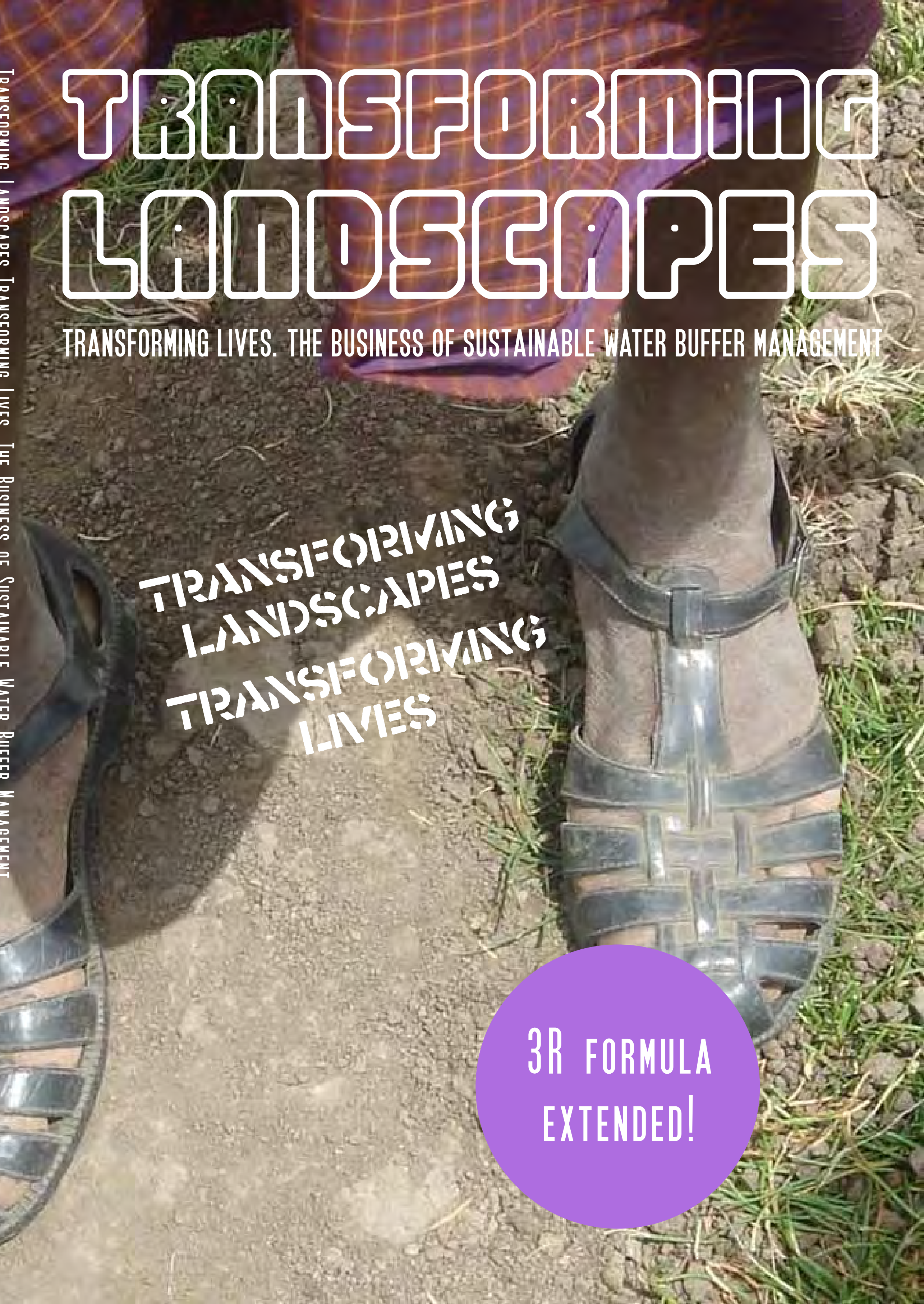
TRANSFORMING LANDSCAPES

TRANSFORMING LIVES. THE BUSINESS OF SUSTAINABLE WATER BUFFER MANAGEMENT



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Foreword

Water is key to food security. We will not achieve global food security without water security. The integrated management of land and water buffers – the theme of this publication – is pivotal here. This book provides three important messages.

The first message is that we need to get to scale. Scale is not the sum total of many small things, but the transformation of landscapes, the soil and water processes underneath, the microclimates, and in fact entire economies. This requires new but tested governance systems and business models – that are based on the quantum benefits that integrated landscape management can bring. We need to get away from isolated interventions and single investments with their single rates of return. We need wholesale change.

The second message is that if we want to manage land and water we should not 'divide and rule' the water, but we should make stronger more resilient buffers and extend the chain of water uses. This must include 'recharge, retention and reuse (3R)', and a better appreciation of the links between land, moisture, groundwater, rivers. There are techniques that work well in some places but are not yet known everywhere or applied in an appropriate way. This book describes several of these. There is large promise here.

The final message is that buffer management should be an intricate part of green growth. The examples in this book make the point of 'more environment, more economy' and also 'more economy, more environment' and this means in the end: improved livelihoods. In a world of growing stress and climate change risks integrated landscape and water management offers jobs, better chances for young people, safer livelihoods, more environmental services and more economic opportunities.

In conclusion we encourage you not to just read this book – but challenge scale issues and apply some of the cases' wisdom and principles in your own domain.

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Transforming Landscapes, Transforming Lives
The Business of Sustainable Water Buffer Management

1. Introduction: transforming landscapes, creating buffers

This book is about sustainable land management, the development of water buffers and the business case underneath it. It is part of the discussion on the green economy: investment in natural resource management makes business sense. This also applies for investment in land, water and vegetative cover. Some of the parameters may be different – returns may not always be immediate – but essentially both the financial payback and the economic dividend of investing in integrated landscapes – if done properly – are rewarding. The social impact moreover is important – investing in sustainable land and water buffers will transform lives and economies. Having a buffer gives a sense of security and the reassurance that come what may one's livelihood is secured.

Box 1: Seeking triple wins

Increasingly the barriers between poverty alleviation, rural development and natural resource management investments are disappearing. This was also the outcome of the recent portfolio review of IFAD, recommending to seek 'triple-win' outcomes through integrating agricultural development with ecosystem management and climate adaptation (Buck et al., 2011). New central concepts in environment and natural resource management programming – recommended by the review – are integrated landscape management and working at scale – underpinned with innovative financing, from insurances to payment for ecosystem services. Within each specific area integrated landscape management will help maintain or restore ecosystem services, optimize returns from sustainable agriculture and help improve the livelihoods of those dependent on the landscape. Landscape management is to be supported by institutions for local planning and negotiation, public policies, market mechanisms and norms and values.

The main message is that 'large-scale environmental degradation is not necessary and can be reversed.'[1] The GLADIS survey by FAO and ISRIC (Bai et al., 2008) established that land degradation was still on the increase in the period 1991-2008 – it now concerns almost a quarter of the global land area. The important message, however, 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%). Several examples in this book are testimony of this. The reversal from degradation to sustainable production has in some cases been very rapid – a matter of years. This change, moreover, has happened where population pressure has increased – in fact it often seems to go hand in hand. There are many examples of 'more people, more trees, more

1 See also Liu, J. (2010)

Box 2: 3R: Recharge, Retention and Reuse

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 in 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 can be the welcome by-product of, for instance, inefficient irrigation or leakage in water systems.

Retention

Retention slows down the lateral flow of groundwater. This helps pond up groundwater and creates large 'wet' buffers. In such conditions it is easier to retrieve and circulate water. Retention hence makes it possible to extent the chain of water uses. With retention the groundwater table is also heightened. Slowing down or even controlling lateral outflow of the water table affects soil moisture and soil chemistry: this can have a large impact on agricultural productivity.

Reuse

Reuse is the third element in buffer management. The large challenge of 3R is to make water revolve as much as possible. Scarcity is not only resolved 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. Rather, where possible, one should try the opposite and capture air moisture, such as dew. 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 in the chain of uses.

livestock, more water, better lives and better economies' [2] (see also Critchley, W. 2010).

What is important is to start the process of reversal everywhere and ensure better storage of water in the landscape; as shallow groundwater, as soil moisture or in local surface reservoirs. A central concept is 3R: recharge, retention and reuse. Recharge adds water to the buffer; retention slows down the outflow and increases water tables; and reuse takes care of the recirculation of water in the system (Box 2). The larger idea is that tackling a local water crisis is not so much about allocating scarce water, but to extend the chain of water use and reuse as much as possible within a basin, taking into account all people and the environment across the entire basin.

