface water discharging to groundwaters.

21 See also UNEP (2010), Mainstreaming the Economics of Nature. Nairobi.

22 The value of Forest Ecosystems, Secretariat of the Convention on Biological Diversity, November 2001.

these different values in an abnormal year. To retrieve these values, there are different valuation techniques, such as valuation based on a production function, a travel cost analysis or contingent valuation techniques. Against these benefits are the costs. These costs are generally easier to retrieve. These relate to investment, operations and maintenance costs of the measures taken and the financing costs. Less obvious are cost items like the environmental costs, the opportunity costs of water and the costs of foregone production.

4.2 Time and scale

In order to make a proper assessment if this activity or program is worth, all costs and benefits, including the economic ones, need to be taken into account. This also implies that the period over which the project/activity/investment is considered has to be long enough to allow all effects to materialise. In several cases there is a gap between the investments and the benefits. Generally, the costs are concentrated in the beginning of a project, while the benefits accrue later on. Future values must be assessed at a point in the future when all benefits would have accrued. In connection to such investments (t 1), the benefits (especially the indirect, social, intangible etc.) are effective later (maybe t 15). Discounting them will reduce the assessment of full benefits[23]. Hence, in order to be able to compare these costs and benefits, a discount rate is used, to determine accurately the current value of future benefits and costs. The level of this discount rate is very important. The higher this rate, the lower the current value of the future effects. For example, if one takes the discount rate to be 6%, the cost of environmental degradation that will take place in 50 years will be only approximately 5%[24] of the same amount of loss today. There is no simple rule for choosing the right rate. Generally, for commercial projects, the weighted average cost of capital is taken, which is the average costs of financing projects. For government projects, one would generally take the interest rate of government bonds as the discount rate – but this may have nothing to do with how solid the investment in buffer management is rather with the confidence levels of markets in the investing government. In order to give a proper weight to natural/ecological assets and properly weigh the future environmental effects of measures or investments, there is a strong case for using low discount rates, in the order of 1–3%.

Moreover, as discussed in chapter 3, scale is important. Some 3R measures have a small-scale character, like reservoir tanks or rooftop rainwater harvesting, which is essentially a measure taken for a limited number of houses. In order to reap the benefits of water buffer management, the measures have to be of a certain scale. This has been the experience in Niger and Burkina Faso (regreening), in Tigray Ethiopia (soil and water conservation) and in China (plastic mulching). Working at scale reduces costs – new supply chains, broad-based knowledge and skills, and general changes in economic systems. Working at scale also affects benefits – significantly changing microclimates, sedimentation processes and securing groundwater levels. Achieving scale is particularly important for downstream and off-stream benefits – such as better base flows and accessible groundwater tables, more carbon sequestration, better bio-diversity. In general,

23 The ‘time preference’ – the discounted value given to the future benefits is based on experience and comparison with similar programs. Some benefits will accrue quick and other may concern a longer period.

24 Formula used for depreciation: $f = p\,(1\text{-}d)^n$; f: future value, p: present value, d: discount rate, n: number of years.

improved integrated landscapes are less vulnerable to climate change and to natural calamities. Successful land and water management practices have significant effects so they become the routine and the norm rather than innovations and exceptions. Here, the tipping point effect plays out. Though it is difficult to determine the exact scale of measures that is needed to have the 'tipping point' effect[25], the bandwidth at which the scale effect starts to play out can be assessed and needs to be taken into consideration in the analysis of costs and benefits.

4.3 Risk analysis

In assessing the benefits one must also take the risks of the benefits materializing into account. Particularly, benefits that accrue over a long period of time may be subject to such risks. Active risk management involves identifying risks well ahead and, where possible, considering safeguards to minimize their occurrence.

A common instrument is the sensitivity analysis. As per this method the potential impact of risk on the base case (most likely situation) is assessed and the cost benefit ratio is recalculated under various assumptions and scenarios. For the main categories of benefits as described in 4.1 an assessment can be made and their impact on the overall benefits in the base case can be determined. The same applies for the long term 'life-cycle costs' that may be affected, for instance, by price changes. Note that the risks can occur either way: there may also be factors that increase the benefits over assessed for the base case. Important risks in assessing the costs and benefits of water buffer management are presented in box 11.

4.4 Economic and financial costs and benefits

The most common way of comparing the measures or investments and their consequences is through a Cost-Benefit Analysis (CBA) where both the costs and the benefits are expressed in terms of a common denominator money. When the total benefits are calculated to be larger than the total costs of a measure or investment, it is considered worthwhile[26].

Here, a distinction has to be made between financial costs and benefits and economic costs and benefits. Financial costs and benefits are those that have consequences on the financial returns. They include increased agricultural yield, better quality crops that have a higher price at the market or more timber and fuel wood. Economic costs and benefits relate to the society as a whole. These could be related to agricultural production but also concerns benefits that do not directly relate to a financing organization, such as improved health conditions for the population or an improved environment. These economic effects need a translation to value the effects in monetary terms[27].

25 For instance, as to water supply and sanitation there is evidence that there is some kind of S-curve-relationship between investment in increased coverage and increased benefits in terms of health saving costs and time spent on fetching water, with a certain threshold after which a relatively high low levels of additional investments bring about relatively large increases in benefits and a saturation point after which relatively high levels of investments are needed for relatively low levels of improvement.

26 This is a simplification, since it also will depend on alternative options to invest in. If there are opportunities that bring about larger returns, it will be more attractive to invest in these opportunities.

27 In the economic cost calculation for instance an effort is made to assess the real costs – i.e. without taxes or subsidies.

Box 11: Important risks in assessing costs and benefits of water buffer management

On-site

- Particularly the possibility of engaging in horticulture may be affected by changing commodity prices. Horticulture in particular is generally a high-value activity, but also more susceptible to price fluctuations.
- On-site benefits also depend on an assessment of the actual benefits of the interventions and the scale effect. The hard data on this is limited – particularly given the wide variety of areas in which buffer management is applied.

On-stream

- Benefits such as flood mitigation are affected by the likelihood of floods occurring and of other measures to reduce flood impacts. They also depend on an assessment of the beneficial or destructive impacts of down stream floods. Downstream flooding can be used – if properly managed – to sustain farming, build up soil cover and recharge groundwater downstream.

Off-stream

- These benefits are subject to the value attached to factors such as climate change mitigation. The price of carbon credits can be a proxy but these prices by themselves have been reflecting the functioning of the trading mechanism rather than an intrinsic value. Also, the effect of methane emissions has not been subject to the same rigour of analysis as carbon dioxide emissions, although their effect on climate change maybe more substantial than so far assumed. Soil moisture management and water buffering have a substantial effect on methane emissions.

Resilience

- The likelihood of unusual years occurring and the effect of climate change on this are a matter of informed predictions and include an element of risk.
- Risks often arise as effects of climate change or of unusual weather events – on which there is limited hard data. The effects of an unusual weather event may also be positive: for instance, high-frequency, heavy rainfall may lead to more infiltration than moderate rainfall, depending on the soil condition and shallow hydrogeology of an area.

Many of these risks are subjective, and there is an element of judgment involved in assessing them. Perceptions of risk may differ from one expert to another – but what is important is to make the assumptions as explicit as possible so that they are open to debate. It is also important to keep building up and sharing data sets on the various risks. In general, it appears that information on both costs and benefits is available but scattered.

It is important to mention that water buffering activities are not only economically justified but also financially feasible. This takes the analysis into a different territory – in which the interests of different stakeholder groups are considered.

To assess whether water buffer management will 'fly' an assessment is required of costs and benefits on the financial status of key stakeholders: farmers, government, investors, downstream users, the public, including an identification of the main beneficiaries and losers, with estimates of their gains/losses. The assessment should include an estimation of the financial implications of the project for public capital and recurrent budgets. This part of the analysis provides a basis for understanding the incentives for crucial stakeholders – especially farmers – to support, or resist, the project and also assess where public resources – from the government, international sources or for 'credit' schemes are best spent.

All this helps us to think on how financial instruments and transfers can be used to create the conditions that make 3R investments acceptable to different parties, and to provide the right incentives. The cases in chapter 5 also describe the financing modalities that can be used.

In several cases land and water use at one place affects water availability, sedimentation and local climate elsewhere in the landscape. The 'downstream' and 'off-stream' benefits may be local or they may extend throughout the landscape. The question, then, is how do remote beneficiaries pay for these services. To address this, the concept of Payment for Environmental Services (PES) was developed – or more specific to the case of landscape management, Payment for Watershed Services (PWS). In PWS land users are financially compensated for the environmental services they render – preferably by those that benefit from these services. However, these systems are not taking off in a in a major way (Porras et al., 2008) yet[28]. There are a number of explanations: the complexity of the transactions, the difficulty to quantify and monetize the benefits and, at times, plainly the absence of a remote party that has the capacity to pay[29]. Therefore it is often far more promising to build the business case by reinforcing the direct, on-field benefits of 3R measures that also serve the larger picture of more stable buffers. There are many examples of buffer management being self financed by land users – either in the form of off-season labour or from local investment, sometimes in co-sharing arrangement with parties that can provide short-term capital. Sometimes this requires the support of new governance or financing arrangements. One example is a banking facility in Eastern Uganda. A land owner is given credit to plant and look after trees on his land by a bank. When the trees mature after ten years, the returns from them are shared by the bank and the landowner. In such a situation, security of tenure is a must. In several parts of the world commercial use of small forestry is prohibited, or there is no security of tenure. This keeps people from investing in their own water buffers.

Figure 18 links the different types of benefits with possible financing modalities. There is a large potential to learn from good practices in different parts of the world, and innovate. As in the application of 3R technologies there are many breakthroughs possible in the financing of water buffer management too.

28 Porras, I., Grieg-Gan, M. and Neves, N. 2008. All that glitters: a review of payments for watershed services in developing countries. London: IIED.

29 van Steenbergen, F., L. Knoop and A. Tuinhof (2011), Transforming landscapes, transforming lives: the business of sustainable water buffer management.

5 Cases

The 3R methods which are described in the previous chapters are illustrated in this chapter with many practical examples.

Fourteen cases from around the world demonstrate some of the most important methods. Each case presents an introduction to the applied techniques and describes its implementation, together with an indication of the costs and benefits and the financing mechanism. Examples of techniques in all four categories -groundwater storage, soil moisture storage, closed tank storage and open reservoir storage - are included (see table 6).

The first two examples (case 5.1 and 5.2) show how aquifers can be recharged by the implementation of dams, which either serve to increase the water stored in the aquifer (as in the case of sand dams), or to raise the groundwater table in the dam's surroundings. After that, two cases (5.3 and 5.4) show how traditional and modern methods can be applied to use groundwater to fulfil the demand for water in an effective and sustainable way. Different methods of recharging the aquifer with fresh water -or avoidance of fresh water loss from the soil - makes it possible to create a fresh water bubble in a brackish environment. This can be used as drinking water or for agriculture, as is illustrated with examples from Bangladesh, Paraguay, and the Netherlands (case 5.5-5.7). The next four cases (5.8-5.11) deal with increasing the soil moisture through infiltration from the surface (often leading to an increase in groundwater recharge itself). This includes the techniques of gully plugs, water spreading weirs and plastic mulches, and a combination of such techniques in a soil and water conservation project at scale. Finally, three cases (5.12-5.14) demonstrate the practice of storing water in open water ponds and closed tanks, for either irrigation or drinking water purposes.

A snapshot comparison of the cases from the angle of the different costs and benefits is given in Annex III.

Table 5. Overview of cases in this book, where last column refers to the kind of technique, where A is groundwater storage, B is soil moisture storage, C is closed tank storage and D is open reservoire storage (see figure 3) and the numbers refer to the subcategories (see figure 4)

	Title	Country	Description	Category
Groundwater recharge by the implementation of dams				
1	Sand storage dams	Kitui, Kenya	The impact of a cascade of sand storage dams in a stream to provide drinking water	A1
2	Check dams in forests	Pasak Ngam, Thailand	Reviving forest and water resources with small dams for run-off retention and recharge	A1 & D1
Traditional and modern methods to use groundwater more effectively				
3	Improved karezes	Qila Iskan Khan, Pakistan	Modernizing the ancient technology of karezes to stabilize the groundwater supply	A3
4	Water augmentation through managed aquifer recharge	Central areas of Namibia	Aquifer recharge through well injection to secure the water supply of the city of Windoek	A3
Storing fresh groundwater in salty aquifers				
5	Creating fresh water bubbles in brackish groundwater	Bangladesh	Gravity injection of fresh water in shallow aquifers for drinking water	A3
6	Freshwater storage in areas with saline groundwater – Tajamares	Chaco, Paraguay	Infiltration from depressions to store fresh water in shallow salty aquifers for drinking water	A2
7	Fresh water conservation with controlled drainage	The Netherlands	Retaining fresh water in the soil by controlled drainge	A1
Increasing soil moisture and groundwater tables from the top				
8	Recharge and soil fertility with gully plugs and bunds	Terai, India	Integrated use of various methods to reduce run-off and ersoion	B1 & A1
9	Greening semi-arid landscapes –water spreading weirs	Sahel region	Greening semi arid landscapes with dams to spread run-off and increase infiltration	B2 & A2
10	Biodegradable plastic mulches	China, India and US	The booming business of mulching to conserve soil mositure and reduce evapotranspiration	B3
11	Soil and water conservation at scale	Tigray, Ethiopia	Variety of water conservation and water harvesting measures to regreen Tigray	A1, A2, B1, B2 & D1
Storing water in open water ponds and closed tanks				
12	Surface water harvesting tanks	Amhara, Ethiopia	Surface water harvesting and storage in a covered reservoir, used for irrigation	D2
13	Buffering highland and spring water	Andes, Peru	Reducing the impact of melting glaciers by open water storage for natural recharge and irrigation	D2
14	Rooftop harvesting and multiple water use	Nepal	Harvesting rainwater for domestic water supply	C1 & D2

5.1 Sand storage dams

Kitui, Kenya

In the previous 3R book "Managing the Water Buffer," the case of sand dams applied in the Kitui valley in Kenya was presented. The case is extended here with a cost benefit analysis (CBA) that was performed in the study "Economic Valuation of Water Buffering", A. Tuinhof, et al. (2011). The analysis is based on interviews and a socio-economic analysis of the situation in a village with and without sand dams, before and after its construction. The results of the CBA are summarized in the costs and benefits section.

Technology

Sand storage dams are relatively small and built into the bed of a seasonal river. During the wet season sand that is transported by the river accumulates behind the dam. As a result, a sandy layer is created in the riverbed that grows every wet season until it levels the top of the dam (figure 16). This sandy layer acts as an aquifer that is recharged by water running through the river, and in which water is retained for use in the dry season. The construction of a sand storage dam leads to larger volumes of water stored in the riverbed. This ensures higher water quality and availability, usually lasting throughout the dry season. An important advantage of sand dams over open water dams is that the storage of water in the newly formed aquifer makes the water less susceptible to contamination and diseases. Also, the storage of water in the soil reduces evaporation-loss significantly.

In the Kitui District, sand storage dams have been implemented on a large scale, and frequently in cascades. The implementation in cascades provides some hydrological benefits. It reduces the loss of water due to leakage, since a downstream dam will retain the water that leaks from upstream dams. Also, groundwater levels are raised more extensively by dams constructed in cascades, as compared to a stand-alone dam. This ensures improved water availability and more extensive regeneration of vegetation over a larger area. An additional, indirect positive effect of

Figure 15. a) Sand storage dam; b) Fetching water in Kitui (Photo: Acacia Water).

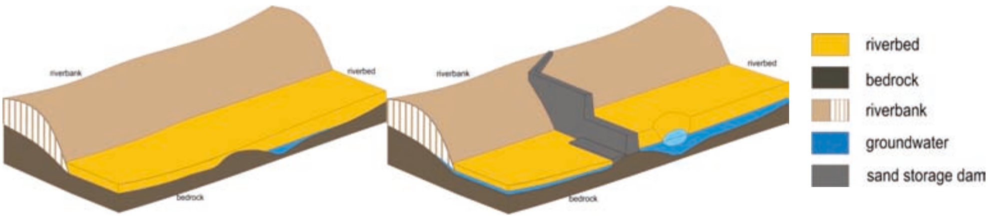


Figure 16. Riverbed during the dry season without (a) and with (b) a sand storage dam. The area behind the dam is filled with sand and water during the wet period.

implementing sand storage dams or other water harvesting techniques on a large scale is that it enables communities to come together and share experiences and knowledge, thereby promoting community participation.

Where is it applied?

In the Kitui District, situated 150 km east of Nairobi, 750 sand dams have been constructed. It is a semi-arid area, with two wet seasons per year. Rainfall is highly erratic and usually falls during a few intensive storms. Most rivers in the area are seasonal and flow only during the wet season. Before the construction of the dams, people had to walk larger distances to fetch water.

The sand dams are built on riverbeds. Whether a riverbed is appropriate as a construction site can be verified by checking the following characteristics:

- the riverbed should have a width of approximately 20 m and contains coarse sand;
- the riverbanks should be steep on both sides and have a height of approximately 1 m to 1.5 m;
- the banks should preferably consist of clayey material or rock outcrops;
- the presence of groundwater a few months after the rains have ceased. This indicates that downstream of this location a natural flow and a (semi)impermeable layer prevents leakage to deeper aquifers.

The selection of sites is a very important part of the implementation process, and it is advised that an expert is consulted on the matter.

Costs and benefits

The costs of the construction of a dam is in the range of USD 8,000-12,000. The figure includes a 30-35% contribution from the community in the form of labour. Additional costs have to be added for the installation of 2-4 dug wells with a hand pump (total USD 2,000- 3, 000). The total investment costs therefore may vary between USD 10,000 - USD 15,000. Annual maintenance and monitoring costs are estimated at about 10% of the investment costs per year.

A sand dam provides about 1,500 - 2,000 m^3 of storage during a rainy period. Assuming 2 rainy seasons, the total storage capacity is about 4,000 m^3/year. On an average, 25 families or about 150 persons use a dam. The benefits of the sand dam have been studied based on data of the socio-economic situation in a village with (Kindu) and without (Koma) sand dam, and by comparing the situation before (1995) and after (2005) the construction of the dam (table 6).

The access to water was improved, thus time for fetching water was reduced and more time was available for agricultural activities. Therefore agricultural and industrial production increased and resulted in more income. For one sand dam (25 families) the net increase in family income was 25*125= USD 3,000/yr.