Landscape management is very important in all of this and buffer management and landscape management are intimately linked. It is key in optimizing recharge both from natural processes and special measures, from dotting the landscape with planting pits (terraces, bunds and infiltration trenches) to making use of natural landscape elements (depressions, wetlands, levees and ridges)

2 See also Critchley, W. (2010)

to slow down and guide water to areas of high recharge. Landscape management also effects retention: avoiding or closing gullies and deep drains enables water to remain in the landscape and soil moisture is pulled down. Landscape management is key in creating large wet buffers – areas where water that is 'lost' through infiltration is easily retrieved and reused.

This book contains a series of cases of large-scale landscape transformation – often with a considerable component of innovation. Several cases show that sustainable buffer management can be done at scale – be it the development of agro-forestry in Niger; the soil and water conservation programme in Tigray, Ethiopia; the 'monkey-cheek' (retention) programme in Thailand or the rehabilitation of the Loess Plateau in China. All these interventions cover huge areas – in excess of 500,000 ha. The scale argument can be taken a step further. In many areas buffer management should be done at scale. What is important is the entire transformation of landscapes: not piecemeal interventions that do not add up. If landscapes are transformed at scale, many processes change with it: the hydrology, the sedimentation processes, the micro-climates, the soil chemistry and nutrient cycle and the regeneration of vegetation cover. Also by working at scale, side effects – either locally or downstream – can be better managed. Most importantly with scale comes the transformation of lives and economies.

This publication consists of several chapters. It first discusses landscape management processes at scale – what to do where and how; how water buffer management and sediment go together (Chapter 2). Chapter 3 then presents a number of cases. These cases are chosen for the scale they achieved and/or for the innovation they contain. They suggest that there are many opportunities for promoting integrated landscape and buffer management, and the need to have a business approach – to see it as part of 'green growth' rather than as 'welfare economics'. This requires good choices so as to optimize costs and benefits as well as widening the range of business models in buffer management and 3R. This is discussed respectively in Chapters 4 and 5. In many areas impressive strides have been made in creating resilience against climate variability and at the same contributing the food security and growth – but there are also many unutilized opportunities, some in the world's poorest areas. Ultimately, this publication aims to move the discussion forward on how to implement triple win integrated landscape approaches and create the funding mechanisms for them.

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2. Knowing what to do where and how

In integrated landscape management and buffer management at scale it is important to know what to do where: where sediment is moved or retained and new soils build up; where water infiltrates and what land cover and land management support this; how shallow groundwater travels, how it feed rivers and is fed by it, how it links to soil moisture and how soil moisture management interacts with micro-climate. These links are multi-faceted and specific to each landscape – the climate (arid or humid), the hydrogeology (impermeable surfaces or infiltration zones, presence of shallow or deep aquifers, and interaction with rivers), slope and soil condition (erodible, deep or shallow, and infiltration capacity) and the economics of the area (agriculture, pastoralist, forest, nature, urban, and hydropower). Though many links are well-understood, there are no standard prescriptions.

Buffer management at scale also has a strong interaction with land use planning, including the planning of built up areas and roads. Roads, for instance, when they are placed on embankments greatly affect surface run-off and hence infiltration. A lesson from several of the spectacular landscape transformations described in this book is the importance of strong local leadership: self-organized movement, local planning processes, facilitative role of local government and reliance on farmers as innovators and educators, success be getting success, scale leading to transformation. In knowing what to do where, four landscape management processes are particularly important:

1. Water recharge, retention and reuse (3R);
2. Sedimentation;
3. Vegetation and land use;
4. Micro-climate.

Recharge – the first step in 3R – is an important element in buffer management – where and where not to have rainfall infiltrate, and how to optimize this recharge process. In very arid areas for instance hard impermeable surfaces where no rainfall infiltrates, help to concentrate overland flow to a few oasis-like areas that can sustain life. The cases from Iran and Turkmenistan in this book are examples of this. Infiltration is the process by which water on the ground surface enters the soil. Infiltration rate is the rate at which soil is able to absorb rainfall or irrigation. It is measured in millimetres per hour. The rate decreases as the soil becomes saturated. If the precipitation rate exceeds the infiltration rate, run-off will usually occur unless there is some physical barrier. It is related to the saturated hydraulic conductivity of the near-surface soil – the capacity of the soil to convey water. Some water that infiltrates will remain in the shallow soil layer, as so-called ‘green water’ and some will gradually move vertically and horizontally through the soil and subsurface material. Eventually it may enter a river stream by seepage into the stream bank, creating dependable ‘base flows’. Some of the water may infiltrate deeper, recharging groundwater aquifers. If the aquifers are porous enough to allow water to move freely through it, people can drill wells into the aquifer and use the water for their purposes. Water may travel long distances or remain in groundwater storage for long periods before returning to the surface or seeping into other water bodies, such as streams and oceans.

There are a number of factors that affect the recharge rate and, to an important extent, this is a function of the landscape. Anywhere in the world, a portion of the water that falls as rain and snow infiltrates into the subsurface soil and rock. How much infiltrates depends greatly on a number of factors: the nature of the rainfall or precipitation; the saturation of the soil; the nature of the soil; and the characteristics of the landscape and so-called artificial recharge measures (Table 1). The type of land cover has an important influence – with forests and grassland taking care of high infiltration levels and built up areas causing mainly run-off (Figure 1).

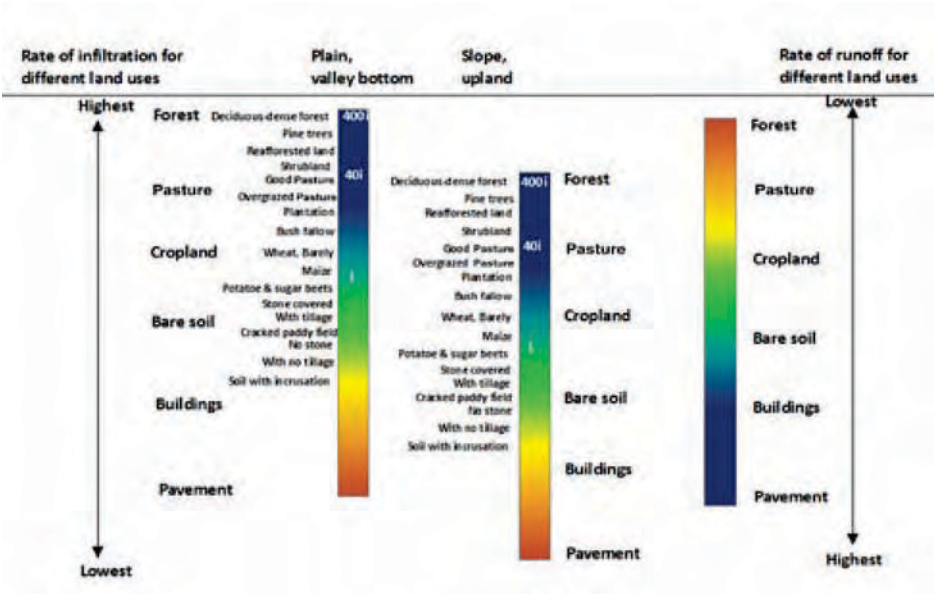

Figure 1: Generic summary of infiltration rate and run-off rates for different types of landuses. Infiltration rate for different slope properties is also shown (i, 40i and 400i-refers to the scale of infiltration between different land use types).

A second important process is sedimentation. The discussion on soil conservation has long been dominated by concerns on erosion. This is justified – erosion removes nutrients in a wholesale manner and rutting and gullying both at landscape level and at field level depletes soil moisture. A special manifestation is the man-made removal of sands and gravel from local river beds – in particular close to urban areas where this is used as building material. This mining of river sand and gravel can destruct the ability of rivers to buffer floods and has resulted in the depletion of groundwater in adjacent wells (Figure 2).

There is another side to sedimentation processes. Sediment is not necessarily always a hazard but it can be an asset as well. It helps build up or renew soils – creating new land and plugging gullies and depressions. So-called 'warping' (see Chapter 3 on the Loess Plateau in China) has been used in many parts of the world to trap sediment for beneficial use. Sometimes sediments are systematically sold – for instance soil used as the foundations for housing or transported to barren lands. Landscape management is important here – some sediments are more useful than others. Farmers in spate irrigated areas sometimes close the inflow of silt-laden water as the sediment in it is coarse and would spoil the land fertility, whereas the sediment from other areas is used to build up or rejuvenate farmland.

Table 1: A quick guide: What determines infiltration at landscape level?