Other vulnerability indicators, such as social or environmental benefits have not been taken into account and are not assessed. Nevertheless we presume significant changes as direct positive impacts in education levels, nature conservation, decreased costs for food distribution, health care and subsidies for drought adaptation as well as indirect positive impacts such as decreased migration and reduced health impacts from droughts. Assigning monetary values to these aspects however, is complicated and therefore not included in the study. Even without taking these extra benefits into account, the case study shows that investments in sand dam construction in general have a positive economic return.

Retaining water in a sand dam costs USD 0.6 - USD 0.8 /m^3 on average (table 8); the corresponding investment cost per consumer is USD 17- USD 25/yr. Whether the investment is able to return itself depends on the benefits, discount rate, and the lifetime of the dam. In a typical case, the net present value - indicating the net sum of the annual benefits over the lifetime of the structure - is positive at USD 6,000 after 15 years and USD 10,000 after 20 years.

Table 6. Summary of measures benefits (Lasage et al., 2008) 1000 Khs = 14 USD; 0: unchanged, +: slightly improved, - : slightly deteriorated

Indicator	Kindu (dam)		Koma (no dam)	
	1995	2005	1995	2005
Access to drinking water wet season (km)	1	1	1	1
Access to drinking water dry season (km)	3	1	4	4
Domestic water use (l/day)	61	91	136	117
People exposed to drought (No)	420	0	600	600
Health	0	+	0	0
Households with irrigated crops (%)	37	68	38	38
Agricultural water conservation (l/day)	220	440	160	110
Brick and basket production (Ksh/yr)	1,500	4,500	0	0
Household incomes (Ksh/yr)	15,000	24,000	15,000	15,000
Vegetation density /biodiversity	0	+	0	0/-

Financing mechanisms

The concept of sand storage dams is already known for decennia and there are numerous examples of sand dams constructed in many countries such as India, Zimbabwe, Burkina Faso, Ethiopia and Kenya. These are mostly isolated initiatives under which only a few dams have been constructed in a village by a local NGO or by a group of farmers to enhance their water supply.

In close collaboration with local communities, Kenyan NGO SASOL took the initiative in the 1990s to ensure water availability for rural communities in the Kitui District through the construction of sand storage dams. In the decade that followed, more than 750 dams were built, successfully providing communities with water for domestic use and small-scale irrigation. Communities were involved in siting and construction of sand storage dams through sand dam management groups, providing knowledge, labour and raw materials. After construction, these groups ensure the maintenance of dams and protection of the water quality. They also promote ownership and, thus, sustainability.

Table 7 . An example of the cost and benefits of one sand dam in USD/m³

Costs						**Benefits**	
Total investment cost (USD)	Life time (year)	disc rate (%)	Investment cost (USD/yr)	Maintenance cost (USD/yr)	Total annual cost (USD/yr)	Annual storage (m^3/yr)	Total cost per use (USD/m^3)
14000	20	0.05	1100	1400	2500	4000	0.63

Implementation

When an appropriate site is selected, the design is made based on the cross sectional profile, peak river flow and the required water yield. Then, the actual construction can start. After construction, it can take between 1 and 10 wet seasons for a sand storage dam to become completely filled with sediments and water, depending on the characteristics of the upstream catchment. If a sand storage dam is properly constructed, it requires little or no major maintenance. However, if any cracks or weak points are observed in the sand dam, a technical engineer and mason should inspect the structure and execute repair works before the following rainy season to prevent further damage. Also, the area upstream of the dam should be kept clean (removal of animal droppings, dead animals, rocks and trees (parts) to prevent damage and contamination of the water.

Successes and challenges

A large number of sand dams have been constructed and are in use. The incomes of beneficiary families have increased substantially compared to the reference situation. The distance to drinking water source in the dry season has reduced substantially and more water is available for agriculture. Typically, the increase in income surpasses the construction and maintenance costs of sand dams, which makes them profitable. However, it remains a risk when both the investment costs and the discount rate are at the high end of their ranges, the net present value may become negative. It is therefore a challenge to construct the sand dams as cost-effective as possible and to maintain them properly to extend the lifetime of the investment.

Sand dams provide downstream benefits as they reduce the river's peak flow and may therefore prevent downstream floods. However, base flow during the dry season may also be reduced by the dams which capture river water. This could be compensated by releasing groundwater from the aquifer behind the sand dam, which may even increase the downstream base flow during the dry season.

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5.2 Check dams in forests

Pasak Ngam, Thailand

When forests are destroyed water resources may disappear as well. Such is the case in Northern Thailand. Many areas in the region that used to be fertile started to suffer from droughts due to deforestation. As streams have dried up, communities in the watersheds experience water shortages for agricultural and domestic use during the dry season. A series of measures was undertaken to reverse this development. Here is a summary of the results of the Pasak Ngam Project and the DNP check dam project in Thailand.

Figure 17. Example of check dam, Thailand (Photo: Hydro and Agro Informatics Institute (HAII), Bangkok)

Check dams are built across water routes such as small gullies and streams, especially upstream or at the watershed areas. They help to slow down the speed of water, increase percolation and obstruct the flow of sediments. Simple check dams are constructed with the use of natural materials that are locally available such as rocks, logs, bamboo, sticks and branches. More sophisticated dams are constructed using rocks and steel rods (Gabion weirs). Concrete is used for making permanent check dams. Check dams are particularly beneficial for reforestation as they conserve both soil and water. When the water is blocked by check dams, the soil can absorb more water and moisture can penetrate into the wider area around the dam. Check dams can be cheap and very easy to build. The characteristics of check dams can be varied depending on their purposes. For example, check dams that are built only to keep the soil humid do not have to be as big as check dams that are built to block sediments.

Where is it applied?

Pasak Ngam village is located in Doy Saket district, Chiang Mai province in the North of Thailand. It is situated to the north of Maekuang Udomthara reservoir. The village consists of 102 households and a population of 347 people. The community area of 0.64 square kilometers is surrounded by the Khun Maekuang national forest. The forest covers an area as large as 112 square kilometers. The village lies approximately 400 meters above the sea level on a plateau between mountain ranges on the east and the west sides.

Pasak Ngam is located in a part of the watershed area where numerous streams are located, which flow into the Maekuang Udomthara reservoir. Due to its location within the watershed and being in the vicinity of both the reservoir and the national forest, the village is strategically important from a natural resource conservation point of view.

"Pasak Ngam" literally means the village of beautiful teak forest. From 1960 onwards however, the government granted forest concessions, and villagers and outsiders started to cut down large parts of the forest for wood and to use the fields for grazing. As a consequence, the areas within the watershed gradually deteriorated and streams dried up. As livelihoods of the villagers are highly dependent on the now diminished water resources, a group of villagers has tried to stop deforestation and restore the water balance with the use of check dams.

Implementation

In order to bring water back to these areas various initiatives aim to help communities take measures to capture and store rainfall for use in the dry season. Dozens of these initiatives flow out of the concept of natural resource conservation and restoration taught at Huay Hongkhrai Royal Development Center (HHRDC)[30]. King Bhumibol Adulyadei developed initiatives to revive water and forest resources in the country.
In succession of the activities of the HHRDC, people of Pasak Ngam village managed to stop gradually with illegal logging practices and improve conservation agriculture practices. Key in reviving the forest and improving conservation agriculture were the construction of check dams in the area. The planning for the construction of check dams started with surveying and mapping the areas. Necessary data collected included: (a) Geographical features of the watershed (including soil types, slopes, erosion rates, etc.), (b) precipitation and river discharge statistics, (c) water routes (lengths, widths, and depths), (d) local available materials for construction of the check dams. Based upon this information and the specific purpose of the check dam (forest and water conservation, agriculture or domestic purposes) the construction sites were selected along the water routes.

The check dams constructed can roughly be categorized into 3 types:
I. Basic check dams, simply constructed check dam using local available materials. This type of dam is built to trap sediments and slow down movement of the water in the watershed areas or first order streams. The construction is built across the streams that are approximately 1 to 4 meters wide and 0.5 to 1 meter deep. The basic check dam has many forms and can be constructed in different ways depending on available materials. Many are built according to the local wisdom. Examples are:

- Pigsty or crib weir. This method uses logs and wooden sticks to make a frame that look like a sty or crib. Inside of the frame rocks, soil sacks or sand sacks (or sand mixing with cement) are placed. Foundation of the frame should be fixed into the ground at least 0.3 meter deep. If the stream is wider than two meters and water level is rather high, more weirs should be built in cascading steps.

30 The conservation concepts of the center emphasize on coexistence and interdependence of human and the forest without causing negative affects on one another. The center supported villagers to be more self-reliance by introducing conservative agriculture so that they relied less on the income from logging

- Bamboo weir. Bamboo sticks (and logs) are used to make two panels. These panels are placed parallel across the stream. Soil is put between the two panels until it is full. Different sizes of rocks might also be placed in front of and behind the panels to make the weir stronger (figure 18).
- Sack weir. This weir is more suitable for the streams that are not steep, not wider than two meters, and has a low water level. This method uses sacks of soil or sand mixed with cement placing on top of each other for 4-6 rows. Sticks are hammered on and around the sacks to fix them together.
- Gabion weir. In order to build the weir, rocks are laid on the floor of the stream for foundation. Gabions containing rocks are placed across the stream. Steel rods are used to fix gabions together. Concrete, rocks and bamboo sticks might be added to strengthen the weir. In case it is needed to store the water, sacks containing sand mixed with cement can be used to put in front of the weir.

Figure 18 a and b. Villagers were building a basic check dam across one of the small gullies with local materials. (Photo: Hydro and Agro Informatics Institute (HAII), Bangkok)

II. Semi-permanent check dams, constructed with rocks and steel rods coating with ferroconcrete. The foundation of these dams should be fixed at a depth of 0.7-1 meter below water bed level. This dam is often constructed across the second order streams to block sediment and partly store water for usage. The construction is more costly, but rather durable.

III. Permanent check dams are constructed with ferroconcrete, often at the end of water routes that are not wider than four meters. The foundation of the dam should reach hard soil or rock layer which is around one meter deep. Across the stream, the dam should be built about 1-1.5 meter deep into the banks on either side. This type of dams is strong and durable but the cost of construction is also higher. It is appropriate for areas with a gentle slope and large amount of water run-off. This dam is most suitable for storing water for usage during the dry season.

Costs and benefits

The costs of building a check dam varies depending on its type and material. A basic check dam costs 500-1,000 Baht (USD 17 - USD 34) if constructed with locally available material; and 1,000-5,000 Baht (USD 34 - USD 167) if building materials have to be purchased from outside the area. For semi-permanent and permanent check dams, the cost of construction could go up to 10,000 Baht (USD 334).

Continuation and maintenance of the Pasak Ngam project proved to be sustainable. As it is the villagers who drive the project (with support from outsiders), it has truly responded to their needs. They have developed a sense of belonging, awareness and responsibility for what they have built with their own labour. Moreover, given their past experiences, they are now much more sensitive to the importance of water-availability to the quality of their lives.

A few years after the implementation of the project, little by little, the villagers began to experience changes:

- Streams and gullies started to have more and more water. Some of the rehabilitated streams now have water all year round, again.
- Check dams contributed to conserve water for domestic use, tending water for cattle and agriculture.
- Since there is water for agriculture, the villagers do not need to travel to the city to look for jobs. They can stay in the village with their family. Moreover, the villagers have made natural trails and opened their village for eco-tourism and study visits, as an additional source of income within their own village.
- Forest areas recovered and gradually increased canopy cover. Furthermore, when the forest and biodiversity are restored, forest foods, medicinal plants, and natural materials are abundantly available for villagers to collect. This creates extra income and reduces expenses of the households all year round.
- Soil humidity has increased.
- Vegetation cover and forests have grown more dense.
- The occurrence and severity of forest fires has reduced significantly.
- Biodiversity of the area is improved. Villagers have observed that insects, fish, crabs, and birds in the area have increased in numbers. Moreover, they have noticed the return of many species that had disappeared for years.

Financing mechanisms

The people of Pasak Ngam received funding for the check dams through cash and in-kind support from their partner institutes, networks and connections, such as Huay Hongkhrai Royal Development Center, Coca-Cola Foundation Thailand, Hydro and Agro Informatics Institute and the Siam Cement Group. The construction of check dams was supported by different organizations from both private and public sectors. Labour was mostly contributed by the villagers themselves. Many check dams were also built solely by the villagers without support from the outsiders. Some were built by volunteers from schools, non-governmental organizations and private companies.

Successes and challenges

Perseverance and collaboration among the villagers were key to the success of the project. With the help of Huay Hongkhrai Royal Development Center, villagers have built more than 300 check dams at the headwaters of the seven main streams around the village. Since then, 500-1,000 check dams have been successfully constructed across water routes annually. As yearly maintenance is important, villagers take turns every year in surveying and repairing check dams and spillways. Further, the villagers established a "forest conservation and protection group" which watches out for forest fires and illegal logging. The group helped to plant the forest and to construct firebreaks. Community rules for gathering forest food and forest materials were collectively drafted and written down. This was done to minimize conflicts among the villagers and lessen the impacts of human activities on the environment.

The improved water regulation in the upper part of the watershed of Pasak Ngam village is not only significant to the Pasak Ngam villagers, but also to those who live downstream in Chiang Mai and Lampoon provinces. This is because the Maekuang Udomthara reservoir provides water for domestic and agricultural uses in both provinces.

In the case of semi-permanent and permanent check dams, it is important to consider the strength of the dam in the context of the problem of erosion from heavy rain or flooding. The foundation should be strong and there should be a sufficient number of spillways to release floodwaters, so that they do not damage the dam.

Check dams should be constructed after the rainy season. It is recommended to plant trees that can grow well in damp areas (such as the Willow-leaved Water Croton) around them. Their roots help secure the soil around the dams. Once these trees are established, reforestation can be started in a wider area.

Check dams that are built in steeper areas are recommended to be built over shorter distances.

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5.3 Improved karezes

Qila Iskan Khan, Pakistan

Karezes – or vertical wells - are among the oldest systems of drawing groundwater. The technique originates from Iran and goes by different names: qanats, foggara and aflaj. In the Balochistan Province of Pakistan, they are called karez. In karezes, water is channelled to farmland using gravity, saving a considerable amount of labour as compared to irrigation from dug wells using manual labour or Persian wheels.

Technology

A karez is an almost horizontal, underground conduit that originates within an aquifer at a higher elevation and transports water by gravity. Usually, the karez starts at the foot of a mountain, where underground springs are common (figure 19). At this place, karez developers excavate one or two deep vertical shafts into the water bearing strata. As these wells provide the bulk of the total water supplied by the karez system, they are called mother wells. They have been reported to be up to 50 metres deep. Once the mother wells are established the other wells (“ventilation shafts”) are dug in a more or less straight line all the way to the command area. These downstream shafts do not penetrate into the aquifer and are only used as shafts for the underground horizontal conduit. Some karezes tap into the subsurface flow near dry riverbeds.

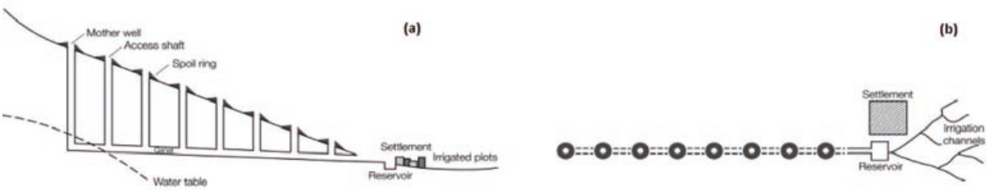

Figure 19. Typical cross section and bird view of a karez system (Source: Kamaz, Z. 2010)

The construction of karezes involves using the access shafts to dig the horizontal sections between them. This is an extremely difficult job, especially when water starts flowing, and is performed by specialized workers. A reservoir is often constructed at the end of the karez, from which water is drawn for livestock. The irrigation canals start downstream of the reservoir. Maintenance of karezes is challenging. Debris and vegetation can block the water flow in the karez and need to be removed every year (figure 20).

Where is it applied?

Karezes are common in large parts of the world but they are generally in decline for two reasons: (1) the intensive use of groundwater causing water levels to drop and (2) the very high costs of maintenance. Qila Iskan Khan in Balochistan is no exception to this. This small village of 82 households is situated in Pishin District. Precipitation is sparse and hardly exceeds 200 mm annually. Despite this limitation, the economy of the village is based on agriculture and therefore directly dependent on availability of water. Water coming as subsurface flow in the Burshore Manda River is diverted with the use of a karez system.

Figure 20. A specialized Karez cleaner in Qila Iskan Khan, seen with a dot of grass removed from the underground canal bed. Due to the high risks involved and the special skills required, it is a well-paid job (Photo: IUCN Pakistan, 2010).

Figure 21. Qila Iskan Khan, Balochistan, Pakistan

An infiltration conduit is excavated below the riverbed and the water is subsequently carried to the command area through a 1.75 km long tunnel. Until the 1990s this supported a very high value horticulture. Some 24 hectares of the land were developed for the cultivation of apples and grapes, irrigated by the karez, as well as by tube wells. However, during the 1996-2003 droughts, both the karez and the agricultural wells were badly affected. The discharge decreased drastically, resulting in the drying out of the orchards. The karez itself got choked at several places and was abandoned. The majority of the villagers migrated to nearby towns - with only two families remaining in the village to look after the land and other assets.

Implementation

With the help of IUCN the karez system of Qilla Iskan Khan was modernized and its catchment was protected. First, the underground conduits of the five feeding branches were cleaned up by a specialist karez digger from Afghanistan. A new technology was introduced: the stone pitching of the karez was replaced by thick PVC pipes. Once enough room was created, these perforated PVC pipes were inserted into the underground canals. The flows from the karez conduits were then combined into one main channel and water was transported through a 700 meter long PVC pipe of 30 cm diameter (figure 22 a), to a newly constructed water reservoir (figure 22 b). The earthen pond with a total volume of 1,420 m^3 was lined with geo-membrane to reduce seepage losses. Water conveyance losses were reduced to almost zero through these measures and the effective water availability increased several folds. By storing water in the reservoir it also became possible to concentrate flows to the orchards. Besides, the catchment was protected by planting olive trees and not allowing livestock grazing in order to improve local recharge. Eyebrows (micro-catchment areas) were introduced for water conservation. Two washing pads for women and a nursery with 40,000 container plants were set up.

Figure 22. a) Villagers taking rest during improvement of the Qilla Iskan Khan karez system. They are installing a 30 cm wide PVC infiltration pipe inside the karez; b) The constructed geo-membrane reservoir (Photo: IUCN Pakistan, 2011 and 2010).

Costs and benefits

The total project cost amounted to 2,300,000 PAR (equal to USD 300,000), of which 20% was contributed for by the users.

In the first cropping season after completion of the project, farmers experienced promising yields (table 8). Vegetable production did very well, especially that of green bell pepper, tomatoes, brinjals and ridge gourd. The production was enough to send two truckloads per day to the nearby market of Pishin during harvest time. In total, selling vegetables provided the people of Qila Iskan Khan an income over 14 million PAR (USD 149,000). The benefit of the project is clear if one considers that project costs were only one sixth of the returns generated in the very first year.

Financing mechanisms

The activities were financed as a project. The farmers' contributed labour and cash as part of the finances. The investment helped restore the karez system to a level where it became possible to keep it functioning smoothly. The cost of maintenance was greatly reduced following the introduction of PVC infiltration galleries.

Soon after the rehabilitation efforts, water flow in the karez increased from 20 to over 70 l/s and water could be stored for longer. This enabled farmers to expand the area under irrigation, from 24 hectares of orchards and fodder crops prior to the project to 120 hectares of just vegetables in the cropping season of 2011.

Out-migration from the community has started to reverse. Many have started coming back to their village to restore their lands. Agriculture activities are in full swing now. The increased water security has also allowed farmers to diversify and intensify their cropping patterns. As a result, grape production has increased and a wide variety of vegetables have been introduced in the area, including tomatoes, onions, green peppers, carrots, brinjals and ridge gourd.

Table 8. Crop yields of the improved Kareze system in 2011

Crop	Quantity produced (kg)	Market price (PAR* kg^{-1})	Total Income (PAR)	Production before Intervention (kg)
Wheat	79,400	28	2,223,200	23,000
Tomatoes	71,300 **	30	2,139,000	Nil
Green Pepper	40,600**	50	2,030,000	Nil
Brinjal/Ridge Gourd	53,500**	35	1,872,500	Nil
Lady Finger	18,100	60	1,086,000	Nil
Onion	6,770	30	203,100	Nil
Grapes	65,000	55	3,575,000	40,000
Carrot	60,000	20	1,200,000	Nil
Total	394,670		14,145,600	63,000

*PAR: Pakistan Rupee; **Measured during production

Successes and challenges

Besides increased crop production, other successes of the project include: (I) a 40,000 plants nursery developed for low-delta/high value crops like olives, almonds and pomegranate, (II) rain-fed crop production in the eyebrows and (III) increased vegetation cover in the watershed for livestock keeping. The case of Qila Iskan Khan is now widely regarded as a success story, and being replicated in other areas in Balochistan.

The PVC infiltration pipe technology also resolved one of the largest challenges of maintaining karezes – the daunting task of restoring underground conduits in the gravelly riverbed.

The restoration and upgrade of the karez with the use of PVC pipes has stabilized the flow of water. This upgrade is expected to prevent the problems, which led to the failure of the system in the first place, during the droughts between 1996 and 2003.

Although the karezes provide a sustainable water flow, the growth of a village requires higher water flows. As further substantial increase in the flow in the karez is not possible, other water sources need to be identified to support the water needs of the village that are set to grow.

A video of the karez system in Iskan Khan is online: www.iucn.org and www.thewaterchannel.tv

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5.4 Water augmentation through managed aquifer recharge

Central areas of Namibia

Namibia is the most arid country in Sub-Saharan Africa with frequent droughts and a spatially uneven distribution of water resources. Perennial rivers are only found on the northern and southern borders of the country. However, they are at a considerable distance from the major demand centres in the Central Areas of Namibia (CAN) and the country is largely dependent on groundwater.

The main source of water supply to the larger urban centres in central Namibia are dams on ephemeral rivers. The Inflow into these dams is irregular and unreliable, and evaporation rates in Namibia's arid climate are high. Consequently, the assured safe yield of these dams is low. Steady economic development has resulted in increasing water demand in the CAN. In the very near future, existing water resources will not be able to meet the expected demand in a sustainable way.

Windhoek, CAN's capital city, owes its existence to the presence of springs, which provided an ample supply of water when settlement began. A well field was later established and through time, as the city grew, storage dams were then established in the ephemeral rivers. Windhoek currently obtains its water from a 3-dam system (supplied by NamWater), a wastewater reclamation plant within the city, and from a municipal well field.

When the three dams are operated on an individual basis, the 95% safe yield is only 13 Mm^3/yr, mainly due to the huge evaporation losses from Omatako and Swakoppoort Dams. Through the integrated use of the three dams, water is transferred and stored in Von Bach Dam, which has the lowest evaporation rate due to the dam basin characteristics. This operating procedure improves the 95% safe yield from the 3-dam system by approximately 7.0 Mm^3/yr to a total of 20.0 Mm^3/yr. According to water demand forecasts based on the expected growth scenario, the demand for water will increase from the current 25.0 Mm^3 to approximately 40 Mm^3 in 2021.

Technology

In the NamWater Study (2004) for additional water supplies to the CAN, three main development options were selected for evaluation:

- Managed Aquifer Recharge of the Windhoek Aquifer (using surplus water from the Central Area dams to increase the underground stored reserves)
- Tsumeb and Karst lll Aquifers utilized only for emergency supply to the CAN
- A pipeline link from the Okavango River for supply to the CAN when required (figure 23).

The best of these options was found to be managed aquifer recharge of the Windhoek Aquifer, to be done in combination with deep boreholes, to increase access to a larger volume of stored reserves (larger water bank through deeper boreholes).

Over abstraction of the Windhoek Aquifer since 1950 created an underground storage facility estimated to have a 21 Mm^3 capacity. The facility can be filled through natural and artificial recharge. The total estimated storage which can be abstracted from existing boreholes is approximately 15 Mm^3 giving a total usable storage ("water bank") of 36 Mm^3. Through the drilling of deep abstraction boreholes, the size of the "water bank" will be increased to approximately 66 Mm^3 which can bridge in excess of 2 years' supply of the Windhoek demand.

This managed aquifer recharge option involves taking water from the 3-dam system when there is surplus water available, purifying it and injecting it into the Windhoek Aquifer via the boreholes (see figure 24). This results in lower evaporation and lower overflow losses at the dams. In years when the surface sources cannot deliver enough water, the stored underground water can be abstracted. In effect, the Windhoek Managed Aquifer Recharge Scheme improves the efficient utilisation of existing sources, thereby increasing the volumes available and improving the security of supply.

Costs and benefits

In an evaluation of alternative water supply augmentation options in the CAN, the best option was found to be the creation of a water bank through managed aquifer recharge of the Windhoek aquifer in combination with deep boreholes, to increase the access to a larger volume of stored reserves (Table 9).

Steady economic development has resulted in increasing water demand in the CAN and in the very near future, existing water resources will not be able the meet the expected demand in a sustainable way. Windhoek is, therefore, at the threshold of insufficient water supply. In the event of extreme water shortages, the real economic losses as a result of non-availability of water would be catastrophic to the Namibian economy. The decline in economic output is directly related to the magnitude of such water shortages. Windhoek contributed approximately 50% of the N$ 5.26 billion (USD 620 million) manufactured goods (excluding fish processing on shore) sector in 2006, the closure of industry in Windhoek due to non-availability of water would result in a N$ 2.63 billion (USD 310 million) loss per year to Namibia based on the 2006 Gross Domestic Product.

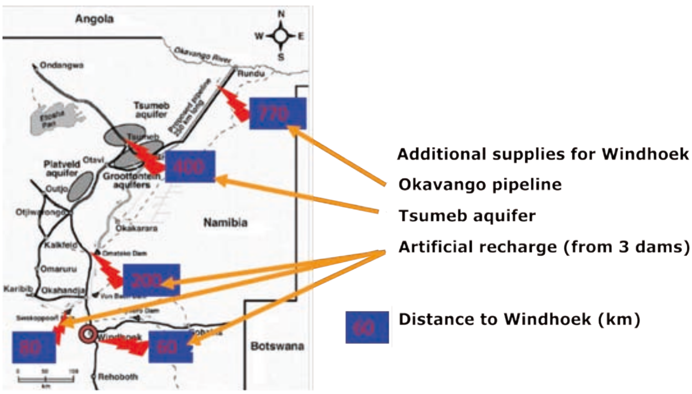

Figure 23. Additional water supply options to Windhoek

On a national scale, the optimization of production from the dams supplying Windhoek and the Windhoek aquifer reduces the need to import costly water from remote sources in the north . This would also help defer the construction of a link to the Okavango River, a project which is both costly

Table 9. Costs of water (2011)

Existing and additional supplies	Type of supply	Cost (USD/m³)
Existing supplies	Groundwater	0.71
	Surface water	0.90
	Reclaimed waste water	1.19
	Re-use	0.71
Additional supplies (figure 23)	Okavango pipeline	35.6
	Tsumeb Aquifer	4.3
	Managed aquifer recharge	2.0

and fraught with environmental problems. The measure will also help downsize significantly the size of future augmentation schemes.

Institutional aspects

The security of supply through managed aquifer recharge must be fast tracked, since the shortage of additional water in times of drought will have a devastating effect on the economy. It is important that the service providers and the regulatory body cooperate closely in order to complete the project successfully. Furthermore, the involvement of the major stakeholders to ensure local and national ownership of the project is essential.

The aquifer infrastructure is currently owned and operated by the City of Windhoek while the bulk of water supply infrastructure in the CAN is owned and operated by NamWater. The management and operation of the Managed Aquifer Recharge system requires expertise and dedication, and this needs to be addressed to ensure the optimum utilization of the available resources and infrastructure. It is essential that the management of the system is properly co-ordinated between NamWater and the City of Windhoek.

In 2007, a trilateral memorandum of understanding was signed between the Department of Water Affairs and Forestry, NamWater and the City of Windhoek in order to try and secure funding for the project. The Department of Water Affairs and Forestry established a Technical Steering Committee for the Windhoek Managed Aquifer Recharge Project (WARSCO). The members represent NamWater and the City of Windhoek; a representative from the Department of Water Affairs and Forestry is the chairperson. With regards to the success of this project, the importance of a regulator to monitor compliance to the water service plan of the service providers, and to the conservation and demand strategies, cannot be over-emphasised. The management of the resource and maintaining its affordability must be undertaken in a joint manner.

It was realised by the members of the WARSCO that certain institutional, technical and financial aspects require attention. Due to the importance of a reliable water supply to the CAN, it is suggested that the Windhoek AR Project is classified by the Government as a project of strategic importance to Namibia.

In order to monitor the implementation of the project it is recommended that the three dams including the shared infrastructure (downstream of Omatako Dam) and the Windhoek Aquifer be declared as a Water Management Area in accordance with the Draft Water Resource Management Act of 2004 (after promulgation following the amendments to the new Water Resource Management Act).

Stakeholder participation

The Namibian Water Policy stresses the need for an integrated approach to water resources management and it is recommended that an advisory Basin Management Committee is established according to the Draft Water Resource Management Act of 2004. The engagement and collaboration of key national stakeholders in project scoping and design, in order to develop a relevant profile for water management, is considered as an element essential for success. Furthermore, the opportunities for public-private partnerships must be actively explored and engaged in.

Conclusions

The main objective of the Windhoek Managed Aquifer Recharge Scheme is to improve the security of water supply to the Central Area of Namibia (CAN), to meet expected increase in demand which is very important for the sustained economic growth of Namibia. Implementation of the Windhoek Managed Aquifer Recharge Scheme is the best solution, as it has been proven through various feasibility studies between 2002 and 2004.

Figure 24. Drilling of deep boreholes, to increase access to a larger volume of stored groundwater reserves.

Apart from the Windhoek Artificial Recharge Scheme being the most cost effective option, the project can be phased as required and will downsize or delay the immediate implementation of future augmentation schemes. It will contribute towards making low yield alternatives more viable and have minimal environmental impacts compared to other alternatives.

Failure to make use of this opportunity will have devastating consequences for future security of supply to the CAN. The declaration of Water Management Area and the enhancement of public and stakeholder participation would be the key to success. Given the relatively unknown effects of global warming on security of water supply, storing of water reserves underground for use during periods of scarcity is a novel solution.

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5.5 Creating fresh water bubbles in brackish groundwater

Bangladesh

Water shortages are acute in Bangladesh during the last months of the dry season, even in districts where there is no natural storage of fresh groundwater. In these areas, measures are needed to secure year-round availability of drinking water supplies. UNICEF in collaboration with the Department of Public Health Engineering (DPHE) has initiated an action research project to improve the situation. It aims to utilize the abundance of water in the rainy season to augment depleted fresh water storage in urban and rural areas. An area of interest is the coastal region of Bangladesh where fresh water availability is reduced by widespread brackish groundwater. Fresh water sources are not available during large parts of the dry season (November-June) .The project is implemented by Department of Geology, Dhaka University and Acacia Water of the Netherlands. Four test sites were completed and tested in 2011 and another 16 sites will be completed and tested in 2012.

Figure 25. a) Collecting water from dry pond bed; b) Waiting for supply of water via truck

Technology

The technology involves infiltrating pond water and rainwater below the covering clay layer (10-15 meter) in the shallow aquifer through infiltration wells, and creating a fresh water bubble in the aquifer for use during the dry season.

The design of the infiltration schemes consists of a water source (a pond and /or a roof), from which water is infiltrated into the aquifer by 4 to 6 infiltration wells with diameters of 30 to 55 cm. When pond water is used for infiltration, the turbidity is first removed using sand filters to avoid clogging. Water is circulated from the storage tank to the infiltration wells through PVC pipe connections fitted with gate valves and flow meters. A number of observation wells have been installed at different locations and depths to monitor various physico-chemical and hydrogeological

Figure 26. Site location

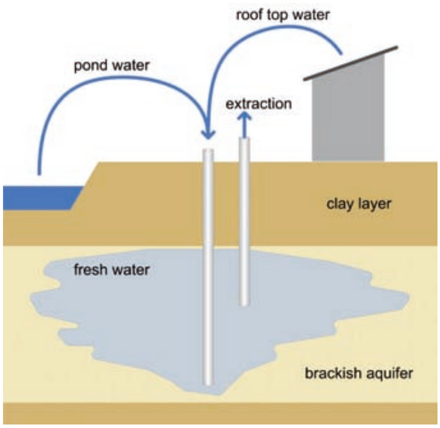

Figure 27. Infiltration scheme design

parameters for testing the infiltration rates and monitoring the build up of the fresh water bubble (see figure 28).

The testing of 4 sites during the 2011 monsoon showed that approximately 600-800 m^3 of water was infiltrated from the pond system in Batiaghata, and 400 m^3 in Assasuni where pond infiltration started late in the monsoon. The infiltration rates at sites with only rainwater in Paikgachha (Laskar) and Shyamnagar (Munshiganj) were in the order of 200-250 m^3.

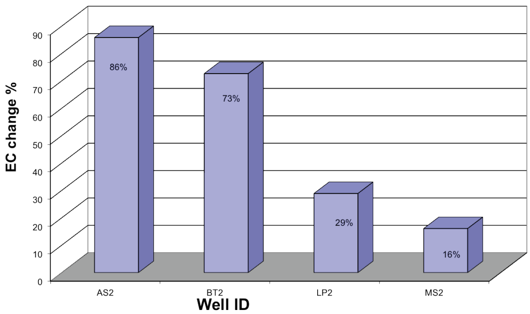

Figure 28. Change of EC over time expressed in % reduction from initial conditions

The salinity data from Batiaghata and Assasuni clearly illustrate the positive impacts of infiltration on the salinity of the groundwater. At the end of the infiltration period the electrical conductivity (EC) in Batiaghata had lowered from 2.6 to 0.7 mS/cm and in Assasuni from 6 to 0.8 mS/cm. At these sites people have already started fetching water for drinking purposes. Observations at the other sites showed that with only rainwater infiltration, the volumes were not enough to reduce the salinity and make the water drinkable, suggesting that further research is needed for intervention in high salinity sites. A site with high salinity was deliberately chosen in order to test the upper limit of groundwater salinity that can be reduced by infiltrated rain and pond water. Apart from salinity, there has been improvement of quality in terms of iron at three sites and arsenic at the one site where initial arsenic concentrations was above the WHO provisional guideline value of 0.01 mg/l.

Where is it applied?

In the coastal plain of Bangladesh the suitable areas for construction of these sites depend on a number of physical, chemical and social criteria:

- Where deep fresh groundwater is available, it is usually the main source of fresh water. The first


Figure 29. a) Well construction; b) Typical infiltration well

step therefore is to map these areas. Once the areas without (or with a low density of) deep tube wells were identified, the availability of other water supply technologies such as shallow hand tube well, ring wells, very shallow shrouded wells and pond sand filters were considered.

- The areas having no or very few of such options were identified for the next phase of investigations. During this phase, social criteria such as population density and proximity to a piped water supply were also considered. Additionally, village scale GIS maps were produced for such areas, and in some selected areas exploratory drilling, installation of test tube well and sampling from existing water sources were carried out.

An assessment of the conditions in Khulna, Satkhira and Bagerhat Districts shows that about 2 million people live in areas where there are no other (deep or shallow) fresh water sources available in the dry season. Other criteria for the selection of suitable sites are:

- relatively thin clay cover (less than 15 m),
- considerable thickness of shallow aquifer (20 m),
- moderately high electrical conductivity of groundwater (<10,000 uS/cm)
- other water quality parameters such as low iron and arsenic,
- availability of suitable source water from a pond (government or privately owned, fresh water, no fish culture) and roof (community or government owned building or corrugated iron roof with adequate size),
- socio-economic factor such as local partner NGO, good accessibility and willingness of the community to participate, and
- consultation with (and approval of) the district and upazila level DPHE officials and local government institutions such as Union Parishads.

Assuming that some of these criteria reduce the upscaling potential by 50%, there is still scope to reach 1 million people with these systems.

Costs and benefits

The cost of a combined pond and rainwater infiltration system is approximately Tkh 600,000 (USD 7,500), half of which is the cost of physical construction. The other half is spent on designing, supervising and monitoring. In this project, works were completed with locally available material,

Table 10. Capitalized costs per m³ for construction and operation & maintenance for 5 typical solutions (field study, 2011)

System type	No. people served	Consumption (l/c/d)	No. days per year	Total volume (m^3/yr)	Capitalized annual costs for construction and operation & maintenance (USD/m^3)	(USD/cons)
Aquifer storage	250	15	200	750	3	6
Rainwater harvesting	11	6	150	10	13	11
Reserved osmosis	500	12	200	1200	12	29
Rural piped system	1,500	25	365	13500	1	8
Village water vendor	200	15	200	600	8	24

using local contractors at all stages of construction and drilling. Only a few items such as gate valves and water meters were procured in Dhaka, the national capital. The work was supervised on the spot by a field hydrogeologist and design engineer from the Dhaka University team.