Infiltration affecting parameter	Process/mechanism of infiltration control
Rainfall properties-and soil hydrology	
Rainfall duration	Infiltration capacity rapidly declines during the early part of a storm and then tends towards an approximate constant value after a couple of hours for the remainder of the event.
Rainfall intensity	Intense rains produce more floodwater than infiltration.
Soil moisture content (initial-antecedent condition)	Like a wet sponge, soil already saturated from previous rainfall can not absorb much more, thus more rainfall will become surface run-off.
Evapo-transpiration	Some infiltration stays near the land surface, which is where plants put down their roots. Plants need this shallow groundwater to grow, and, by the process of evapotranspiration, water is moved back into the atmosphere
Soil profile properties	
Soil texture	Water infiltrates more easily through the larger pores of a sandy soil (higher infiltration capacity) than, for example, through the smaller pores of a clay soil (lower infiltration capacity). Soil swelling most strongly affects the rate of infiltration. When cracked, swelling soil mixtures are flooded with water that is rich in clay particles, the swelling gradually closes the fissures, healing the fractured plough pan.
Soil structure	Soil structure refers to the way the individual mineral particles stick together to form lumps or aggregates. A soil with large cracks has a high infiltration rate. The rain drops hit the surface with considerable force which causes a breakdown of the soil aggregates and drives the fine soil particles into the upper soil pores. This results in clogging of the pores and the formation of a thin but dense and compacted layer on top of the soil, which greatly reduces the infiltration rate. Soil crusting decreases infiltration, increases erosion, and impedes vegetation establishment. Crusting is greater in exposed soils than soils under vegetation. Greater crusting in exposed soil is attributed to lower soluble salt and labile carbon (C) contents and an associated increase in the dispersion of clay. Greater crusting of soils from burnt plots can be ascribed to a reduction in soil carbon and soluble salts as well as a greater exchangeable sodium percentage.
Artificially induced soil properties Tillage induced soil pore structure (tillage method)	Overall, soil pore systems under conventional tillage (ploughing to the depth of 20 cm) result in a higher contribution of large flow-active pores compared to reduced and no tillage treatments, enhancing infiltration and water storage capacity.
Earthworms, termites, sowbugs, earth burrowing organisms	By increasing soil macro-porosity and creating transport pathways of preferential flow, earthworms, termites, sowbugs and earth burrowing organisms increase the rate of water retention and infiltration.

Landscape properties and landscape position and associated soil properties	
Land use land cover type	As shown in Figure 1, generally the infiltration rate varies from highest to lowest according to the following order (given all other parameters are constant): forest cover>pasture>cropland>bare land>bare soil>buildings>pavement. Impervious surfaces, such as parking lots, roads and developments act as a 'fast lane' for rainfall - right into storm drains that drain directly into streams. A dense vegetation cover protects the soil from the raindrop impact, reduces sealing of the soil and increases the infiltration rate. Both the root system and the organic matter in the soil increases the porosity and hence the infiltration capacity of the soil. Forested catchments normally have a higher infiltration rate. Fields growing potatoes and sugar beets are the most sensitive to surface run-off, especially the compacted parts (tracks). Surface run-off also occurs occasionally on maize fields. Wheat appears to enhance infiltration capacities by creating cracks (preferential flow paths) around the roots. Stones on the surface of the soil enhance infiltration and protect the soil against erosion. Surface stones retarded surface run-off, increased final infiltration rates, and diminished sediment concentration and soil loss.
Landscape position	Upland and side slope soils have consistently lower infiltration rates compared to the soil in the valley bottom; excess water over infiltration derives run-off in uplands and slopes, excess water over field capacity of sol derives run-off in lowlands.
Slope characteristics (slope angle, slope length)	Water falling on steeply-sloped land runs off more quickly and infiltrates less than water falling on flat land. With increasing slope length the time it takes for a drop of water to reach the cultivated area increases, which means that the drop of water is exposed for a longer amount of time to the effects of infiltration and evaporation.
Fracture properties	Increased fracture aperture and flooded water depth temporarily increases the rate of infiltration.
Artificial recharge (infiltration) rates	
Artificial recharge rate	A range of measures exist to 'harvest water' and increase infiltration, from on-site measures – such as terraces, contour bunds, recharge wells or infiltration trenches, to measures at village or landscape level – infiltration trenches, water spreading, spate irrigation, injection wells and dune infiltration. There is a large variety of meausures – Chapter 3 showcases some of these.
Agronomic and pastoralist practices	Agronomic measures strongly affect infiltration: ploughing or animal trampling can open compact soil surfaces; planting pits and grass strips can intercept run-off; and mulching retains moisture.
Cyanobacteria	Cyanobacterial mats, which develop on the surface of groundwater recharge basins tend to reduce the rate of effluent infiltration into the ground. This organism is capable of rapid gliding, forming raft-like structures, producing an extracellular sheath, and secreting copious amounts of mucus with remarkable clogging capacity.

(This table is based on references, see reference list)

Figure 2: Only hard rock left after uncontrolled river sand mining in Kitui (Kenya) - destroyed the capacity to absorb and buffer flood water

Vegetation is an important third factor in landscape management – and one that is often relatively easily influenced by reforestation, agricultural land development or rangeland management. The assumption is often that forests contribute a lot to increased recharge (Figure 1), regulating flows and reducing erosion. This is true in many cases – but it is also dependent on the location. In arid and semi-arid landscapes the increased recharge may be offset by the higher water consumption from the trees – creating a negative effect (Hayward, 2005). There are a lot of factors at play. Planting trees in degraded tropical areas usually improves soil biodiversity, which improves soil structures. This helps to mitigate overland run-off, reduce flood peaks and increase infiltration, especially on steep slopes. In turn this reduces gully formation and so improves the ability to retain water and moisture. The abstraction of subsurface water by trees and rooting systems reduces the risk of landslides, especially in vulnerable areas. Water consumption by trees is also dependent on several factors. Young eucalyptus plantations for instance consume much water but this tapers off as forests mature. When deep aquifers are available more water can percolate and the difference between trees and shallow rooted vegetation is much less. Scale is also important. Different from small areas, large-scale forestation creates 'climate feedbacks' – and generates more rainfall. This effect is also dependent on the heterogeneity of the land cover (Chapell and Bonell, 2006).

The final element to take into account is the management of micro-climates. In today's discussion on global climate change the importance of micro-climates and the scope for improvements is often forgotten. Yet in most localities the micro-climate is as important as the larger climate. There is a strong link between local land and water management and micro-climates. Windbreaks affect the evaporative effect of wind and help retain soil moisture – which in turn affects soil chemistry (Box 3). Mulching reduces water loss from soil evaporation and also regulates the soil temperature. In some areas the use of stones increases the capture of dew complementing scarce rainfall. In other areas wind is channeled to regulate temperature or avoid too much moisture (Figure 3).

Box 3: Getting the soil chemics to work

The amount of water in the soil is closely connected to groundwater levels. Soil moisture in turn influences the chemical processes in the soil. These chemical processes are important for crop growth. Particularly nitrogen-fixation depends on water availability in the soil. There are several ways by which nitrogen is fixed for plant availability from the plant unavailable N_2 in the atmosphere. One route is through soil bacteria – such as *rhizobia*. These soil bacteria form nodules on the roots of legumes. When sufficient soil moisture is available, the bacteria can fix large quantities of nitrogen. Soil moisture also directly influences the growth of the *rhizobia* bacteria itself. Another route to nitrogen fixation is from bacteria that live inside the vascular system of the plant, called *endophyte* bacteria, such as the *azospirillum* species. These endophytes convert nitrogen gas from the sap flow into amines and ammonium nitrogen for plant use. Both types of N-fixing bacteria use energy provided by plant carbon to fix the nitrogen. Because of this mechanism the plant can regulate the amount of nitrogen that needs to be fixed. When limited soil moisture is available for plant use, the plant supplies less carbon to the bacteria, which fix less nitrogen in response. When the soil moisture conditions are optimum, the plant supplies increasing amounts of carbon, resulting in an increased amount of fixed nitrogen. This feedback system works better than supplying fertilizer at the beginning of the season, when an over- or under-supply of nitrogen can lead to smaller production. In temperate areas blue-green algae take care of nitrogen fixations. Their activity is again dependent on moisture and soil characteristics – particularly in clay and calcareous soil nitrogen fixation by blue-green algae is intense.