In table 10 the capitalized costs per m^3 for construction and operation and maintenance for 5 typical solutions are shown, based on real data from the field in November 2011. In the first row of the table, the costs of the infiltration and storage in aquifers can be found. As a comparison, the costs of some alternative techniques are shown in the table as well. The second and third rows in the table are alternatives in our areas of intervention. The last 2 are found in the vicinity of our target area, where pockets of fresh groundwater serve as the source of water for water vendors, or where deep fresh groundwater is available to feed a rural piped scheme.

The primary benefit of the systems is the access to cheaper and safe drinking water in the dry season, since the alternative options like water tankers/vendors, rainwater collection or reversed osmosis are more expensive and less reliable. Moreover, the infiltration schemes are less prone to droughts than rainwater harvesting and have the overall advantages of decentralized operation and maintenance, which gives the community control over the management of their water source. It is noteworthy that these systems stayed also protected from cyclonic flood inundations occurred during cyclones Sidr and Aila.

Implementation

The best results are obtained from a combined pond water and rainwater system. Such systems provide an average recoverable volume of 750 m^3/year (based on recovery efficiency of 0.75) and can serve 240 consumers with 15 l/day during the dry season (150-200 days). Advantages of a combined system are:

- The investment costs per m^3 of water is lower than for only rainwater or only pond water systems;
- Injection of pond water can continue during days of no rain and pumping pond water can be

stopped during rainy days;

- the rainwater will reduce the salinity of the pond water resulting in better quality of the injection water.

The lessons learnt during the construction and testing of the 4 sites in 2011 are being used in the construction of an additional 16 sites which will be tested in 2012. Two alternative designs will be included in this final testing phase:

- Direct gravity infiltration near the pond with an underground sand filter (no pump needed)
- Roof top rainwater infiltration near schools and possibly other buildings with large roofs, like cyclone shelters.

Successes and challenges

The outcome of the 2011 testing shows that the infiltration technology is feasible, can be locally constructed, seems to be appreciated by the local population and is probably financially competitive to alternative solutions in areas without fresh groundwater resources.

- The testing of the new technology, managed aquifer recharge, for safe water supply in coastal regions of Bangladesh has been mostly successful. At two out of four sites, people are now able to use the facilities for drinking water. However, the recovery factor is yet to be tested. That can be done after the monsoonal rains.
- It is possible to construct such units using locally available materials and drillers under the supervision of hydrogeologists and engineers. Involving NGOs in collecting field data and conducting continuous monitoring has been very useful.
- The criteria for site selection, site-specific design, constructions and monitoring are well established. They can be used for upscaling. The local community showed keen interest in the research and liked the outcome, as water could then be collected through a hand pumped well - the most liked and widely used method in rural Bangladesh.
- The partnership among researchers, consultants, government officials, development partner and NGOs has proven to be very effective in successfully demonstrating the potential of the technology.
- Local well drillers can be trained to build such systems under the supervision of professionals.

All in all, there is good potential for providing safe water to over 1.5 million people in the costal districts of Bagerhat, Khulna and Satkhira using managed aquifer recharge.

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5.6 Freshwater storage in areas with saline groundwater – Tajamares

Chaco, Paraguay

Areas with saline groundwater are among the most difficult to deal with in terms of drinking water supply. Water resources and water storage options are limited, especially in arid and semi-arid regions, where surface water storage in open ponds causes high evaporation losses. An innovative alternative is the careful management of fresh groundwater lenses that provide a lifeline even in such places.

Technology

The buffering of rainwater during the rainy season is crucial to ensure domestic water supply in dry areas. For this purpose, surface water storage and artificial groundwater recharge was carried out by using 'tajamares' in the Chaco region in Paraguay and other regions in South America. Tajamares are natural depressions but can also be constructed artificially. They collect runoff over a large area and store it in a surface reservoir, or feed local freshwater lenses. These freshwater lenses float on top of the saline aquifer. They occur when the following conditions are met (figure 30):

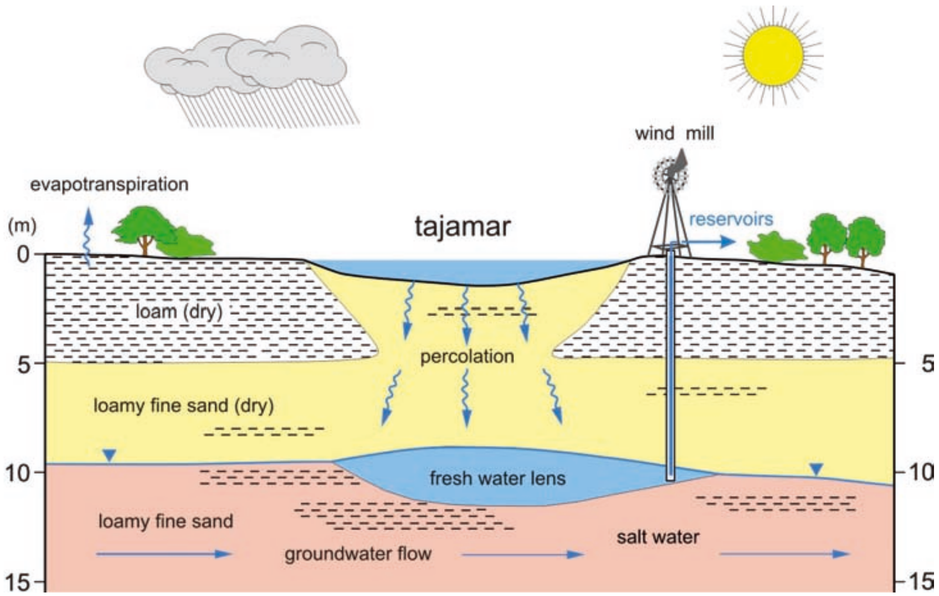

Figure 30. Fall conditions for a tajamar are fulfilled, rainwater infiltration results in the formation of a freshwater lens. A windmill pumping the groundwater mechanically to the surface.

- The depression is fed by a large catchment area;
- High intensity rainfall events occur (more than 35 mm), so that water can accumulate in the depressions or tajamares;
- Sandy soil in the depression or tajamar facilitates the percolation of water;
- The unsaturated zone is sandy and highly permeable, so that a buffer of sufficient storage capacity is available;
- The groundwater table is at least 4 metres deep, so that evaporation is avoided;
- There is only very low velocity flow of groundwater – so the freshwater lens is not disturbed and does not mix with the surrounding saline groundwater.

Where is it applied?

The Chaco – with a surface area of 240,000 km^2 – covers two thirds of Paraguay. The area is scarcely populated and mainly undeveloped. Much of the groundwater is saline, and there are no perennial rivers or lakes. Therefore, drinking water resources for the local population are limited.

The geology of Chaco is characterized by sand, silt and clay deposits from the Andes. Hence, aquifers alternate with impermeable clay layers. The groundwater flow is low with a velocity between 0.6 and 1.8 m/year (Junker, 1996). In the central part of the Chaco, the shallow groundwater table lies at a depth of 3 - 15 m. The groundwater in the area ranges from brackish to extremely salty (Echeverria, 1989; Godoy, 1990). The mean annual precipitation is between 800 mm and 900 mm, reaching up to 1600 mm in peak years. The larger part of the rains occurs between November to March, when evaporation is also at its peak.

Costs and benefits

Table 11. Costs of the tajamar Ganadero with a capacity of 30,000 m^3

Recharge Area for the Tajamar	500 ha
Water Storage Capacity	30,000 m^3
Construction Costs	24,000 euro
Life Time	15 years
Interest Rate	5%
Annual Capital Recovery	2312 euro/yr
Maintenance and Distribution	180 euro/yr
Water Price	0.08 euro/m^3

The general costs based on a tajamar were roughly USD 24,300 – serving a community of 400 people (60 houses). These costs involve the recharge structure and the distribution network, including a windmill, five cisterns, a hand pump and the pipeline.

The tajamar systems provide a water source under very difficult conditions. They also serve as a tool for climate change adaptation as they draw benefits out of high intensity rainfalls. A tajamar with a volume of 30 000 m^3 provides drinking water for up to 1200 persons. The water price is

Table 12. Benefits of the tajamar Ganadero

Market Price of water in Chaco	1.78 euro/m³
Costs of the tajamar water	0.08 euro/m³
Benefits	1.70 euro/m³

calculated based on the material costs. With an interest rate of 5% and a life time of 15 years we have a water price of 0.08 Euros per m³ (0.1 USD per m³). The labour needed for construction and maintenance is not included in the calculation, but that can be contributed by the communities themselves. Apart from providing drinking water, tajamares enable livestock farming in Chaco. Depending on the irrigation intensity of the pasture, the production rate is between 1 to 1.5 cattle per hectare. According to the Asociacón Rural de Paraguay (ARP) the additional water available (apart from what's needed for irrigation) contributed to an increase of 36.1% in livestock farming in Paraguay between 2005 and 2010. An additional benefit concerned the production of vegetables that was made possible. The economic growth in Chaco had a strong effect on the labour market, which related directly to farming activities but also to secondary production processes in Chaco. Indigenous people benefitted most as they were disproportionally faced with water shortage.

Financing mechanisms

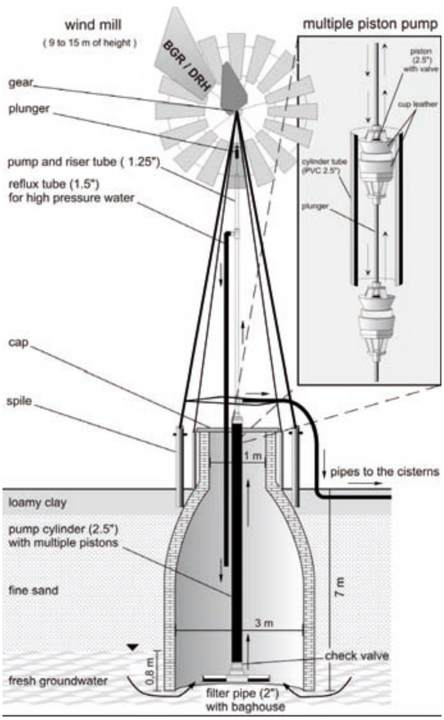

Figure 31. Schematic overview of windmill.

Communities had to describe their water problem clearly and define their contribution to the project. The input of the communities consisted mainly of construction works and the transport of material, whereas the project provided construction material, tools, and consulting.

Implementation

Consultancy was provided to the communities only after their interest in improving their drinking water supply was proven. Where the local hydrogeological conditions were suitable, the community built tajamares. For the planning, construction and maintenance of the tajamares, water committees were founded within the communities. The local communities received support, but planned and constructed the tajamars themselves. Thus, a sense of ownership was developed and transfer of technical know-how took place. This is indispensable for guaranteeing that the water supply schemes are operated and maintained well into the future. Locally available construction material and a simple, tested technique were used to facilitate maintenance by the communities. This provided additional support to the local economy.

To avoid contamination by animals the tajamar was fenced off. The objective of the project was to achieve safe and sustainable drinking water supply all year round.

Successes and challenges

Since the beginning of the project in the 1990s more than 75 villages, schools and public institutions in Western and Central Chaco got interested in joining the project. They recognized the benefits of participating in the construction of tajamares. Four years since the beginning of the project, half of the villages in the area seemed to have taken responsibility for their tajamares. Obviously, success depended on the organisational structure of the water committee and the ownership.

The tajamares construction was scaled up during the last years which led to large-scale economic benefits. As intense livestock farming creates a strong incentive to clear the native woodland to enlarge the pasture area, the challenge is to integrate this traditional technology into a sustainable land-use management process.

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5.7 Fresh water conservation with controlled drainage

The Netherlands

In the previous 3R book "managing the water buffer" controlled drainage in the Netherlands was presented. Here this case is more extensively discussed with information from the factsheet 'Peilgestuurde drainage' by STOWA and the report 'Zoetwater Verhelderd; Maatregelen voor zoetwater zelfvoorzienendheid in beeld' by L. Tolk, from the research project knowledge for climate.

Figure 32. a) Controlled drainage installed in fields in the Netherlands, where the drains are connected to a collector drain; b) and a vertical pipe which acts as the control unit for the water level. (Photos: Acacia Water)

Technology

Drainage is often applied to agricultural areas. Traditionally, its purpose is to carry away rain water and to lower the groundwater level in order to avoid wetness damage to the crops. However, the fast removal of the rain water decreases the capacity of the soil to retain water until the dry periods. With controlled drainage, the water level in the ground can be influenced and altered over the course of a year. It provides the possibility to increase the groundwater level so that water can be stored in the ground, and to decrease the groundwater level to prevent wetness damage.

Controlled drainage is based on a relative simple technique, which can either be applied to existing drains, or can be introduced when new drains are installed. The core of this technique is that the drains, that normally discharge their water into ditches, are now connected to a tube. The trick is that the water level in this tube, and thus the groundwater level, can be altered. To accomplish this, the end of the tube, where the water flows out, is connected to a vertical pipe. The head of the latter can be changed, by which the level at which the water flows out is changed. If the overflow from the vertical pipe is at a high level, much water can be stored in the soil. When the level is decreased, the water stored in the ground will flow out, until the groundwater table is in equilibrium with the head of the vertical pipe.

It is possible to collect the water that is released from the drains when the head of the outflow is lowered. A pilot to test this will begin shortly at Texel in the Netherlands. In principle, the water quality is good even if the deeper groundwater is saline, since the upper layer of water that is extracted from the soil in this manner consists of fresh water that floats over saline water in the ground. The quality of the water, however, depends on the practices on the field from which it is drained, such as whether pesticides and fertilizers are being used on it.

In saline groundwater environments, the controlled drainage practice has another advantage. In this area the so-called fresh water lens becomes substantially larger if the winter groundwater level is increased. Normally fresh, rainfed water floats on top of saline water. In areas with saline seepage this provides a buffer against salinization of the root zone. With traditional drainage, the fresh water is discharged and this buffer is reduced. Moreover, a lower groundwater level increases the seepage flow, thus increasing salinization. These two negative effects of traditional drainage can be reduced by controlled drainage. If the groundwater level is increased in winter, the fresh water lens will grow thicker, and the buffer against salinization can thus be increased.

At the start of the growing season, or when heavy equipment has to enter the field, the groundwater level can be lowered quickly to the desired depth. This prevents damage to the crops due to wetness. If enough water is available, the water level in the field may be increased when water shortage occurs in the dry period. This is done by increasing the water level in the drains, which then function - depending on the soil conditions - as subsurface irrigation channels. By this dynamic control of the groundwater level through controlled drainage, more water can be stored in the ground, without the risk of wetness damage.

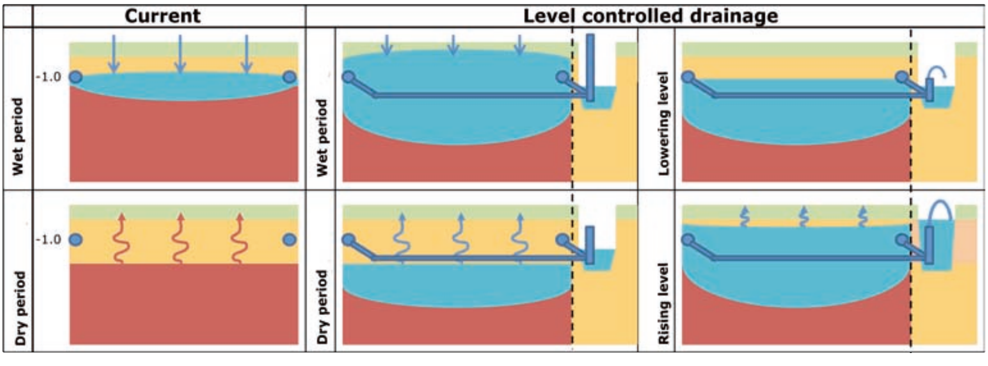

Figure 33. Controlling the water level in the soil and increasing the amount of fresh water stored in the soil with drainage in which the water level can be dynamically controlled. Blue indicates fresh and red salt water. The left panel shows the traditional drainage, and the middle and right panel the increased amount of fresh water with controlled drainage, in the wet (upper panel) and dry (lower panel) period.

Where is it applied?

Controlled drainage has been applied in several pilot projects in the Netherlands. The effectiveness of controlled drainage depends, among other factors, on soil conditions. The resistance of sandy soils is limited and controlled drainage over such soils is shown to be effective. In clay soils, the effect may be less pronounced. Controlled drainage pilots, currently underway, are testing such soils.

Controlled drainage increases the amount of water that can be held within a region, only if it is used as a substitute for traditional drainage. It is only applicable to areas that are drained, or need to be drained, to avoid wetness damage.

It can be applied to reduce peak floods, especially when the growing season does not coincide with the wet season. In drained areas, where peak floods need to be reduced at a given moment, the groundwater level can be increased. Controlled drainage may be used in such cases as a means to increase the buffer function of the soil.

In areas with saline seepage, like in low lying deltas all over the world, the fresh water lens may be increased with controlled drainage. Moreover, the technique helps to harvest fresh water from the soil in an otherwise saline water environment. In extended coastal areas, where the shallow groundwater is saline, controlled drainage can reduce the risk of salinization of crops.

Costs and benefits

The costs of the construction of a controlled drainage system are about € 4000 per hectare if new drains are also installed at a distance optimized for controlled drainage. The costs can be lower if the system is applied to existing drains, at about € 600 to € 2400 per hectare (table 13). The exploitation of a controlled drainage system is slightly less than that of traditional drainage, since it was found that the flushing of the pipes to clean them could be done more easily when the drains are connected. If the system is used for infiltration, or if the water that comes from the drains has to be saved, additional expenses must be made to store the water (in a basin, for example). This would be the most expensive part, and the cost of the basin would exceed the cost of the actual controlled drainage system.

The benefits of the system lie in the increased water holding capacity that decreases peak flow, the reduced irrigation requirement due to the increased groundwater level, and the buffering against salinization. Thus, the external water request is reduced and crop yield increases. The quantification of the latter benefits is still under investigation. As salinization in coastal areas becomes more severe due to climate change, the benefits of controlled drainage will assume greater importance.

Table 13. Costs for the construction of controlled drainage (Tolk, 2012)

	Lifetime (yr)		Construction (euro/ha)				Total (euro/ha/yr)	
	min	max	min	max	min	max	min	max
Drainage tubes	10	20	0	1600	0	160		
Collector drain and vertical pipe	15	20	600	2400	30	160		
Total (average)							30	320

Financing mechanisms

At the moment, most controlled drainage systems in the Netherlands are pilot systems that have been financed by research institutes. However, once their benefits are clear, the investment will be the responsibility of the farmers. If the prudential considerations are advantageous, the Dutch farmers may decide to invest in controlled drainage to overcome drought or salinization. Where controlled drainage is necessary to control peak run-off, the water board may provide a subsidy to the farmers to install controlled drainage. One Dutch water board has already made the application of controlled drainage for water quantity control obligatory.

Implementation

Controlled drainage becomes functional immediately after construction. After installation of the collector drain and the vertical pipe, the system can be used to raise the water level during the wet period, and lower it in the growing season or if heavy machines have to enter the land. If the system is also used to infiltrate water in a salinized environment, a basin or another storage for the infiltrating water should be constructed as well. This is more expensive and means that agricultural land is lost at the location of basin. Therefore, the construction of the basin will be the most difficult part in the implementation if the system is also used to collect water from. The controlled drainage technique itself is relatively easy to implement.

Successes and challenges

Water boards in some parts of the Netherlands have adapted controlled drainage as a solution to diminish peakflows. Pilots have shown promising results, in terms of increasing the amount of fresh water in the soil. The challenge now is to make the technology marketable. Therefore, the benefits need to be clearly articulated and more commercial pilot projects need to be carried out. The communication of the successes, which are already visible, should help to convince farmers about controlled drainage as a relative cheap solution to salinization. Water boards in other parts of the Netherlands may follow the one that already uses controlled drainage against flooding. A challenge here is to facilitate shift in the responsibility from the water boards to the farmers and to promote small scale, decentralized measures.

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5.8 Recharge and soil fertility with gully plugs and bunds

Terai, India

The Terai region of North Bengal in India is characterized by high rainfall – especially during the monsoon period between May and September. Although rainfall reaches 2200-3000 mm a year, a program of 'wet watershed management' yielded high dividends. By the development of bunds and dikes, surface water was better controlled and retained. Moreover, gully plugs secured groundwater levels – and this made the cultivation of rainfed paddy more secure.

Technology

Several techniques were used to better retain water and stabilize groundwater levels in the North Bengal Terai area. The main techniques used were:

Figure 34. Constructing a gully plug to retain groundwater (Photo: Richard Soppe)

Gully plugs constructed in the natural drains in the areas. These plugs replenish groundwater resources by increasing the infiltration and at the same time they reduce erosion and stabilize the gully bed. This also contributes towards raising of the groundwater table, as gullies are the lowest drains in the area.

Graded bunds and barrier bunds to capture sheet flow. The graded bunds are placed at a slight angle with respect to the contour lines. The height of the bunds is relative to the slope of the land and the area to be inundated. This impounded area is not more than 15 cm deep. The bunds are built in a series and serve to gently spread water or retard sheet flow. They also prevent the formation of gullies, the lowering of the water table and the drying of the upper layers.

Field bunds keep water from gushing from field to field. Instead, they ensure that a field basin is filled up before the water neatly topples over to the next field basin. Like other soil structures they are preferably constructed in the middle of the dry season to allow them to settle under the impact of cattle and human movement, and be strong enough before the new monsoon starts.

Protection bunds along rivers and gullies have two functions: they prevent uncontrolled flooding from the streams, and keep water from gathering in the rivers and gullies too quickly and in large quantities.

Where is it applied?

The Terai is the extensive area that borders the Himalayan region – stretching from Nepal to Assam state in India. The 'wet watershed management' techniques used in the North Bengal Terai could also be applied over a much larger area. They would also be of use in other flat, high rainfall areas – such as parts of Southeast Asia.

The Terai itself has been an agricultural frontier area for the last few decades. Formerly consisting of riverside grasslands, savannahs, and evergreen and deciduous forests, the area has been converted into highly productive farmland, sustained by the high and dependable groundwater levels. Seasonal water scarcity is a challenge. Firstly, the major part of the annual 2.800 mm precipitation takes place in the monsoon period between June and October. Secondly, climate change makes the beginning of the monsoon and monsoon precipitation very erratic (GWB, 2011). Overall, monsoon rainfall has decreased by 3.1%, and annual rainfall decreased by 8.8% over the last decade in the Terai zone (GWB, 2011). Thirdly, the coarse structured soils have low water retention capacity, limiting water delivery during dry spells. In order to maintain the rare grassland ecosystem, and secure water availability for the rain dependent crops, a wide range of interventions were undertaken to recharge and retain groundwater, secure soil moisture and provide supplementary irrigation.

Costs and benefits

Average investment costs for design, planning, and construction of the Soil Water Conservation (SWC) techniques in the Terai were about USD 90/ ha.

An evaluation of the economic return of these measures was undertaken at six sites by Despande and Dey (1999). According to the findings, the use of the gully plugs and various bunds under the wet watershed program resulted in:

- An increase in the cropping intensity from 90% to 201%;
- Stabilization of the water table throughout the monsoon season, reducing the impact of dry spells during the period. This was a major concern. After the wet watershed program, the high and stabilized groundwater tables (and sustained soil moisture) made it possible to overcome the impact of such short drought periods that otherwise greatly reduced the yields of rain fed paddy;
- Increased soil fertility, leading to higher content of organic matter in the soil. Thanks to this, soil moisture could now remain at a level required for crop growth, for 9 additional days during the dry period.

These benefits translated into an increase in the gross production value from USD 370 to over USD 3,500 /ha. Better soils and improved access to water also lead to an increase in land value, from USD 646 to USD 1,772/ha. The benefits, therefore, far outweighed the average investment costs of USD 90/ha.

Similar results can be seen in other programs in this area. An example is the Hill Area Development Program (HADP), which assists communities in smart and sustainable resource use. It is active in the hilly areas of Assam and West Bengal states and was initiated by the Government of India during its 5th Five Year Plan. Although the watershed approach was used it was still at "preliminary levels at implementation stage" (PEO, 2010). Nonetheless, one third of the beneficiaries reaped benefits of land and water development activities. On average each beneficiary extended their land holding by 0.3 hectare; included up to four new crops in their cropping systems; and could increase their yield by 75% on average. Thus, the project beneficiaries were able to increase their incomes significantly. It is estimated that these increments added up to a benefit of up to USD 250 per year (PEO, 2010).

Financing mechanisms

One great strength of wet watershed programs is that the required material investment is very limited, and that they are mainly labour intensive. Almost the entire budget is spent on labour and the program implemented in the lean period. This contributes importantly to the local economy. In case the structures get damaged in the future, it is the task of the maintenance committee to seek additional funding from the local panchayat / pradhan[31] (Mahapatra, N. 2002). The committee is also responsible for maintaining its own financial resources (PEO, 2010).

Implementation

Implementation of the project in North Bengal was the responsibility of the Soil Conservation wing of the Department of Agriculture. The implementation was carried out through 'beneficiary committees' formed by local farmers. After the project's completion, its state and performance was assessed by maintenance committees.

Successes and challenges

- Institutional: Local residents were intensively involved in the design, implementation and maintenance of structures. This was key to the project's success.
- The measures taken significantly improved yields and incomes of a largely poor population. Investments paid themselves back within one year.
- The implementation of activities generated additional employment opportunities.

The average per capita land holding in the state is often less than one third of a hectare (one bigha). Despite this, cropping intensity in West Bengal is one of the highest amongst all the states in India. It increased from 131% to 185% over last two and half decades putting tremendous pressure on soil and water resources. This makes the harnessing of recharge and retention of vital importance. Secondly, the impact of climate change in the region needs to be addressed (see table 14). The region, thus, faces a number of challenges that urge for proper water management.

31 Head of the Village Council, an elected village-level administrative body in India.

Table 14. Climate change impacts and strategies in the Terai Zone of West Bengal (Source: Table 6.2 and 6.6 in GWB, 2010; pp. 60; 69-70; 80)

Climate change	Proposed strategy
• Long winter periods are conducive to wheat production in this region, but increase in winter temperatures reducing wheat yields. • Long span of winter is an advantage which can be exploited.	• Encouraging indigenous cultivars: Introduce short duration wheat varieties
• Degradation of quality seeds.	• Encouraging indigenous cultivars
• Temperatures have increased 1.5 C° and continue to rise.	• Plant head shade to fruit trees and construct greenhouses for vegetables, wherever the temperatures are exceeding the tolerance level of plants
• Nutrient loss by enhanced leaching. In Terai region due to leaching there is deficiency in lime, Zinc and Boron.	• Undertake effective soil nutrient management, e.g. green manuring enrich the soil in 200 days • Introduce "No tillage" in all agro-climatic zones

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5.9 Greening semi-arid landscapes - water spreading weirs

Sahel region

The approach of constructing water spreading weirs in the Sahel region is described in a project by KfW and GIZ that has been implemented on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ). In this section a selection of their report "Water-spreading weirs for development of degraded dry river valleys. Experience from the Sahel" by Nill et al (2012) is presented.

Figure 35. a) Water in water-spreading weir; b) Water-spreading weir in Kalfou (Tahoua region, Niger) (Photos: GIZ/Aboubacar Mounkaila).

Technology

Sparse vegetation cover and structurally damaged soils reduce rainfall infiltration into the soil, resulting in more runoff and soil erosion on plateaus and slopes. Runoff is concentrated in the valleys, in which heavy floodwaters wash away fertile soils and lead to deep erosion of the riverbed. The annual, recurrent small and medium-size floods that normally cause temporary inundation of the valleys and deposition of fertile sediments no longer occur. These dynamics can be reversed with water-spreading weirs and stabilization measures in the drainage basin.

Water-spreading weirs are structures that span the entire width of the valley. They consist of a spillway in the actual riverbed and lateral abutments and wings (figure 36). Floodwaters are spread over the adjacent land area above the structure, where they eventually overflow the lateral wings and then slowly flow back towards the riverbed below the structure. The lateral spreading of the water causes the land area above and below the structure to be flooded and supplies it with sediment. Water infiltrates, gullies in the valley are filled and the riverbed is raised. Thanks to the infiltration, the water table also rises in a few years. In 15 rehabilitated valleys in Niger, for example, the average depth of the water table increased from 12.5 m to 3.5 m below the surface.

Water-spreading weirs are usually built in series in order to rehabilitate as much land area in the valley as possible; moreover, structures in series are less susceptible to damage. Additionally, small stone walls are built between the weirs and below the last weir, and deep gullies between the weirs are stabilized with filter dams in order to reduce runoff and silting in the valley.

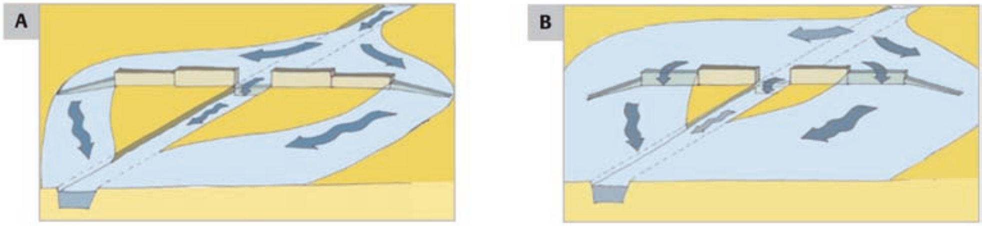

Figure 36. Schematic water-spreading weirs a) with moderate runoff, the spillway in the actual riverbed and the lower wing walls located on the outsides of the weir overflow. b) as runoff increases, the higher wings overflow as well. Source Nill et al (2012); Bender (2011).

Where is it applied?

The water spreading weirs have been applied in semi-arid regions in West-Africa. Over the last 12 years, water-spreading weirs have been introduced and improved as a new rehabilitation technique for degraded dry valleys in Burkina Faso, Niger and Chad.

Water-spreading weirs are especially well-suited for the large-scale rehabilitation of wide and shallow dry valleys that have been seriously degraded and in which severe gully erosion prevents the regular flooding that would normally be typical there. Water-spreading weirs are also suitable for improving agricultural productivity in more or less intact valley floors.

Costs and benefits

The costs of water-spreading weirs vary greatly, depending on physiographic settings, structure, and level of cost for companies. In Burkina Faso and Niger, the costs per weir range from 600 to 1,500 euro/ha, depending on the construction (e.g. with or without a ford) and physiographic setting. Individual water-spreading weirs in Burkina Faso cost on average approx. 12 million CFA francs (~18,000 euro) per weir, and between 30 and 36 million CFA francs (46,000 euro and 55,000 euro) per weir in Chad. The average annual maintenance costs are estimated to be 0.5% of the construction costs. Nine weirs costing 253 million CFA francs (0.39 million euro) were built in Gagna, Burkina Faso.

Water-speading weirs have far-reaching positive ecological, economic and social effects. Water-spreading weirs increase and diversify agricultural production by making more arable land area available, increasing yields and making possible 1 to 2 additional crop cycles per year. This contributes substantially to food security and higher incomes for the beneficiaries. Thanks to the rising water tables, the natural vegetation of the valleys and the availability of fodder for livestock improve. Water for drinking and for watering livestock is more readily available, which in turn eases the workload of women. The more intensive production stimulates other business activities and generates income, helping to reduce poverty and stabilize the local population.

Prior to the rehabilitation, it was not possible to grow a crop during the dry season in 8 out of 15 valleys in Burkina Faso, whereas in others it was only possible to grow an irrigated crop to a limited extent on small fields in direct proximity to the river. Since the rehabilitation, at least one additional crop cycle is now possible on larger fields during the dry season in 13 out of the 15 valleys. The experiences in Niger and Chad are similar.

The value of the total production in 2010 from rainfed crops, post-rainy season crops, irrigated crops and fishing was an estimated 245 million CFA francs (0.37 million euro) in Gagna, Burkina Faso where nine weirs costing 253 million CFA francs (0.39 million euro) were built. Assuming that the sum of production costs, salaries and wages, and net income without weirs is one half to one third of the total production, the investments will clearly pay for themselves within a few years.

By 2010 more than 200 water-spreading weirs had been constructed in the Tahoua region (Niger). 4,731 farms in a valley system in Niger (which were direct beneficiaries of rehabilitation measures) each had approximately 0.6 ha of arable valley land prior to the rehabilitation. Thanks to the water-retaining weirs, this was increased to 2.2 ha. Millet and sorghum yields increased on average by 85–90% and 25–30%, respectively. Data from Niger, which are based on millet as the main grain species, indicate production growth by a factor of 5.8 (Table 15).

Table 15. Changes in arable land, yield and production in 11 rehabilitated valleys in Niger (Source: Nill et al (2012); Betifor (2010).

Element	Situation before water-spreading weirs	Situation afterwards	Difference	Growth factor
Area under cultivation (ha)	2,847	8,132	5,285	2.9
Yield (kg/ha)	333	675	342	2.0
Production (t)	948	5,489	4,143	5.8

Financing mechanisms

Construction of water-spreading weirs is financed by project money, for which the villages that are interested can submit a request. In Chad the community agrees to assume 10% of the costs, not to exceed 500,000 CFA francs (760 euro). In Burkina Faso, the villages submitting the request undertake to assume 3% of the costs.

The construction work is performed with intensive manual labour (HIMO by its French acronym) by workers from the local villages, thus generating local income-earning opportunities during the construction phase and training local craftsmen for the future maintenance of the structures. After the construction is finished the villages or village communities are (financially) responsible for the maintenance of the weirs.

Implementation

In constructing water-spreading weirs, the first step is to identify basically suitable valleys in a region and inform the respective villages, communities and technical services about the possibilities and prerequisites for rehabilitation. Interested communities then submit a written request to the project in-charge, which is examined by an approval committee. The socio-economic conditions and structures in the valley and the willingness of the local people to cooperate are assessed in the subsequent feasibility study. Then the basic construction parameters are defined and the anticipated costs are estimated in a preliminary technical study. The information delivered by these studies provides the basis for the final approval of the construction.

After approval, a detailed technical study is conducted, on which the invitation to tender and ultimately the selection of a construction company is based. One of the principles of implementation is intensive participation by the communities and villages so that the responsibility is transferred to the local level as soon as possible. The community is the client; it issues the invitation to tender and accepts the work in the end. A management committee, made up of representatives from the local villages and communities, is set up in the chosen valley. It acts as the contact for all external stakeholders and helps with the organization of the work. Under the leadership of the management committee, future rules of use are agreed and documented. This can be in the form of a local use agreement, or may take place within the scope of a more comprehensive land-use planning process for the entire drainage basin system.

Successes and challenges

Under the project, hundreds of water spreading weirs have been constructed in three countries. They strongly increased the agricultural production, both by increasing the amount of cultivatable hectares, as well as the production per hectare, especially in the dry season. The challenges lie mainly in ensuring that the management committee is still able to function after the end of the project and that the local structures (e.g. the communities) are able to maintain the water-spreading weirs, particularly in the event of severe damage.

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5.10 Biodegradable plastic mulches[32]

China, India and USA

Over the last twenty years or so, the use of plastic mulch has been booming especially in Asia. In China, for example, plastic mulch can be seen covering entire valleys since the government subsidizes its production to stimulate grain production. In 2004, just over 10 million hectares of Chinese agricultural field were covered by plastic film (Rabobank, 2006; Brown 2004). This area has at least doubled by now, especially in drought prone provinces in North West and South West China such as Xinjiang and Yunan, where the use of plastic mulch is now very common.

Technology

Plastic mulch is a very thin film that is applied over the soil in order to reduce weed growth, reduce evaporation, and raise the soil temperature. The typical thickness of plastic mulch in the USA is between 0.6 to 1.0 mm. It is sold on rolls 1,500 m in length and 1.6 m wide (Sarnacke and Wildes, 2008). The thickness and color of the mulch is based on the farmer and his/her crop preferences.

Black mulch is the most common type used worldwide as it has the ability to control weed growth. It does not let sunlight pass through, thereby inhibiting photosynthesis in weeds. Transparent mulch is used to promote early season crop growth as it lets sunlight pass through and warm the soil, sometimes to quite high levels. However, weed growth under transparent plastic mulch can be extensive and controlling it requires the use of a herbicide prior to laying the mulch. Sometimes, transparent plastic is used to heat the soil (40-60 °C) in order to sterilize it, to control soil-borne diseases and insect pests (Katan, 1981). White, silver or aluminium coloured mulches are used to re-direct sunlight that has passed through the leaf canopy back up into the leaves, thus promoting higher yields. In areas with high temperatures, white mulch can be used to facilitate crop production by cooling the soil. Mulches also vary in thickness and porosity which, in turn, impacts soil moisture, nutrient uptake, and longevity of the mulch itself.