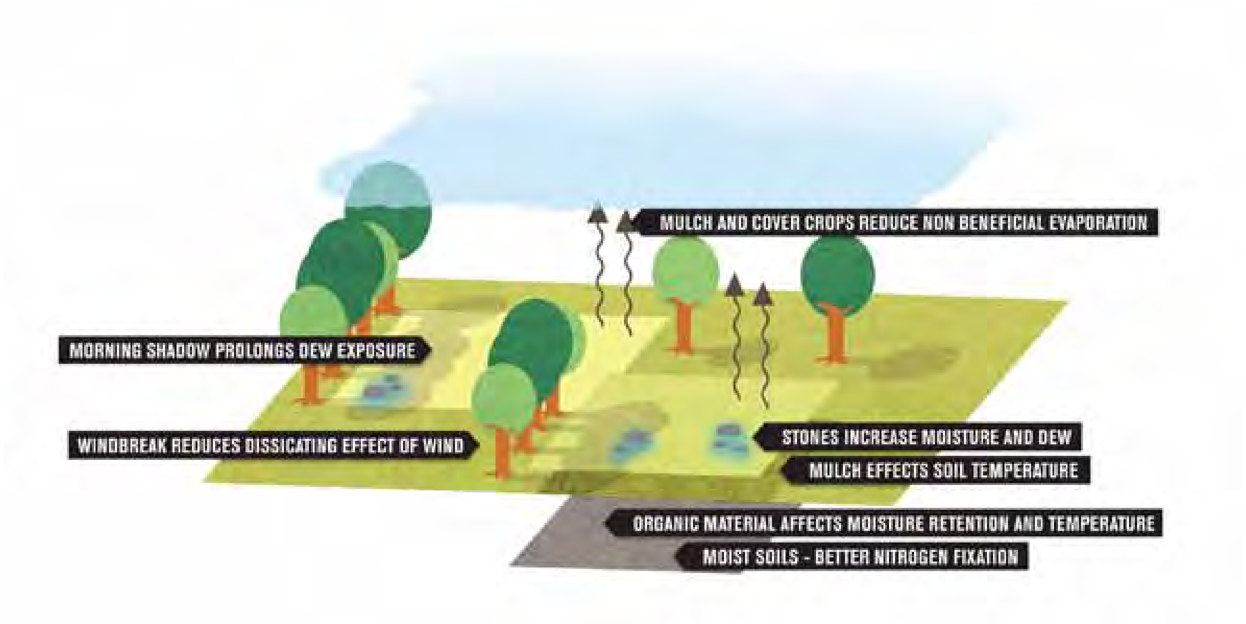

Figure 3: Factors in managing the micro climate

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3. Cases

This book is a sequel to 'Managing the Water Buffer for Development and Climate Change Adaptation' (van Steenbergen and Tuinhof, 2009). In keeping with the preceding publication, this book presents a large number of cases of sustainable buffer management. The locations vary from arid to humid environments. The cases cover pastoralist, agro-forestry and farming systems. The infographics present both the techniques in this book and the preceding volume (Figure 4 and 5).

Table 2: Cases categorized by techniques and their main effects

#	Cases	Recharge	Retention	Reuse	Erosion Control	Soil harvesting	Micro cimate
1	Re-greening - improved indigenous soil and moisture conservation Niger and Burkina Faso	√				√	√
2	Soil and water conservation at scale Tigray, Ethiopia	√		√	√	√	√
3	Water retention through 'monkey cheeks' Thailand		√	√			
4	Harvesting sediment with warping dams Loess Plateau China		√		√	√	
5	Flood water spreading Iran	√				√	
6	Using natural landscapes Turkmenistan	√	√	√			
7	Fanya juu terracing Tanzania and Kenya	√	√		√		
8	Maximizing recharge Cascade Check Dams Yemen	√	√	√			
9	Groundwater retention weirs Maharastra, India	√	√	√			
10	Controlled intensive grazing Savannah Grasslands, Africa	√	√				
11	Shallow tubewells in flood plains Africa			√			
12	Plastic mulches, biodegradeable alternatives China and US		√				√

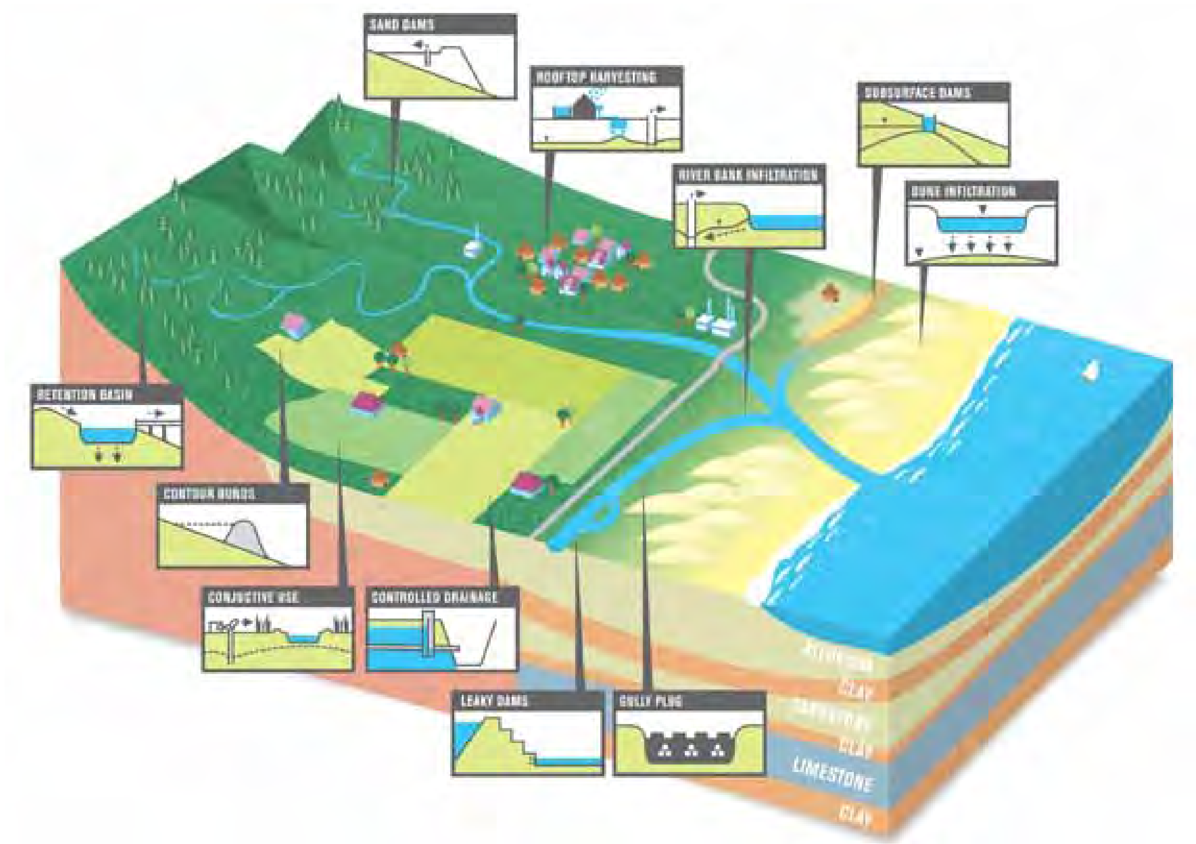

Figure 3: Buffer management in the landscape (Van Steenbergen and Tuinhof, 2009)

The variety of cases suggests that that there is much scope for better land and water buffer management in many different places. Innovations common in one place are not yet common elsewhere – be it the use of 'biological engineers' (Iran), the use of retention weirs (India), widespread mulching (China) or using storage ponds along irrigation systems (Thailand). The different cases can be classified according to the 3R techniques used and the effect on erosion control, soil harvesting and the management of the micro-climate (Table 2).

Several cases concern landscape transformations at scale that have taken place in the very recent past. They are proof that environmental degradation is not inevitable, and can be reversed given the right circumstances, leadership and initiative. The cases describe the planning and implementation process, the techniques used and the cost and benefits involved – in the hope that more is mainstreamed. For several cases so-called QR codes are added that, when scanned, provide access to video links on the cases concerned.