Where is it applied?

Plastic mulch is used extensively in horticulture, especially in vegetable and fruit production. However, in China, mulches are often also used in the production of grains such as maize.

The plastic mulch market experienced an explosive growth over the past two decades. The global use of plastic mulch almost tripled during the period 1999 to 2007, from 1,220 to 3,200 thousand ton (Sarnacke and Wildes, 2008). This growth is largely due to the intensive use of plastic mulch on the

32 Contributed by: C. Miles and T. Marsh. Washington State University; USDA SCRI Project No. 2009-02484.

Table 16. World mulch film market, in thousands of tons (Table J in Sarnacke and Wildes, 2008).

Area	1999	2007
Northern America	150	160
• U.S.	90	60
• Mexico	60	100
Latin America	90	160
Europe	410	640
• Spain	n.a	70
• Italy	n.a.	60
• Germany	n.a.	50
• France	n.a.	50
• Others	n.a.	100
• Eastern Europe	n.a.	310
China	850	1950
Rest of the world	200	290
Totals	1,220	3200

Asian continent (Table 16). In China, the expanded use of plastic mulch is due in part to government subsidies, especially in drought prone provinces in the northwest.

There is a growing market for bioplastic mulch as well, due to high removal costs of petroleum-based plastic mulches. In the USA, public and private concern about the disposal of plastic products is supporting the market for bioplastic mulches, even though they are 1-3 times more expensive than plastic mulches (Jiang et al., 2012). Based on the market analysis of Sarnacke and Wildes (2008), the increase in demand for bioplastics in the USA is driven by:

- Large retailers, such as Wal-Mart and Target, selling bioplastics for their packaging products,
- Public concern over the depletion of petroleum-based raw materials,
- Manufacturing companies' desire to develop more sustainable raw material sources,
- Improvement in properties of bioplastics,
- State and federal government support for bio-based plastic products, and
- Increasing cost competitiveness of bioplastics with respect to petroleum-based plastics.

Costs and benefits

Growers must balance the costs and benefits of mulch use. Application and removal of plastic mulch requires additional labour and costs, but this is outweighed by the increase in crop production, which is normally about 50% but can go up to 4 or 5 times the normal output (Sanders, et al., 2011). The increased expenditure on mulch is partly compensated for by savings on labour and energy costs of weed removal and reduced irrigation needs.

Drip irrigation is widely used in combination with plastic mulch as it has a 90% water use efficiency. The total water usage under the technique is generally half that of furrow irrigation or overhead sprinklers (Kovach et al., 1999; Hartz, 1994).

The production of Polylactic acid (PLA) mulch is increasing with the growing demand for bio-based plastics. Besides, costs of polyethylene mulch are fairly comparable to alternatives (currently only approximately 15% higher) (see also www.cupdepot.com). An alternative material, PHA (PolyHydroxyAlkanoates), is produced by bacteria and is currently significantly (about three times) more expensive than PLA.

Figure 37. Experiments with Biobag (BioAgri) biodegradable mulch showing extensive degradation at the end of the cropping season, reducing removal costs (Photo: Russ Wallace, 2010).

There is increased concern regarding plastic mulch residues in the soil and the overall costs of plastic mulch usage. Costs of mulch removal and disposal in the USA were estimated at USD 250 per hectare in 2004, a costly disadvantage of its use (Olsen and Gounder, 2001). These concerns have led to a search for biodegradable mulch alternatives (figure 37).

Financing mechanisms

Due to the proven benefits of plastic mulch, subsidy programs are in place in many countries to promote its use. Government funding for mulch is especially common in the Asian continent. In India, the government subsidizes 50% of the costs farmers bear to purchase and install plastic mulch. Depending on the state and crop, the maximum subsidy is between Rs 7,000 - Rs 20,000/ ha, or USD 126 - USD 361/ ha. A farmer can avail this subsidy for a maximum of 2 hectares of cultivated area (NCPAH, 2011). In order to promote implementation, the Government of India has established a single authority dealing with plastic mulch: The National Committee on Plasticulture Application in Horticulture (Singh et al., 2010). Likewise, China has an active subsidy program to stimulate plastic mulch usage among farmers in arid zones. Starting in the 1990s, China subsidized plastic mulch as part of the Food and Clothing program of the Ministry of Agriculture. Subsidies for plastic mulch were up to 20% of the mulch market price. They were aimed at stimulating the production of maize (World Bank 2001). Due to its substantial success, this subsidy program continues till date. It was expanded in 2010 when the central government offered a subsidy of USD 23.4 /hectare to maize farmers in the provinces of Yunnan, Guizhou and Sichuan, Guangxi Zhuang Autonomous Region and Chongqing Municipality, to use plastic mulch. The total area cultivated by these farmers was estimated at 1.68 million hectares (China.org; 2010).

Implementation

Plastic mulches can be applied manually or mechanically onto the soil. Holes are punched in the mulch and seeds or seedlings are placed in the exposed soil (see figure 38). Holes may be punched

Figure 38. Plastic mulch use (Photo: MetaMeta)

before or after the mulch is placed on the soil. To punch the holes before, the plant spacing has to be determined first and the plastic mulch folded accordingly. For instance, if crop spacing is 45 cm, the plastic mulch should be folded every 45 cm and holes punched with a (heated) steel pipe.

Before applying plastic mulch on the field, the soil should be ploughed and the right amount of manure and fertilizer should be applied. The field should be formed into beds that are approximately 0.5 m less wide than the mulch. A furrow should be formed along either side of the bed. The plastic mulch should then be unrolled or unfolded down the length of the bed. One of its ends should be anchored at one end of the bed, or pinned down by placing bricks or other heavy objects on it. Then, one side of the mulch should be placed in the furrow which should then be backfilled. The mulch should then be pulled tightly over the bed and its other side should be placed in the furrow on the other side of the bed (which should then be backfilled). This way, mulch should continue to be rolled out and secured with soil within furrows on each side of the bed, until the entire length of the bed is covered. Place seeds or seedlings in the soil through holes in the plastic film. For seedlings that are small or not erect, the leaves will be vulnerable to burning if they lie on the plastic mulch (and it can get very hot).

Successes and challenges

Challenges of using plastic mulch are financial and environmental. The price of plastic mulch is approximately USD 0.10 to USD 0.14/m^2 or about USD 700/ha. While this is generally considered affordable in the US, it is too high a cost in many other countries. Subsidies are used to offset the cost of mulch and increase its use in many of these countries.

Table 17. Commercially available agricultural mulches labelled as biodegradable.

Mulch Product Name	Constituents	Manufacturer
Ecoflex	PBAT[1] is major component	BASF, Germany
Bicosafe	Fully biodegradable copolymers such as PBAT[1] and PBSA[2]	Xinfu Pharmaceutical Co., Ltd., Zhejiang, China
BioAgri	Starch, vegetable oil derivatives, and undisclosed biodegradable synthetic polymers	Novamont, Novara, Italy
Bio-Flex	Blend of PLA[3] and co-polyester	FKuR, Willich, Germany
BioTelo	Starch, vegetable oil derivatives, and undisclosed biodegradable synthetic polymers	Dubois Agrinovation, Waterford, Ontario, Canada
WeedGuard Plus	Cellulosic	Sunshine Paper Co. LLC, Aurora, CO

Depending on its thickness and use, the lifecycle of plastic mulch varies between 1 and 10 years. A downside of the increased use of non-biodegradable plastic mulch is that their disposal is often unsustainable and contributes to pollution, especially in countries where disposal systems are not organised. Some governments counterbalance this negative impact by imposing fines on improper disposal (Jingze et al., 2012). Biodegradable mulches may prove to be the alternative that helps meet this challenge (table 17).

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A1, A2, B1, B2 & D1

5.11 Soil and water conservation at scale

Tigray, Ethiopia

The land scape of Tigray, North Ethiopia, has undergone a remarkable transformation. An intensive program of soil and water conservation has been implemented over the last four years which has restored vegetation, caused groundwater levels to rise and base flows to become more regular and has had effects on the micro climate. The keys to the success were working at scale and local planning.

Technology

In the soil and water conservation program in Tigray a variety of measures was undertaken. These included physical measures (stone bund, hill side terrace, trench bund, gull treatment, micro-basin and pitting for plantation), biological measures (area closures for regeneration, grass strips, and afforestation) and water harvesting measures (river diversion, mini dam, water harvesting check dam, open hand dug well, spring development) (REST, 2011). Whereas earlier the emphasis was on controlling soil erosion, from 2009 the focus shifted more to water harvesting and retaining moisture. With this new techniques were introduced, such as infiltration ditches along stone bunds in low rainfall areas. Other new elements introduced were gully treatments, new grasses, and fruit trees on the treated lands. All individual techniques were implemented using the watershed approach covering an area in its entirety, which has maximized impact. Soil and water conservation was to focus on cultivated and uncultivated land in the new approach. Cultivated land should be primarily conserved by the farmers and watersheds should be conserved by public mobilization. Another change was that area closure was introduced systematically: areas with soil and water conservation were closed from animals for at least five years to allow grasses and other vegetation to grow again and feedlot livestock was introduced.

In the period 2004-2009 over 167,000 hectares of degraded hill sides were rehabilitated, 275.000 km of stone embankments constructed; 900 million seedlings planted, 66.000 km rural roads constructed (EC, 2011). In total over 6 million soil and water conservation structures were built in Tigray (table 18). From 2009 the program was thoroughly reoriented with a large emphasis on local planning and water buffer management at scale. In three years 568,000 hectares were treated.

Where is it applied?

Tigray is situated in the North of Ethiopia and has a semi-arid climate with rainfall between 400-700 mm. It has a population of 4.4 million and a land area of 5.3 million ha. Twenty percent is cultivated, almost all of it by small holdings. Farmers in this region were vulnerable to drought related crop losses. Other major threats in crop production are frost, pests and high mortality rates. In order to improve household resilience to these shocks a wide range of soil and water conservation techniques were implemented in this region. The watershed movement of Tigray is getting a following in other parts of the country.

Costs and benefits

The benefits of this very recent programme still need to be quantified – but the following key observations have been made by farmers and visiting observers:

- Enhanced water infiltration and increase moisture to their farmlands.
- Increased crop yield (50-100%) due to improved moisture conditions, especially areas with limited rainfall.
- More secure base flows of local streams and reduced sedimentation.
  Reduced flooding of farmlands.
- Emergence of new springs at lower parts of the catchments and rising of groundwater levels.
- Change in the micro-climate around the treated watersheds and around closure areas.

The monetary costs of the program have been small as the largest part is done through farmers own contribution. The norm for this are standardized – for instance a able-bodied man's labour output is equal to the construction of two large eye-brow basin or four small half-moons, the excavation of a one meter deep trench or 4 meter of stone bunding.

Figure 39. Watershed management being implemented at scale in Bikr, Tigray. The hills are protected with stonebunds and terraces. The riverbed that had dried up was treated with gully plugs that forced the bed level up and enhances more recharge to take place along the course of the river. The grazing areas alongside the river were 'regreened' and it became possible to develop shallow dugwells in the area. The grazing was also controlled with only bullocks allowed to graze on the pasture (as they do the hard work). No animals were allowed into the riverbed (in which grasses in the gully were only allowed to be cut by hand.) The lady in the photo is the community appointed range manager - giving fines to people who let their livestock trespass. (Photo: MetaMeta).

There has been some additional support under the Productivity Safety Net Program and this has brought cash into the local economy. A main lesson from the recent program has been however that the main driving force is the change in land productivity and assured water buffers. Earlier food for work and cash for work programs had a dynamic of their own, whereby the labour opportunities sometimes take precedence over the impact on productive resources.

Table 18. Water recharge/conservation structures implemented in watersheds of Tigray until 2008 (Source: Tigray Bureau of Agriculture and Rural Development, 2011 and EC, 2010)

Type of structures	Unit	Quantity
Percolation pits and ponds	Number	9052
Micro basin	Number	4031663
Large semi-circular structures	Number	31627
Eyebrow basin	Number	532974
Herring bone	Number	190043
Sediment storage dam	m^3	6675
Rockfill dam	m^3	162470
Gabion Check dam	m^3	573775
Stone check dam	m^3	1232015
Cut-off drain	km	26159

Financing mechanisms

The bulk of the work in the soil and water conservation program was undertaken by organized voluntary labour. To this contributions from the so-called Productive Safety Net Programmes were added.

Under the free labour arrangements every able-bodied community member was required to work 40 days in 2009 and 2010 free of any payment. In 2011 this was lowered to 20 days (as it had been prior to 2009). In contrast to the earlier initiatives, this arrangement was very popular as the starting point was local planning and the results were significant. There were norms as to what was to be done in a days work – for instance 5 m of stone bunding. The norm for women was half of that for men. The work was done in the off-season: January and February.

Contributions from the Productive Safety Net Programme were integrated with the soil water conservation programme. Labour provided as part of the PSNP by chronically food insecure people was rewarded by cash or food. Inflation of food prices during the program caused majority of the participants to ask for food instead of cash. Food was further prioritized, as participants experienced traders to raise food prices considerably as soon as cash was transferred to them. This shift was complete the opposite of PSNP intensions to phase out food supply, as it hoped: “that through the provision of cash transfers, the PSNP would enable smallholders increase consumption and investment levels and while stimulating the development of rural markets”.

Implementation

From 2009 to 2011, 568,000 ha were treated under the soil and water conservation programme and, in addition, farmers also invested considerably in their own land improvement (levelling, terracing, soil amelioration) and in some places well development. Besides the regional governmental agencies, major implementation partners are WFP, CARE, REST, SC-UK, CHF, FHI, CRS, WVI and Plan International (Slater et al. 2006). Local planning and implementation, something that was missing in the earlier efforts, has been key to the success of the program . Under the aegis of the regional Bureau of Agriculture and Rural Development (BoARD) a system was set up and capacity was developed, as follows:

- The Tigray Bureau of Agriculture and Rural Development provided training and planning support to the districts (woredas).
- Woredas gave training and support to village clusters (tabias).
- Tabias (in coordination with Woreda representatives) offered training to farmers at sub-catchments. The main activities were carried out at this level.
- Organizations like farmer unions, women associations and youth associations were involved in the planning and implementation of soil and water conservation activities.

Successes and challenges

There are a number of useful lessons from the programme in Tigray. First, as mentioned, is the importance of scale and speediness of implementation – provided of course the right thing is done. Second is the central significance of local planning and local implementation, and the importance to see buffer management as more than the control of soil erosion. Related to this is, third, the value of a decentralized and somehow disorganized process of implementation – there were no formal designs and much of the activities were recorded at the lowest level of administration only, but somehow this worked. Finally, the role of tradition: many new practices were created, improved and implemented. There is sometimes a tendency to see traditions of having to be rooted in a long past, but the Tigray programme shows that traditions can be created in a short interval too.

Also the number of trees increased for households that participated in the program. It could be the case that participation in PSNP (where tree planting and subsequent forest management work on public lands are usual activities) leads to households becoming more skilled in forestry, and that they switch to increased forest planting as a result.

Some challenges remain. One evaluation of the safety net program showed that people remain persistently in these programmes, and that supplementary activities in agricultural development and micro-credit need to be introduced. Also many small scale irrigation activities are promoted – but there is scope to improve on the range of options at the disposal of farmers (such as introducing manual shallow well development) and the quality of design and construction services in public programs.

There remain many opportunities to further improve on the activities implemented, particularly as the watershed program has this considerable momentum and local ownership with techniques unknown such as bio-engineers, cascade check dams and improved spate irrigation.

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Figure 40. Transforming landscape at scale in short time span (Photo: Tigray Bureau of Agriculture and Rural Development).

5.12 Surface water harvesting tanks

Amhara, Ethiopia

Yearly precipitation statistics of 770 mm (Lalibela) and 1.660 mm (Chagni) camouflage the periodic water scarcity experienced in large parts of Amhara National Regional State (ANRS), Ethiopia. More than 85% of the rains arrive during the Meher season from June to October, leaving arable land resources without any further water supply in the remaining months. In order to prolong water availability, over 10.000 rainwater harvesting tanks were constructed in Amhara National Regional State (ANRS). Water stored in these tanks benefit surrounding households, providing water during the entire irrigation season from December until May/June.

Technology

Rainwater harvesting tanks are large pits excavated at central points in the watershed to capture overland flow during intensive rain events. Typically, the tanks have a trapezoidal shape with the top of the tank measuring 10 by 9 metres and the bottom 6 by 6 metres. The depth of the structures is 3 metres and the storage capacity is about 120 m^3. A roof consisting of wooden poles and plastic sheets covers the tank to reduce water losses due to evaporation (see figure box 12).

The walls of the tank are stone masonry and the floor is made of concrete, preventing percolation losses. During the rains, the overland flow is directed to the tank by a V-shape structure placed half

Box 12: SWISHA Project

Over 10,000 water tanks are constructed in Amhara National Regional State (ANRS). Dozens of the rainwater harvesting tanks, such as the one in Mekabia village, were realized with financial support from the CIDA-funded Sustainable Water Harvesting and Institutional Strengthening in Amhara (SWHISA) Project. Technical assistance was provided by a team of international and national consultants from Hydrosult Inc. (Canada) in association with Agrodev (Canada) and Oxfam Canada.

perpendicular to the direction of the slope. Before entering the tank the water is led through a silt trap, preventing excess silt from entering the tank. Once the tank is full, it is closed and the captured water is stored till the start of the dry irrigation season starting December. At the start of the season the water of the rainwater harvesting tank is lifted using a treadle (pedal) pump (figure 41 a). When the water is being lifted to the barrels, enough head (pressure) is created to feed the water into a drip irrigation system situated lower (figure 41 b).

Figure 41. a) The treadle pump used for lifting water from rainwater harvesting tank to the barrels; b) Drip system with two barrels and laterals. (Photos: MetaMeta).