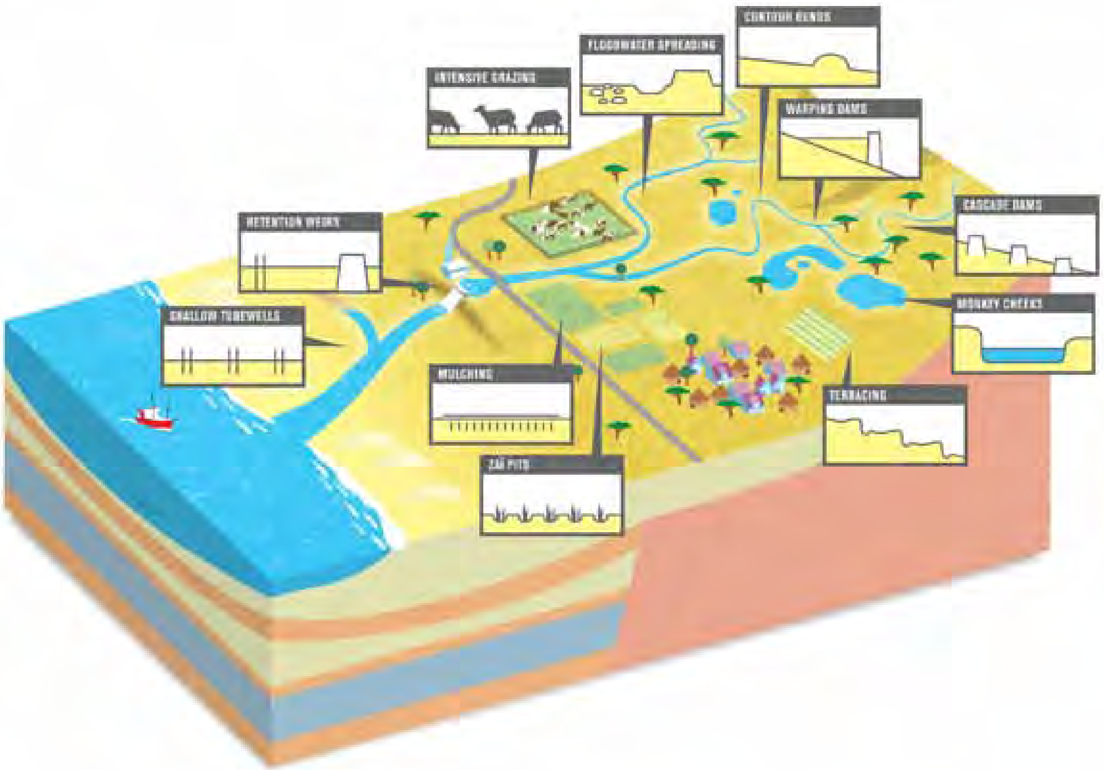

Figure 4: Buffer management in the landscape (this book)

Reference

Van Steenbergen, F. and Tuinhof, A. 2009. Managing the water buffer for development and climate change adaptation. Wageningen, The Netherlands: 3R Water Secretariat.

3.1. Re-greening – improved indigenous soil and moisture conservation

Niger and Burkina Faso

Introduction

For many years the Sahel has remained a by-word for resource degradation and destitution. In the devastating drought of 1969-1973 many lives were lost and livelihoods were destroyed: trees and livestock died, water levels dropped, yields for staple crops such as sorghum and millet declined, and sand dunes expanded at desert fringes. Areas with high population pressure – such as Niger and Burkina Faso – were particularly hard-hit.

From the 1980's onwards however the Sahel has also been the scene of a transformation. Sahelian farmers themselves have steadily turned some of the world's most arid lands into productive farmland – aided by a period of reasonable rainfall. In Burkina Faso and Niger farmers applied traditional systems of agroforestry, water harvesting and soil management, which were modified to suit the changing circumstances implemented to scale. In Burkina Faso an estimated 200,000 to 300,000 hectares were re-invigorated by farmers developing *zaï* planting pits and stone bunds – yielding an extra 80,000 tons of food annually – enough to feed 500,000 people. In Niger 5 million ha were rehabilitated with improved agroforestry systems – making use of the dormant root systems. This has added an estimated 20% to the income of 4 million people.

The scale at which these changes emerged and the process of innovation and adaptation dispels the notion that prospects for arid, land-locked areas are small and that investing in them does not pay. In this regard, the experiences in Niger and Burkina Faso have been the basis for Africa Regreening Initiatives elsewhere in the continent. Building on this farmer-led transformation the idea of a 'Green Wall for the Sahara' was proposed by former Nigerian President Olusegun Obasanjo and presented to the Community of Sahel-Saharan States and the African Union. The Action Plan adopted by the African Union – European Union includes a priority to cooperate to 'address land degradation and increasing aridity, including the "Green Wall for the Sahara Initiative"' as part of regreening the Sahel.

Techniques

The techniques used in the regreening of the Sahel were not new – but they were improved upon and modified to suit current challenges. Most of the experimentation and dissemination was farmer-led. An icon personality for instance is a Burkinabe farmer called Yacouba Sawadogo who began organising farm visits and semi-annual market days to promote planting pits. Yacouba also operates a seed exchange. Farmers brought samples of the crop varieties they cultivated in their zaï,

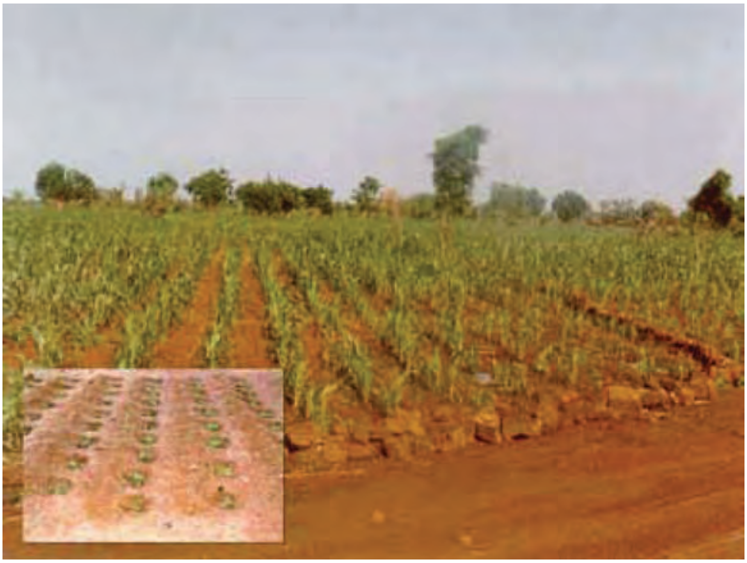

Figure 1: Zaï pits, Burkina Faso

deposited the seeds with Yacouba and then, following his advice, selected the seeds they wanted to plant that season. In the words of a leading soil scientist: 'Yacouba had more impact than all soil and water researchers combined'. Another example is the farmer starting a zaï school – training fellow farmers in the zaï technique on a gravelly area next to the road. This grew to a network of 20 schools with 1000 members – each group charged with improving its own piece of degradated land. The process was also supported by governments and NGOs. For the development of specific compost, pit training sites were established that included, for instance, a hectare of cultivated land as an example to encourage trainees. Depending on the extent of the support programme, the trainees would then be able to take home compost and build and apply it to their own pilot plots. Particularly in Burkina Faso, women's groups became an explicit feature of the widely accepted development of zaï compost farming.

Earlier large-scale projects set up shortly after the drought emergencies had misfired – as they failed to engage the land users.

Zaï

Zaï planting pits consist of 'mini-basins' that store rainwater for plant growth and concentrate crop nutrients. Planting pits are excavated in grids. Planting pits of around 20 cm in diameter and 10-15 cm in depth may amount to 10,000-15,000 pits per hectare. Their dimension and density vary from area to area – depending on the crop grown, the soil conditions (they do not do well on hydroscopic soils for instance) and the need to harvest water. Larger pits and more spacing between them allow more water to be harvested.

The innovation developed through farmers experiments in Burkina Faso was to increase the depth and diameter of the pits and to add manure to them. Once excavated, the pits capture other material – for instance wind-blown soil and leaves. Termites are attracted to the organic material in the pits. They form an army of 'soil engineers'; digging small tunnels that improve the soil structure and cause water infiltration to double, convert organic material – and make nutrients available to the plant roots. The pits with the organic material will retain water in dry spells, allowing crops to survive. Sorghum is the preferred crop because of its adaptation to temporary inundation that may occur in the planting pit. Zaï are well combined with stone contour bunds. These reduce the speed of runoff and allow even more retention of water and soil.

Stone contour bunds

Stone contour bunds had also been in use in Burkina Faso traditionally, but the challenge was always to follow the contour lines, especially where the landscape is flat. Following the introduction of a low-cost water spirit for measuring land levels it became much easier to determine the correct alignment of stone bunds. Mastering the skill of using the level did not take more than two days. The better aligned stone bunds allowed runoff to spread effectively and evenly through the field and trickle through the small opening between the stones. The practice improved soil condition by trapping sediments and organic matter within the plots thus preventing it from washing away with the rain.

Modified traditional agroforestry

At the same time in Niger farmers developed innovative ways of regenerating and multiplying valuable trees whose roots have been lying dormant underneath their land. Based on their experience in managing local woodlands, farmers starting experimenting with a process which became known as Farmer Managed Natural Regeneration (FMNR). Among the mature root systems in the field farmers would choose tree stumps based on the usefulness of the species. The tallest and straightest stems would then be selected, nurtured and protected. At the same time other

Figure 2: Stone bunds with Sorghum, Burkina Faso

stems would be removed. To further promote their growth and production the selected stems would be pruned whilst continuously other stems would be removed. The removal of stems enabled the growth of other crops between and around trees creating an ingeniously modified agroforestry system.
The trees generated a number of important benefits: (a) they improved the local micro-climate by reducing wind speeds and evaporation – thus reducing the impact of drought and heat; (b) they provided fodder for livestock (enough for half of the year); and (c) they provided fruits, firewood and medicinal products. Some species also added nitrogen to the soil.

Costs and benefits

The benefits in terms of food security and farm productivity have been substantial. They explain the speed with which innovations have spread from farmer to farmer. Most of the improvements are done by farm labour in the off-season. Though these labour inputs are substantial, there are no opportunity cost for them. This was in itself an innovation – as traditionally work on zais was unheard off in the dry season.

Zaï and contour bunds

Establishing zaï structures at the beginning of the dry season consists of two main activities, namely digging the pits and covering the bottom of each pit with a 3 cm clay layer. Zaï pits or (planting pits[1]) come in different sizes and densities (pits / ha), and therefore the amount of labour and costs also vary. Where zaï is combined with stone contour bunds, the bunds also need to be constructed. Below are typical ranges of costs for the establishment and maintenance – including the replenishment of manure – of the pits and bunds.

Without these measures productivity is extremely low: 80 kg of sorghum/ha. Zaï and stone bunds can raise yields to 300 to 400 kg/ha in a year of low rainfall to up to 1500 kg/ha in a good year. Experiments show that it is particularly the concentration of nutrients that makes the difference.

Further spin-offs of the new zaï systems include the development of market for manure. Herders have started to systematically collect the manure after harvesting for sale since an increase in demand has led to a doubling of the price.

1 Known as *tassa* in Niger

Table 1: Establishment costs and recurrent inputs for Zai and contour bunds

Zaï and contour bunds: establishment input and costs per ha	
Input	**Cost (USD)**
Labour • 2-150 person days for pits • 25 person days for stone bunds	27-175
Equipment and tools • hoe, knife, digging stick bucket, lorry	50
Materials • clay (0.5 m^3)	0
Total	77-175

Table 2: Recurrent inputs for Zai and contour bunds

Zaï and contour bunds: recurrent inputs and costs per ha per year	
Input	**Cost (USD)**
Labour • 20 person days for the manure • 1 person day for the stone bunds	21
Equipment and tools • Wheel barrow rental	6
Materials • ash and wet straw	0
Agriculture • manure (100kg)	2
Compost transportation	2
Total	**30**

Agroforesty

The costs of implementing the innovative agroforestry system mainly concerns individual labour and relates to the time spent on stemming, pruning and cutting the trees. The benefits are considerable. In Niger in the past 20 years over 250,000 ha/year have been replanted in Niger, adding up to 5 million ha. At an average of 40 trees/ha this implies a total of 200 million new trees. The trees generate a range of benefits, which include reducing wind speed and evaporation, and producing at least a six-month supply of fodder for livestock, firewood, fruit, and medicinal products that farm households can consume or sell. Certain tree species (*Faidherbia Albida* for instance) also enhance fertility by adding nitrogen to the soil. If each tree produces an average annual value of USD 1.2 (firewood, fodder, fruits, medicinal products, improved soil fertility, increased crop yields, etc.) this means an annual production value of USD 240 million. This does not yet include the value of the timber or the carbon sequestered by the standing tree stock. If 4 million individuals are involved in re-greening, this means an increase of USD 60 to the average annual income per capita, whereas average annual per capita income in Niger is currently in the order of USD 280.

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3.2. Soil and water conservation at scale

Tigray, Ethiopia

Introduction

Land degradation has been a main factor in food insecurity in much of Ethiopia – in particular in the highlands, which are densely populated and intensively cultivated. Tigray region, in northern Ethiopia, was a notorious area of food insecurity and parts of it are remembered for the horrifying images of the 1984 famine.

Tigray has a population of 4.4 million and a land area of 5.3 million ha. Twenty percent is cultivated and, nowadays, almost all of it by small holdings. In the varied topography, rainfall averages differ: in the highland areas (between 1500 m and 2300 m) it is close to 900 mm; in the lowlands it varies from 500 mm (in the eastern part) to 1200 mm (in the western part). Besides the rainfall averages, variability is important: rainfall in the region is erratic and unpredictable. Soil erosion has been severe in Tigray. In several places parts of the subsoil have been removed from the sloping land.

Figure 1: Soil and water conservation board on local planning. (Photo credit: Tigray Bureau of Agriculture and Rural Development, 2011).

Box 1: Landscape transformation in Abreha Weatsbeha

Abreha Waetsbeha – located near Wukro – is part of the Sulo catchment. Intensive soil and water conservation has been implemented here over the past five years. As elsewhere in Tigray, the work is implemented both by voluntary labour and labour inputs from the Productive Safety Net Programme. The work in Abreha Weatsbeha consisted of:

- Semi-circles for tree planting.
- Field bunds with trenching – to maximize the capture and infiltration of rainfall run-off.
- The development of gully plugs, overflow channels and rainwater infiltration ponds close to the mini-escarpments surrounding the village.
- Area closure to allow the regeneration of trees and grasses.

A special feature is the development of new farmland in areas previously used for grazing. This concerns sandy tracks close to the foothills, which are now closed to animals. This makes it possible for wild weeds to emerge. These weeds are regularly ploughed so as to increase the organic content and improve the fertility of the sandy soil. Another feature is that, with the soil and water conservation activities, indigenous trees have come back. There is already a long and well-enforced system not to cut any live trees, but with the soil and water conservation activities many new trees have come up.

The recent programme has caused groundwater tables to rise in a spectacular fashion. This has encouraged shallow well development. In the past three years at least 200 shallow dug wells were developed in Abreha Weatsbeha – often located at very close proximity to one another. Excavating one of these large diameter wells costs USD 300 – and is done with some encouragement (in the form of food aid) by the local government. The water is pumped out to the adjacent farmland by treadle pumps or rope pumps and in some cases by monoblock diesel pump sets. The dug wells, however, take up much space and are prone to collapse in the sandy soil. Replacing them with low-cost, manually-drilled shallow tube wells would improve secure access to groundwater.

Figure 2: Using treadle pump to acces the new shallow groundwater. Source: Tigray Bureau of Agriculture and Rural Development (Phtoto credit: Tigray Bureau of Agriculture and Rural Development, 2011).

There has been a remarkable landscape transformation in Tigray in the past three years. Soil and water conservation activities addressed more than 50% of the agricultural land in this short period, building on the steady progress made during the prior ten-year period. The activities have caused crop production to increase by 50%-100% and a large range of innovations to take root. This soil and water conservation programme is very much a story of scale begets scale and success breeding success.

Figure 3: Transforming landscape at scale in short time span (Photo credit: Tigray Bureau of Agriculture and Rural Development, 2011).

Soil and water conservation in Tigray

Soil and water conservation programmes have been practised in Tigray for a long time, but were often interrupted and not implemented at scale. Several techniques were introduced over the years: afforestation, bench terracing and stone bunds. Programmes were often associated with food-for-work programmes. From 1974, the World Food Programme (WFP), for instance, supported terracing and reforestation – undertaken by the Extension and Project Implementation Department (EPID). The long-term uptake of soil and water conservation was often limited, and particularly in the socialist Derg regime the programmes were considered top-down and forced upon. The Tigray Peoples Liberation Front (TPLF) and its outreach wing the Relief Society of Tigray (REST), however, recognized the importance of soil conservation and made it a cornerstone in its programme in Tigray, particularly after it took power.

The area of land that was rehabilitated between 1988 and 2002 in Tigray amounted to 602,000 ha, more than half of what was previously addressed in the country as a whole. The main purpose was reducing erosion through trapping and retaining sediments. In spite of the effort, the results were often unsatisfactory due to lack of effective community engagement, limited sense of responsibility over assets created and unmanageable planning units.

From 2007 the programme was thoroughly revived and reoriented. Particularly from the year 2009 onwards a new thrust in soil and water conservation was introduced in Tigray. The new impetus had several elements:

- Soil and water conservation was to focus on cultivated and uncultivated land. Cultivated land should be primarily conserved by the farmers who cultivate the land, and watersheds should be conserved by public mobilization.
- There was – in addition to erosion control - more emphasis on harvesting water and retaining moisture. In this practice this meant several new techniques. For instance in low rainfall zones infiltration ditches were added to the stone bunds.

- 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.
- Other new elements introduced were gully treatments and new grasses and fruit trees on the treated lands.

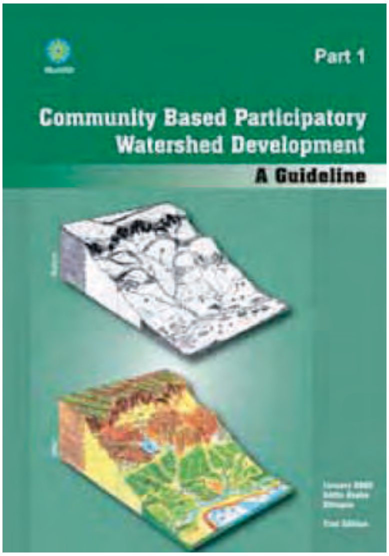

Figure 3: Guideline "Community Based Participatory Watershed Development" and as basis for local planning

The work was undertaken through free labor in the off-season and through contributions from the so-called Productive Safety Net Programmes. Under the first arrangement 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), as a large part of the watershed programme had been completed in the two preceding years. In contrast to the earlier initiatives, the programme 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. In addition to the free labor, contributions from the so-called Productive Safety Net Programme were integrated with the soil water conservation programme. Under this programme chronically food insecure people were earmarked to provide work against payment in cash or kind.