Where it is applied

Mekabia village is part of Yebucher Kebele, and located in Goncha Siso Enesse Wereda, East Gojjam Zone of the Amhara National Regional State. The village comprises of 52 households, providing a living to approximately 208 persons. All households belong to the Amhara ethnic group and they are members of the Ethiopian Orthodox Church. Almost all households depend on a mixed farming system of rainfed crop production and livestock keeping. As most rainfall occurs between June and October, farmers can only grow crops once a year from June to November/December. The major rainfed crops grown in Goncha Siso Enesse Wereda include wheat, teff, beans, maize, lentil, potato, and barely. The cropping season usually starts shortly after the short rainy season in March/April with land preparation. The crops are planted from May until July and harvested between October and December. The yields of rainfed crops are low due to limited use of fertiliser and poor agronomic practices. As the livelihoods of most households is based on subsistence crop farming, they become food insecure in years with less rainfall or long dry spells during the cropping season. The sale of animals, temporary labour migration, and loans are the most common mechanisms to cope with food shortage. Livestock plays a significant role in the livelihoods of the rural households. Oxen are used for land preparation, threshing, and transport. Milk from cows is used for the production of different dairy products, which is either consumed within the household or sold locally. Manure from cattle is often the only source of energy for most households. Sheep, goats and poultry are also raised by most households.

In order to assist the people of Mekabia to broaden their opportunities to grow crops, a rainwater harvesting tank was constructed in the spring of 2007. The tank was constructed just below a hill-top, where three households were located. The estimated size of the "catchment" is not more than a few hectares.

Costs and benefits

The tank allows double cropping by three households of the village by providing water supply during the dry period between December and May/June. It is used to irrigate a total area of 342 m^2. Crops grown are cabbage, onion, beetroot, tomato, and pepper. It is estimated that about 60% of the grown vegetables is used for home consumption. The remaining 40% is sold by the three benefiting households in Gunde Woyne town at a distance of about 5 km from their village. The total annual income from the sale of vegetables is about Ethiopian Birr (ETB) 1,000 (USD 60[33]). Therefore, the estimated value of the harvested vegetables grown with water from the rainwater harvesting tank during the dry season is about ETB 2.500 (USD 150) per year.

The rainwater harvesting tank in Mekabia is built with stone masonry walls and a cement plaster floor. The total cost for this adds up to ETB 31,815 (USD 1,905), whereas the cost of the treadle pump and the drip system are ETB 440 (USD 26) and ETB 2,285 (USD 137) respectively. The construction costs of a rainwater harvesting tank also comprise the labour required to excavate the soil at the tank site, line the walls and the floor, as well as the material required to make the walls and the floor water proof. Materials required to plaster the walls and floor that are available in this area are stone masonry, cement plastering, and plastic sheets (geo-membrane plastic sheets). At the moment, the price of rainwater harvesting tanks finished with stone masonry and cement plastering is far more than tanks that use plastic sheets. Reasons for this difference are that (I) the price of cement has increased from ETB 200-250 per bag (100 kg) to ETB 460 per bag, excluding transport costs which is on average about ETB 100 per bag, (II) the workmanship on the walls and the floor with cement or stone masonry requires more labour than to attach plastics sheets to the tank, and (III) membrane plastic sheets imported from China have been subsidized for several years at 50% of the price. The average construction costs of rainwater harvesting tanks[34] using the aforementioned materials for lining the walls and floor, are presented in table 19.

The storage capacity of these 17 rainwater harvesting tanks is 115 to 130 m^3 and the size of their command area ranges from 300 to 400 m^2. Based on the construction costs and the size of the command area, it is obvious that tanks using geo-membrane plastic sheets for lining of walls and floor - with an average construction cost of ETB 4,843 (USD 290) - is the only option that is financially feasible. Rainwater harvesting tanks made of stone masonry or cement plastering are too costly with average construction costs of ETB 26,097 (USD 1,563) and ETB 23,335 (USD 1,397) respectively.

Table 19. Differentiated construction costs for 3 types of rainwater harvesting tanks in Amhara region

Type of Tank	Life expectancy	Material Costs		Labour Costs		Total Costs	
		ETB	% Total Costs	ETB	% Total Costs	ETB	USD
Stone Masonry	25 years	16,711	64%	9,386	36%	26,097	1,563
Cement Plastering	20 years	10,781	46%	12,554	54%	23,335	1,397
Geo membrane plastic sheet	10 years	767	16%	4,076	84%	4,843	290

33 1 USD = Ethiopian Birr 16,7 (March 2011)

34 The table is based on information of 17 rainwater harvesting tanks in the area of Mekabia and consists of a sample of 6 tanks with stone masonry, 5 tanks with cement plastering, and 6 tanks with geo membrane plastic sheets.

Financing mechanisms

The contribution of the three benefiting households towards the construction costs include the provision of free labour, stones for the walls, as well as Eucalyptus poles and plastic sheets for the roof. The three benefiting households are fully responsible for the operation and maintenance of the rainwater harvesting tank and the installed drip system. The maintenance includes yearly cleaning of the tank by removing silt from the floor of the structure. In order to carry out these tasks successfully and use the rainwater harvesting system optimally, the female and male members of the three benefiting households attended trainings on (I) operation and maintenance of drip systems; (II) cultivation of irrigation crops (i.e. vegetables); (III) scheduling of irrigation; and (IV) raising and transplantation of seedlings.

Implementation

Rainwater harvesting tanks are built at points in the watershed where overland flow during rainfall events is formed and where it can be captured as well as reused. Determination of these locations is most easily done during the rainy season and by close consultation with the residents. Once the place is identified the tanks are excavated by local contractors.

Successes and challenges

The water stored in the rainwater harvesting tank allowed all three families to produce a second cropping. This provided the following benefits to them:

1. An additional annual income of USD 50, allowing them to:
   a. purchase chemical fertilisers for the rainfed crops;
   b. purchase basic food items such as salt and cooking oil; and
   c. improve the condition of their houses.
2. Improved health due to a more diversified diet comprising of more vegetables.

Although the tanks are able to provide these benefits for years, good operation and maintenance are basic requirements to keep their performance high, minimize water losses, and prevent unnecessary risks. Based on experiences gained with the construction of more than tens of thousands rainwater harvesting structures in the Amhara region, the most frequently experienced problems related to the functioning of rainwater harvesting structures and mitigation strategies are presented in table 20.

Table 20. Identified problems and proposed mitigation strategies for optimal and safe use of Rainwater Harvesting Structures

Problem	Mitigation strategy
• Siltation of the structure due to soil erosion	• Treatment of the catchment, including the planting of trees and construction of soil/ stone bunds; to reduce erosion problems • Construction of intake structure with silt trap, to avoid silt entering the rainwater harvesting structure.
• Loss of harvested water through evaporation and percolation • Pollution of harvested water caused by organic matter (i.e. leaves) and dead animals (i.e. rodents)	• Lining the walls and floor of the rainwater harvesting structure in order to reduce water losses caused by percolation. • Construction of roof to prevent water losses due to evaporation and pollution from falling leaves.
• Inefficient utilisation of harvested water at field level	• Use of drip system to improve water use efficiency during the irrigation of the planted crops.
• Accidents with children falling in the structure filled with water	• Construction of a fence around the tank to prevent children from falling in the rainwater harvesting structure

5.13 Buffering highland and spring water

Andes, Peru

The application of high-altitude surface retention dams to adapt to climate change in the Peruvian Andes was introduced in the previous 3R book "Managing the Water Buffer". Over the last two years several new dams and additional open water basins near springs have been constructed in the area. Below, the impacts of these surface retention structures are summarized as documented in the report "Enhancing the sustainable use of natural resources in the Ocoña basin, Peru" by A. Franck et al., 2012). The pilot is part of the ADAPTS project.

Figure 42. a) High altitude storage pond; b) Covered open water basins to buffer spring water (Photos: Acacia Water).

Technology

High altitude dams

Four dams were constructed in the higher altitude regions in Peru under the ADAPTS project. Behind the dams small-scale reservoirs were created to receive water during the wet season. The water stored in these reservoirs is thus at a high altitude and is used at lower altitudes where the higher temperature allows more plant species to grow. Because the amount of precipitation increases with altitude, storing water at higher altitudes - rather than at the point of use - makes it possible to collect more water during the wet season. It is transported via small channels and through existing small river systems.

The dams serve several purposes. The one that is highest in the catchment, at about 4900 m, was built to restore and increase the area of bofedales (high altitude wetlands). These are an important source of food for the lamas and alpacas that are herded at these locations. The small-scale reservoirs recharge the bofedales either by infiltration (and thus increasing the groundwater levels in the valley below), or - if the first option does not work - by bringing the water from the reservoir to the bofedales through small channels, during the dry period.

The other reservoirs are located somewhat lower in the catchment - but still quite high - at about 3900-4300 m. Apart from providing drinking water for cattle, these reservoirs are used as source of agricultural water during the dry period, for fodder irrigation and for irrigation in a reforestation project.

Open water basins near springs

In this area water rights are organized in such a way that farmers get access to water from the springs with large intervals, a system which is based on a long-standing tradition and therefore something that is not very easy to change. To provide water for the periods without water rights, basins were built near the springs or the water distribution channels. These open water ponds are used for irrigation and buffer the amount of irrigation water available. Thus, the natural water supply is rather constant all year round. The water rights system causes a distribution problem, which is solved by the farmers through the retention of irrigation water.

Under the pilot project, two irrigation basins were constructed. Some of the basins were covered with a net to minimize evaporation (figure 42 b). To optimize the water use, the basins were combined with drip or sprinkler irrigation systems (figure 43).

Where is it applied?

In Peru, climate change is regarded as a threat to future water availability, with the glaciers retreating and the amount of precipitation declining. Additionally, the country now faces a pronounced dry season, causing high-altitude agriculture to suffer from water shortage. In the Ocoña river basin in the Andes in the south of Peru, several large glaciers are regarded as important components of the hydrological system. Over the past decennia, Coropuna the glacier at the highest altitude, has already lost 37% of its total volume. Such climate change effects call for urgent action at local and national levels.

High altitude dams

Before construction, the infiltration capacity of the soil was tested. Areas with reasonable infiltration capacity were selected so that the reservoirs behind the dams could serve partly as infiltration ponds and partly as storage ponds. For the dam that was designed to replenish high altitude wetlands, a location was selected where the aquifer recharge would naturally occur some 100 m below the dam. Areas were selected that had a steep enough topography to create a reservoir with a relatively small surface area compared to the depth, so that evaporation losses were minimum.

Open water basins near springs

The basins were located below the spring, but above the irrigated areas, so that the water could be gravitationally transported to the crops.

Costs and benefits

Each high altitude dam costs about USD 36,000 to construct, including transportation and material costs. The basins near the springs were smaller and beneficial to only one farmer family. They were made of earthen walls with plastic cover which comes in two varieties, an expensive one that lasts for about 15 years and a cheaper variant that lasts for 2-3 years. The cost of the cheaper plastic is covered by the resultant increase in yield over one year.

The capacity of the reservoirs in the high part of the catchment ranges from 110,000 - 220,000 m^3. The basins near the springs have a capacity of about 250 - 400 m^3 and can be refilled several times per year with spring water.

Each high altitude reservoir designed for agricultural use can irrigate about 5 hectares. Dams designed for replenishing wetlands are expected to expand the wetlands by a comparable area. Besides, the reservoirs can be used to provide cattle with water. The quality of the cattle is also likely to increase, as it will not have to move long distances in search of fodder and water.

For the open water basins near the springs the increase in irrigated area is about 2 ha due to the combination of basins and improved irrigation systems. The new irrigation system helps fine-tuning the water provision to specific needs of the various crops. A new commercial crop (garlic) is now harvested and other commercial crops such as maize and tomatoes are planned at one of the two irrigation basins constructed under the pilot project. At the second basin, fodder for four extra cows will be produced.

Figure 43. a) Irrigated green fields in the further dry mountain area; b) Sprinkler irrigation (Photos: Acacia Water).

Financing mechanisms

The pilot project has been implemented within the ADAPTS project, as part of 6 pilot projects in different countries. The ADAPTS project aims to enable communities in developing countries to effectively respond to the consequences of climate change in the water sector. The dams and basins were co-financed by the municipalities, which contributed most of the money. The municipality of the local city of Andaray contributed machinery and manpower, while the local NGO, AEDES, provided technical knowledge and shared supervision during the construction phase.

The high altitude dams are currently being constructed and maintained by a municipality of about 300 households. The open water basins are investments made by individual farmers, within the scope of the project and with the support from the local NGO.

Implementation

An important element of ADAPTS lies in the link with institutions at different levels. The project has built relations with the climate change office of the Ministry of Environment. They supported the creation of two Private Conservation Areas managed by the local communities, the municipality, and the regional government of Arequipa. The office is also cooperating in the process of designing a management plan for the sub-basins. A beginning has already been made towards developing such plans for the Chorunga and Arma-Chichas. The approach, of beginning at the sub-basin level in order to create a river basin management plan for the entire Ocoña basin, has interested other influential players and, when effective, might become a model for other Peruvian river basins to follow.

It is expected that these two first projects will be an example to other communities. The application of water retention and irrigation is now taught in a school that also has a pilot field with comparable practices. The pilot projects are not only important for their direct effects on the involved farmers. They also help create enthusiasm among families, communities, and municipalities for engaging in improving current water management systems, both practically in terms of investing in improved systems, and by engaging in developing institutional structures needed to address adaptation issues (like the sub-basin management boards and plans). Some key organizations, such as irrigation and water boards, have crucial roles to play in bringing about the much-needed changes, but they need further strengthening to function better.

Successes and challenges

The pilot project demonstrated that there were direct benefits to be obtained from the irrigation basins. They improved irrigation, doubled the irrigated area and improved crop and livestock production. They hold the potential for further increase in yields when more commercial crops will be applied.

The challenge is to keep up the good results after the basins perish and need new investments. Another challenge is to revise the water rights scheme to optimize the water use. Perhaps the most important challenge is to scale-up and make small-scale solutions as a part of the national resource management strategy.

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5. 14 Rooftop harvesting and multiple water use

Nepal

The Biogas Sector Partnership Nepal (BSP-Nepal) has broad experience in micro-financing biogas projects at household scale in rural areas. Since water is also required for biogas production, they adopted rain water harvesting (RWH) - which involves collecting and storing rooftop water - as part of their adaptation strategy. Currently, biogas plants are combined with rainwater harvesting tanks in areas where other sources of water are not feasible. BSP-Nepal has set up such RWH systems, thus making water available for biogas production, drinking and other small domestic uses, and irrigation in three districts in Nepal, with financial support from the Dutch RAIN Foundation (Rainfoundation.org).

Figure 44. Rainwater storage, Nepal. (Photo: Acacia Water)

Through its previous projects, BSP-Nepal has proven that health oriented interventions like biogas can reach the rural poor using micro-loans. It has installed over 200,000 biogas plants in Nepal, using a combination of micro-finance loans and small subsidies. Currently, this modality is applied to RWH systems, through pilots which started in 2010. This case study describes the results of the pilots for implementation and micro-financing of the RWH systems , summarizing the report "R&D in Rainwater Harvesting: Lessons Learnt regarding Multiple Use" by BSP-Nepal and the paper "Micro-financing Rainwater Harvesting in Nepal: Modality and Challenges" by Dr Indira Shakya, Balaram Shrestha and Charushree Nakarmi.

Technology

Within Nepal, three rural regions were selected for implementing RWH systems. In each of the regions a slightly different combination of techniques was used. In the Salyan district, plastic ponds for micro-irrigation were implemented. In Kavrepalanchowk, clay-cement pond and micro irrigation systems were integrated with existing biogas systems and RWH tanks. In Syangja, fully integrated RWH systems aiming at multiple-use were implemented.

In the project in Salyan, plastic ponds are used to collect the rainwater and excess water from the public water supply. This water is used for irrigation through different micro-irrigation techniques such as sprinklers, piped, and drip irrigation systems. The shape of the ponds is trapezoidal with a surface size of 7.40 m by 3.40 m and a depth of 1.5 m. The capacity of the tanks is 18 m^3. Under this research project 20 plastic ponds integrated with micro-sprinklers have been installed for harvesting rainwater, with the objective to enhance livelihoods of the rural people.

In Kavrepalanchowk, 1 m^3 clay-lined ponds were constructed. These ponds are circular constructions with a top radius of 75 cm, and a depth of 70 cm. They are useful for both waste water collection and rainwater harvesting. The water harvested in the 1 m^3 clay cement lined pond in Kavrepalanchowk is mainly wastewater from the kitchen that has been used for washing vegetables and utensils, and water used for personal use such as washing hands and feet. If these ponds are used for harvesting wastewater from the kitchen, it can be used for irrigating vegetable gardens by using drip systems. If rainwater is harvested, it can be used for domestic purposes.

In the Syangja project, integrated RWH systems aiming at multiple-use were implemented. Here RWH tanks, biogas, toilets, and clay-cement lined ponds with drip systems were combined into one system. BSP-Nepal has constructed stone masonry tanks to meet the household water needs; toilets with attached biogas plants for energy generation, and clay-cement lined water collection ponds integrated with drip irrigation systems for irrigation. This integrated RWH system has been installed at 20 households in the region.

Where is it applied?

Nepal is one of the least developed countries in the world. The majority of its people (86%) live in rural communities and 24.7% of the population lives below the poverty line (Third Living Standard Survey, 2011). It is basically an agricultural country and more than 80% of the economically active workers in Nepal are engaged in agricultural labour. Agriculture is still in its traditional form in large parts of the country, particularly in the hills. The majority of the people living in rural communities are small farmers, tenants and landless poor.

The three regions in which the pilot studies are implemented are located in hilly areas and the middle mountains of Nepal: Kavrepalanchowk is located close to Kathmandu, Syangja is in middle Nepal and Salyan in west Nepal. The area has a monsoon climate. Almost 85 % of the total rainfall in Nepal is generally received within only four months, between June and September. The remaining two-thirds of the year are quite dry across the country. Management of water therefore, plays an important role in the life of the Nepalese people (RAIN Foundation, 2010).

Costs and benefits

The direct costs per 1 m^3 tank were calculated to be around Rs 1500 (USD 17). This estimate is based on the costs of cement, sand, aggregate and skilled labour and excludes community contributions. On including community contributions like unskilled labour, collection of local materials, screening of soil, and other support, the total cost works out to be around Rs. 2100 (USD 25) (BSP-Nepal, 2010). This calculation does not include the cost of transportation of cement from the nearby local market.

A full 10 m^3 closed tank system with drip irrigation requires an investment of about 50.000 - 60.000 Rp (USD 560-680) (RAIN Foundation, 2010 and personal communication I. Shakya, RHCC).