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 (leveling, terracing, soil amelioration) and in some places well development. Key to the success of the programme has been local planning and implementation – something that was missing in the earlier efforts. 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 farmers' unions, womens' associations and youth associations were involved in the planning and implementation of soil and water conservation activities.

The strong local-driven implementation meant a trend break with earlier soil and water conservation efforts – where people mainly participated to receive food for survival. In the past there was often little awareness of the effect that soil and water conservation activities could achieve. Implementation at scale also meant a change in environment – as witnessed from the reemergence of springs, the regulation of local flows and the growth of indigenous trees – causing larger momentum. It created an effect of 'success breeds success' – as it encouraged experimentation with new crops (fruit trees) and new land management methods (mice control). Importantly the collective mobilization programme was complemented by individual investment in land improvement and well development.

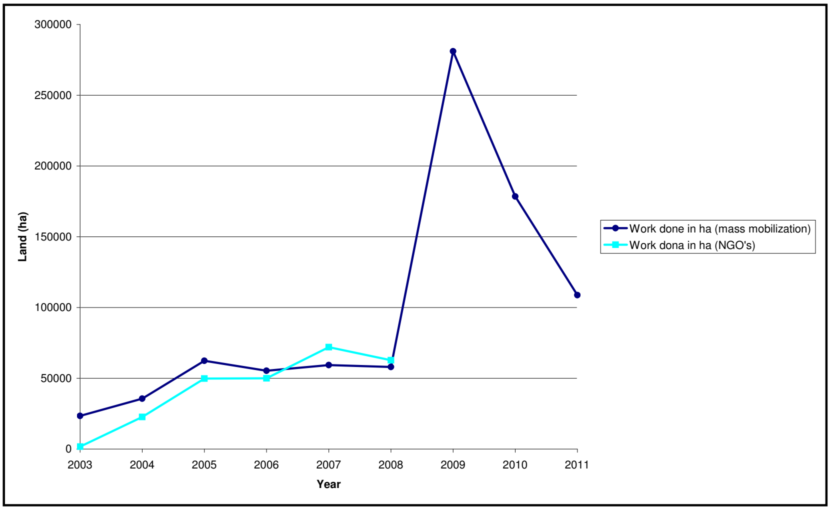

Figure 4:Accelerating landscape improvement in Tigray 2003 - 2011 (Source: Tigray Bureau of Agriculture and Rural Development, 2011)

Table 1: Water recharging/conservation structures implemented in watersheds of Tigray until 2008 (Source: Tigray Bureau of Agriculture and Rural Development, 2011)

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	162469.5
Gabion check dam	m^3	573775.1
Stone check dam	m^3	1232015
Cut-off drain	km	26158.87

In addition to soil and water conservation activities, different water harvesting and recharging structures have been constructed in Tigray. As can be noted from Table 1, some of the structures constructed so far include percolation pits, micro-basins, rockfill dams, check-dams, etc.

Costs and benefits

There are records of soil and water conservation activities carried out in Tigray up to 2011, but interestingly the data are not comprehensive. The programme has been carried out in a very decentralized fashion and, although it is there for everybody to see, there are no neat central statistics. Table 1 is an overview of the type of activities implemented up to 2008. After this, work accelerated and there has been more emphasis on recharge and infiltration.

Table 3: Day-equivalent activities under the Productive Safety Net Program (Source: Tigray Bureau of Agriculture and Rural Development, 2011)

Type of soil and water conservation activity
Terracing in soil (5m long)
Terracing in rock (3m long)
Stone bund (4m long)
Deep trench (1m deep)
Eye brow basin (2 I brow)
Micro-basin (4 micro-basin)
Half moon (4 half moons)

Figure 3: soil and water conservation, Tigray(Source: Tigray Bureau of Agriculture and Rural Development, 2011)

Above (Table 2) is the official norm of the work to be done in a day by an adult man under the Productive Safety Net Programme. The renumeration for a day work under the programme is ETB 10 (USD 0.50) or 3 kg of grain – which is below the normal daily rural wage.

The benefits of this very recent programme remain to be quantified – but the following key observations have been made by farmers:

- 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.

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.

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3.3. Water retention through 'monkey cheeks'

Thailand

Water retention for flood and droughts

Although there is no shortage of rainwater in Thailand, drought is still a major problem in many areas especially in the north-eastern region. This is due to the low capacity of rainwater conservation. According to Hydro and Agro Informatics Institute (HAII), only 5.7 per cent of rainwater is stored.

The term 'monkey cheek' was coined by King Bhumibol Adulyadei of Thailand as a metaphor to promote local water retention systems and is part of the 'New Theory' agriculture. It refers to monkeys filling up their cheeks with excess food. The food is stored and chewed and eaten later. Monkey cheeks essentially are 3R: Recharge, Retention and Reuse. The monkey cheek programme was initially started to solve the flood problems of Bangkok, but has subsequently been replicated

Figure 1: One of the monkey cheeks at Ban Limthong (Photo credit: Hydro and Agro Informatics Institute (HAII), Bangkok)

all over the country, especially in the north-east. The north-east is the driest area – but is also an area that is not suitable for the construction of large dams. Monkey cheeks come in large and small. Larger projects of the Royal Irrigation Department (RID) in 2010 included developing 197 monkey cheek projects with a total storage capacity of 117 Mm^3. In addition there are numerous storages at community level.

Ban Limthong

An example of a village that followed the 'monkey cheek' initiative is Ban Limthong in north-east Thailand. It is located in Nongbood subdistrict, Nangrong district, Burirum Province. There are 108 households totaling 563 people. Wet season rice cultivation is the main crop. Mushroom, tapioca, cowpea, watermelon, cucumber and other vegetables are grown for additional income.

Ban Limthong is situated in the upper Lam Plaimas River Basin. The average monthly rainfall in Nangrong district is 1,380 mm – but the difference between the dry and wet season is large. Where there are rice fields in the rainy season, an expanse of sandy soil dominates the landscape of the village during the dry season. Due to its relatively high location, water supply in the canal to Ban Limthong dried up – requiring long walking distances even to collect basic supplies. Competition for water among surrounding villages was common with the risk of crop failure in a below average rainfall year. In contrast, during rainy season the excessive amount of water often flooded and destroyed farming areas. In Ban Limthong this caused indebtedness and out-migration.

The Government stepped in during these periodic disaster periods. Each year water was trucked in during the dry period, but this was never enough. During floods, sandbags and pumps were distributed. A reservoir was built, but it was in an inappropriate location and it yielded very little.

Investing in water retention

Sharing problems of increasing debts and water shortages brought together a group of villagers led by Sanit Tipnangrong or Na Noi who became involved with the local Suksapattana Foundation. Over time more villagers joined, including those from neighbouring villages. The Ban Limthong group collected information on the demand of water within their own village and worked together with the surrounding villages. Hydro and Agro Informatics Institute (HAII) has supplied these communities with data and the use of information technology in surveying and planning.
HAII arranged for handheld GPS devices and satellite images of the area. In addition, a number of field surveys were undertaken that were used to collect data, analyse community water resource issues and develop solutions. Villagers developed plans for water retention systems, in particular (a) the construction of an irrigation canal system to divert water from the upper river basin, (b) the construction of series of monkey cheek ponds to store water in order to increase water storage capacity and prevent flooding, and (c) small farmer storage ponds. The canal system will be connected to monkey cheeks as well as agricultural areas. The demand of water for drinking and household consumption was set at 120 L per person per day and 5.2 Mm^3 per year for agricultural use.

Irrigation Canal System

The plan for the irrigation canal system was submitted to the district office of the Royal Irrigation Department in 2006 and was built over the two subsequent years. The unlined canal was 3,600 m long and approximately 3 m deep. The water storage capacity is 121,000 m^3 per year.

Monkey Cheeks

The monkey cheeks store water during periods of high rain. They work with gravity flow – the ponds fill when water runs higher in the irrigation canal and floodgates close as the water level in the ponds exceeds that in the canal. In the dry period when the water level of the canal decreases, the water from monkey cheeks is slowly released into the canal. In Ban Limthing, seven monkey cheeks were placed at different points throughout the irrigation canal system.
Seven such monkey cheeks were constructed - each relatively modest in size (see Table 1) – combining a storage capacity of 65,700 m^3. Added to the capacity of the canal, the total water storage is 186,700 m^3. A levee was made around the edges of the monkey cheeks by compressed soil. These levees are typically 10 m wide and 1.5 m high.