In Syangja, 144 people from 20 households have benefited from the project. The harvested rainwater here is used for drinking, mixing the feed for the biogas plant, in toilets, and for irrigation.

Wastewater from the kitchen, collected in clay-cement lined ponds, is used for irrigation via micro drip systems. The water harvested from the pond in Salyan is mainly used for irrigation, cattle, and washing. In this area a total of 135 beneficiaries responded in the field survey. The water in the 1 m^3 clay cement lined pond in Kavrepalanchowk was primarily used for irrigation. An area of about 250 m^2 per household was irrigated through the micro drip system. Additionally, the owners sometimes carried water in buckets to irrigate their farmlands, extending their irrigated land to up to 500 m^2.

The remaining water in the tank was used by the beneficiaries to feed their cattle. The increase in irrigation potential allowed the beneficiaries to initiate kitchen gardening. They were able to grow sufficient seasonal vegetables during the dry period to fulfil their requirements and could sell the remaining vegetables in the market.

Changes in the crop yield have been observed in the winter time, off-season farming. Table 22 shows this increase in yield for the project area in the Salyan district. According to the beneficiaries the marked change was mainly due to the increase in availability of water for irrigation.

Financing mechanisms

Due to poor infrastructure there is limited access to formal financial services in many of the hilly areas in Nepal. An estimated 17.6 million people in the country lack access to financial services (BSP-Nepal, 2011: NEFSCUN, 2009) and only 39.9% of the population has access to commercial banks (BSP-Nepal, 2011: CBS, 2011). The situation is most alarming in rural areas. Micro-finance institutes are filling this gap by providing financial services. It is estimated that there are already several thousands (>11000) of microfinance institutions all over Nepal. Their increasing presence has also led to a reduction in the interest rate normally charged by private sources of loan. (Shakya et al., 2011).

Table 21: Change in agriculture production in the Salyan project. The change in the cash value due to availability of water for irrigation is shown under 'amount' in Nepalese Rupees (1NPR = USD 0.011), the average per household is about 50 USD (Source: Field survey, 2010).

Crops	Quantity (Kg)			Average rate	Amount
	Before	After	Increase/ Decrease		
Maize	12150	12150	0	50	0
Millet	4050	4050	0	75	0
Potato	675	4050	3375	45	151875
Tomato	140	3375	3235	35	113225
Beans	3375	4000	625	125	78125
Gram	2025	2440	525	150	78750
Mustard	1350	1755	405	120	48600
Paddy	4200	4200	0	25	0
Wheat	5560	6116	556	120	66720
Other vegetables	1620	3240	1620	20	32400
				Total	569695
				Average per household	4220.0

Micro finance is an important component of the projects described in this case. For example, the estimated cost of a 10 m^3 RWH system in remote and rural areas is about 500 euro. A subsidy is already in place amounting to 200 euro (40%); 150 euro (30%) are provided as loan and the remaining 150 euro (30%) are borne by the users in kind and/or cash. The loan has to be repaid within 3 years (RAIN foundation, 2010).

The RAIN Foundation has chosen such a modality because the program intends to reach difficult areas and the poorest of the poor. Besides, this modality has proven beneficial for implementing biogas systems for the same type of beneficiaries. An initial sum is made available by RAIN Foundation as seed money, to create a revolving fund for the RWH loan during the piloting phase. Table 22 summarizes the status of the projects implemented in this pilot project (Shakya et al., 2011).

Implementation

The microfinance and RWH pilot project is coordinated by RAIN's Rainwater Harvesting Capacity Centre (RHCC) at BSP-Nepal. Based on the BSP-Nepal pre-feasibility study of the market for RWH and microfinancing, areas with the most potential (Village Development Committee/District Development Committees) for the promotion of RWH with microfinance have been identified by analyzing key factors (such as degree of drudgery women face while fetching water, magnitude of water scarcity, socio-economic and cultural factors, availability and costs of construction materials, and opportunities for generating economic activities linked to RWH). The RHCC will subsequently

Table 22: Status of the implemented projects under micro financing. The principle loan amount is 15,000 NRs, which is about 165 USD.

Name of MFI	**Sindhupalchowk** *Bhotsipa United Saving and Credit Cooperative Limited*	**Palpa** *Satkond Saving and Credit Cooperative Limited*	**Salyan** *Kupindedaha Saving and Credit Cooperative Limited*
No. of households granted funding	22	42	40
Principal loan amount (NRs.)	15,000	15,000	15,000
Interest rate (%) MFI to users	14	14	14
Loan repayment period	3 years	3 years	3 years
No. of instalments	36	36	36
Monthly instalment	512		
Repayment started / will start in	May 2011	June 2012	July 2012
No. of instalments paid back	12	-	-
Paid back amount per households (interest +principal)	6144	-	-

enter into an agreement with a micro finance institution (Schoemaker, 2010).

Selection of the areas for implementing RWH systems is also based on certain criteria. These are areas where no other water sources are available, the distance to water source is too long, or the water source is contaminated. The RWH systems are installed under direct supervision, monitoring, and follow up by a local partner NGO and BSP-Nepal.

Throughout its whole process the project is conducted with a participatory approach. Women, the poor and disadvantaged groups are directly involved in every process such as project data collection, identification, selection, implementation as well as monitoring the performance of the project.

Based on the outcome of the pilot project a strategy will be developed for further improvement of this modality as well as for up-scaling it within the country. The lessons learnt will be shared with concerned government organizations and the implementing partners.

Successes and challenges

In Nepal micro financing was already successfully implemented to finance biogas systems. Currently, this modality is also implemented for RWH systems. The lessons and the financial infrastructure from the biogas projects are used for the implementation of the RWH and the results look promising. In the current projects donor money is still included so that the projects come within reach of the poor people in Nepal.

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6 Concluding remarks

The image on the front cover - from one of the earliest merchant banks in China – shows a coin with 100 rivers flowing to a well. It symbolizes the profit and security that can emanate from proper storage and having a safe reserve that helps to invest and also to overcome a drought. There is a large range of recharge, retention and reuse measures, as illustrated by the cases in this book and in the earlier 3R publications.

The different cases in the preceding chapters all in their own way show the profit that can be made from storage and the larger security it brings. A common denominator is the systematic planning, selection and design of 3R solutions that provide water buffers at scale within a landscape or sub-basin and give the best value for money.

The financing often comes from land users own investment or from public programs. Yet a variety of new financing mechanism are there too – shared investments, special credit programs and payment for watershed services. Also in some cases water buffering can be the side effect of other actions such as water-sensitive road development. To create more secure buffers it is important to not only promote and explore 3R interventions but also to further develop the mechanism whereby they are supported and sustained financially. Whereas the examples in this book make the business case, we also need more 'environmental business people' and credit lines to make buffer management go to full scale.

Figure 45. 'Hout' infiltration pond in desert area of Kassala (Sudan): this is an example of A2. The desert village of Weger depends on entirely on wells fed from the infiltration pond that is recharged annually with flood water from the Gash river). The wells are seen in the middle of the pond (Photo: Abraham Mehari Haile).

Figure 46. Collecting road runoff in a cistern (Yemen) - the first flush is left out as it is contaminated (Photo: Mohammed Al Abayad)

Annex I Classification overview of 3R techniques

Retention method	Recharge method	Typical measures	Synonyms / comparable measures
A. Groundwater storage	1. Run-off reduction: riverbed infiltration	• River bed modification	• Stream channel modification, maintaining riverbeds
		• Gully plugging	• Small dams or weirs
		• Sand dams	• Subsurface dams, gabions, cascade dams (= multiple sand dams)
		• Recharge dams	• Check dams, (groundwater) retention weirs
	2. Land surface infiltration	• Infiltration ponds	• Recharge basins, percolation ponds, percolation tanks, recharge pit
		• Spate irrigation	• Over-irrigation, flooding, flood irrigation
		• Ditches and drains/ furrows	
		• Uphill reforestation	
	3. Direct aquifer infiltration	• Wells	• Dug well, shallow well, deep well; Aquifer storage and recovery (ASR)-AS-TR
		• Riverbank infiltration	• Induced riverbank infiltration, surface water infiltration systems
B. Soil moisture storage	1. Run-off reduction	• Terracing	
		• Contour bunds	• Contour trenches, barriers, grass strips, planting pits, demi-lunes/semi-circular bunds
		• Controlled drainage	
	2. Land surface infiltration	• Soil improvement	• Riping, deep ploughing, conservative tillage
		• Spate irrigation	• Over-irrigation, flooding, spate irrigation, flood water spreading
	3. Evaporation reduction	• Mulching	

Retention method	Recharge method	Typical measures	Synonyms / comparable measures
C. Closed tank storage	1. Rainwater interception	• Rain gutter and tank	• Rooftop harvesting, tanks (above ground, underground), cisterns, reservoirs
	2. Fog harvesting	• Fog shield and tank	
D. Open water storage	1. In the riverbed	• Check dam	• Dams, check dams (open water), retention structures
	2. Outside the riverbed	• Storage pond	• Reservoir, monkey cheek

Annex II The 2 Step wise approach towards the implementation of 3R techniques

Which 3R technique, or combination of 3R techniques, is most favorable depends on both the physical as socio-economic circumstances. For a Nepalese project a step wise approach is formulated, in which different phases are distinguished to translate the request and the local demands translated into a selection of the most favorable 3R technique(s) and their implementation. Key in the stepwise approach is that both the landscape (figure A2.2a) and the local possibilities and preferences (figure A2.2b) play an important role in the selection of the techniques.

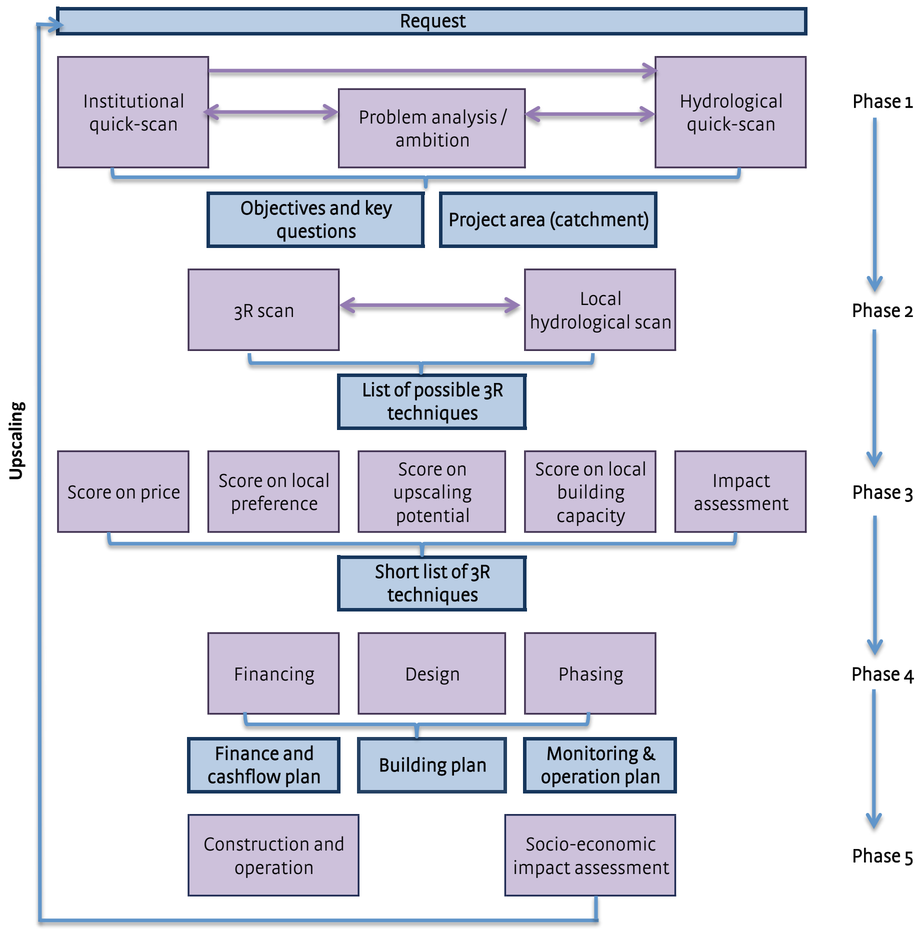

Figure A2.2 Landscape (a) and discussion with villagers (b) in the Salyan district, Nepal (source: Acacia Water)

Annex III Snapshot comparison of the cases on costs and benefits

Table 25. Snapshot comparison of the cases on costs and benefits

#	Cases	Implementation	User benefits			Resilience
		Costs	in-field	on-stream	off stream	drought coverage
1	Sand storage dams Kitui, Kenya	Per dam USD 2500/ year	25 hh, drinking, agricultural, industrial, USD 125/yr/hh	Ground water levels are raised	More food on the market	++
2	Check dams Pasak Ngam, Thailand	Per dam: USD 17 - USD 167	102 hh, cattle, agriculture	Forest products	Recovered forests and biodiversity	+ +
3	Improved karezes Qila Iskan Khan, Pakistan	Improved Kareze: USD 25,000	82 hh, Agriculture, USD 130,000/ yr	Return of people to the rural area from the nearby town	More food on the market	++
4	Water augmentation through managed aquifer recharge Central areas of Namibia	Per m^3 water: USD 2	City Windhoek, drinking and industrial water	Defer costly and env. undesired linkage of rivers	Possible to continue economic development Windhoek	++
5	Creating fresh water bubbles in brackish groundwater Bangladesh	Per infiltration system: USD 7500	250 persons, drinking water			++
6	Freshwater storage in areas with saline groundwater – Tajamares Chaco, Paraguay	Per tajamar: 20,000 euro	60 hh, 400 persons, drinking water 0.10 euro/m^3, cattle and agriculture	Increased secondary production	More food on the market, inreased labour market	++
7	Fresh water conservation with controlled drainage The Netherlands	Per ha : 600 - 4000 euro	Agriculture		Reduce external water request	++

#	Cases	Implementation	User benefits			Resilience
		Costs	in-field	on-stream	off stream	drought coverage
8	Recharge and soil fertility with gully plugs and bunds Terai, India	Per ha: USD 90	Agriculture, 250 USD/yr/ hh	Stabilization of the previously decreasing water table	More food on the market	+
9	Greening semi-arid landscapes –water spreading weirs Sahel reion	Per weir: 18,000 - 55,000 euro	Agriculture, cattle, 40,000 euro per weir/ yr	Rising water tables, fishing availability of fodder	More food on the market, increased natural vegetation	++
10	(Biodegradable) plastic mulches China, India, USA	Per ha: USD 252 - USD 722 + removal plastic mulch USD 250	Agriculture, 50% - 500% increase in crop production		More food on the market	+
11	Soil and water conservation at scale Tigray, Ethiopia				Reforestation	
12	Surface water harvesting tanks, Amhara, Ethiopia	Per tank: USD 290 (10yr) USD 1563 (25yr)	1 hh, agriculture, USD 150/yr		Increase natural vegetation	0
13	Buffering highland and spring water Andes, Peru	Per dam: USD 36,000	5 ha, Agriculture	Greening and cattle feeding near dams	More food on the market, restoration of high altitude wetlands	+
14	Rooftop rainwater harvesting Nepal	Per 1m³ tank USD 25	1 hh, drinking, biofuel, cattle, gardening		Reduced de-forestation after the introduction of biofuel	0

Annex IV Select impacts of Kenya's devastating drought of 2000

Usages	Impact
Drinking water	• Urban drinking water availability decreased – volume of water supplied to Nairobi from storage reservoirs decreased by 55% • Rural water supply – distance to water point increased to 3 km (in the high potential areas) up to 20 km (in the arid and semi-arid lands) • Long water queues and more danger due to longer distance in strange areas. For instance, hyena attacks were reported on people on their way to fetch water • Deterioration of drinking water quality because of over-pumping of boreholes along the coast introduced salt water intrusion; digging of additional shallow wells in urban areas introduced pollution risk from pit latrines; • Animals and people shared the same water source; and effluent from over 2,000 coffee factories in Kenya could not be diluted; sewage oxidation ponds did not work properly due to low flows • Cost of water increased four-fold in both urban and rural areas
Energy production	• Two of five hydroelectric power stations closed • Severe energy rationing, caused companies to close down and induced loss of jobs • It was calculated that the rationing cost USD 2 million in lost opportunity per day
Soil productivity	• Degradation of soil productivity due to drying up of the soil, loss of nutrients, decreased soil cover and increased livestock impact, greater wind erosion and run-off erosion • The destruction of the soil cover caused compaction and fostered the encroachment of undesirable shrub species. Soil compaction, sealing and crusting further impeded the emergence of seedlings
Agriculture	• No harvests in several districts • The national maize harvest is estimated to have dropped by 36% in 2000 wheat production by 50% • The coffee and tea production estimated to drop 30-40%
Forests	• Increased incidences of forest fires as a result of the dry biomass • Slowdown of reforestation programmes • Increase of charcoal burning for commercial purposes, due to lack of alternative livelihoods • Herding livestock- as pastures diminished, livestock keepers turned to the forests in search of fodder. Most gazetted forests were affected

Usages	Impact
Wetlands	• Conversion to arable land; swamps most affected were those that dried up and were used as arable land by farmers • Extensive swamp and river valley cultivation was clearly evident in Embu, Kirinyage, Meru central, Meru South and Murang'a district, especially for vegetable production
Livestock	• Decrease in fodder production – of 60% • Cattle migrated to higher altitudes (e.g. Mt. Kenya, Nyeri) and died from high altitudes diseases like pneumonia. • Large incoming herds carried pests and diseases • In the northern and north eastern part of Kenya, livestock loss between 20 and 85% have been reported • New born animals were slaughtered as a drought-coping mechanism, to enable their mothers to survive • Restocking is estimated to take 5-8 years • Livestock prices decreased by 50-75% due to distress sales • Milk production decreased by 75% • The effects of the drought on milk are exacerbated by the collapse of dairy co-operatives; as marketing has become a problem
Fisheries	• Many streams and dams dried up, wiping out entire populations of fish. In others, the low volume of water has drastically reduced the fish population • Reduced water volumes and increase of water temperature reduced cold water fish such as trout in streams
Economic	• GDP growth rate decreased from 1.4% in 1999 to 0.7% for the same period in 2000 • Month on month inflation rose from 7.6% to 9.8% from August 1999 to August 2000 • The external current account deficit rose from 4.,6% to 7.6% in 2000

Source: UNEP and the Government of Kenya (2000). Devastating Drought in Kenya: Environmental Impacts and responses. United Nations Environment Programme (UNEP), Nairobi, Kenya

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