Figure 2: Small storage reservoirs and canals interconnected to create buffer (Photo credit: Hydro and Agro Informatics Institute (HAII), Bangkok)

Table 1: Constructed Monkey Cheeks

	Dimensions in m (width, length, depth)	Capacity (m^3)	Excavated area (m^2)
Monkey cheek 1	60, 60, 3	10,800	3,600
Monkey cheek 2	40, 50, 3	6,000	2,000
Monkey cheek 3	30, 80, 3	7,200	2,400
Monkey cheek 4	80, 80, 3	19,200	6,400
Monkey cheek 5	40, 60, 3	7,200	2,400
Monkey cheek 6	30, 100, 3	9,000	3,000
Monkey cheek 7	30, 70, 3	6,300	2,100

Small farm ponds

After the irrigation canal and monkey cheeks were built, distribution channels were constructed in order to distribute water to the farming areas that are further away. In order to be able to efficiently manage the water and their farmland for all-year-round agriculture, villagers also built small ponds at each farm according to the 'New Theory' agriculture (see Box 1).

In order to implement this component, Development Cooperation Foundation has set up a revolving fund, amounting to USD 17,000 for the village. In order to take part in the fund, villagers need to be a member and pay a small entry fee. Members can submit their project plan to the fund. After the approval of the project, they will be supported in preparing the area. Moreover, the members need to attend the training programme about how to manage and utilize the pond for maximum benefit. The money lent can only be used for constructing a pond at their farm or other expenses according to the written plan submitted to the fund. Additionally, the members are able to borrow extra investment money with low interest rate for farming activities. The fund aims to lend about THB 20,000 (USD 666) for each pond construction. The aim is to support the construction of 10 farm ponds per year. The members are expected to repay the amount within four years or about THB 660 (USD 22) per month. The fund committee is responsible for fund management and annually reporting back to the Foundation.

Costs and financing

The construction of an irrigation canal system at USD 92,000 was supported by the Royal Irrigation Department. The construction of monkey cheeks was supported by the Coca Cola Foundation Thailand. After reviewing the plan from the villagers, the Coca Cola Foundation approved the budget of THB 1,400,000 (USD 47,000) to support the cost of construction. HAII contacted the Mobile Development Unit of the Thai Military to support the provision of the equipment and machinery necessary for the construction and carried out the project according to the plan. The revolving fund for the farm ponds amounted to USD 17,000.

Box 1: 'New Theory' Agriculture in short

'New theory' agriculture is the concept developed by His Majesty the King of Thailand to efficiently manage water and land in a small agricultural area (average size 16,000 – 24,000 m^2) for the utmost benefit. According to the 'new theory' agriculture, land should be divided into four parts with the ratio 30:30+30:10.

The first part: 30 per cent is reserved for a small pond which should be built to hold 19,000 m^3 of rainwater. This amount is considered to be enough for agricultural use for the whole year for a small farm. Growing eatable aquatic plants and aquaculture in this area are recommended as it provides farmers with extra income and food.

The second and third part: 30 per cent + 30 per cent is the agricultural land. The first half is used for rice farming and the second half is for field crops, herbs, fruit trees depending on the condition of the land and the market. Yields are used for household consumption and the surplus can be sold.

The fourth part: 10 per cent is as allocated to a service area such as houses, roads, canals, storage areas, home gardening and livestock.

The villagers who are the owners of the lands where the irrigation canal system and the monkey cheeks were constructed gave their consent to allow the lands to be used for public benefit. Therefore, there were no costs for procuring land.
The 'Community Water Committee' was established to spearhead the project, make a plan, and later to look after and manage the community water facilities. The committee has also expanded into a collaborative network with nearby communities. A database of water users was made and administrative fees were collected from those on the list. The money collected was spent on the maintenance of the village water supply system and other public benefits.
Vetiver grass has been planted on the edges of each monkey cheek and the bank of the canal to keep them sturdy and prevent soil erosion. This also reduces the costs in dredging and maintenance. The 3 m-long roots of vetiver grass also help reduce water evaporation and keep the soil moist.

The landowner is appointed as the person responsible to take care of the monkey cheek in their land together with five members (villagers). Each group maintains the monkey cheek and uses the area around it to implement mixed farming, experiment with 'new theory' farming, and carry out a cultivation plan for year-round harvesting. Lessons learned and the data collected was shared among the villagers. Successful cases are replicated.

Benefits

The combined system of monkey cheeks, irrigation canal system, distribution channels and small ponds at farm level solved flood and drought problems that plagued the community for decades and created a stable buffer.

It provided villagers with sustainable water supply for agricultural and domestic use all year round. Rainwater that is captured is not only used for growing rice and crops but also for livestock, fish and frog farming that yield extra income. Cultivation is all year round. They no longer suffer from the risk of delayed rain and crop failure due to water shortage. At household level the increased buffers have allowed for greater income that is also more stable and predictable.

The benefits of the canal and monkey cheek systems accrued to farm household in Ban Limthong and surrounding villages – totaling 1,038 households. Water is provided to 608 ha. Their standard of living has improved as they have more saving and debts are gradually resolved. No time is lost in fetching water. Many who have left to work in the city came back to work in the field and be with their families.

The table shows economic effect for an average household (based on a sample of 15). The monkey cheeks buffer development programme added THB 105,500 of net returns per family – equivalent to USD 3,500 – meaning that the investments have a pay back period of approximately three years.

Moreover the system doubles up as a flood protection device. Furthermore, the system is a solution to water pollution problems that often occur in the canals with low water levels. When the water from monkey cheeks is released, it flows along the canal system and helps circulate clean water to dilute standing water.

Table 2: Improvement of average income of a household per year (Baht) - based on sample of 15

	Before implementation	2007	2008	2009 (new theory agriculture)
Income	6,867	102,984	148,489	164,949
Expenses	7,600	46,233	71,163	59,356
Total balance	-733	56,751	77,372	105,593

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3.4. Harvesting sediment with warping dams

Loess Plateau China

Introduction

The Loess Plateau covers an area of 640,000 km^2 in north central China and is home to more than 50 million people. The middle stream of the Yellow River crosses the Loess Plateau. The intense use of the Plateau and the lack of conservation measures have lead to large-scale degradation of the vulnerable land formations – loess being highly erodible. The Plateau has one of the highest erosion rates in the world and the Yellow River itself is named after the color of the suspended fine loess sediment. The river is estimated to receive a staggering 1.6 billion tons of sediment every year. In the 1990s, the Chinese Government started one of the largest landscape transformations in the world – with the aid of the World Bank – the rehabilitation of the Loess Plateau. The objective of the programme was to increase agricultural income and to improve ecological conditions in the tributary watersheds of the Yellow River. The main elements of the programme were the construction of terraces, protection of sloping lands from grazing, and support to farmers in income

Figure 1: Warping Dam in Gansu province, China. (Photo credit: WorldBank office Beijing)

> **Box 1: Warping**
>
> Warping is building up land with moisture-rich soil along rivers and streams. The technique is not unique to the Loess Plateau but has also been used in England - for instance along the Humber and Thames - where silt-laden water was forced to settle in embanked areas, thus producing fertile new land. The same was done along the Yssel River in the Netherlands, where so-called *worpgronden* (warping lands) were developed. In many flood-based farming systems land is developed from sediment: sediment is a constant blessing and not a nemesis as in many perennial irrigation systems.

generating farming activities, such as feedlot livestock development, the introduction of dairy cattle and irrigated agriculture (World Bank, 2005). By reducing the sediment flow into the Yellow River flood risks downstream are reduced drastically and a substantial sum is saved on raising dikes in the Yellow River.

Warping dams

Warping dams are dams built on gullies to harvest and intercept sediments and thereby create new land. The dams are of considerable height - typically up to five metres. The construction of warping dams to harvest sediment, build up land - as well as in the long run to ensure better water retention - has been a main feature of the programme.

As history has it, the first warping dam originated through a natural landslide 400 years ago in Shanxi Province. Sediment was deposited in front of the dam creating warping land, and grain yields increased due to the fertile soil. The dam was heightened by local people to 60 m and farmland of 53 ha developed behind it (UNESCO, 2004).

The construction of warping dams gained popularity after the Chinese Government built a warping dam for experimental and demonstrational purposes in the 1950s. In the late 1970s several warping dams were destroyed due to inadequate construction methods combined with unusually large floods (Zang et al., 2003). From the 1990s construction of warping dams accelerated as part of the West China Development Plan.

In the Loess Plateau Watershed Rehabilitation Projects of the World Bank (2005) the construction of warping dams - alongside other types of sedimentation control dams (Box 2) – also played an important role. In total 1272 warping dams, 264 key dams, 3719 check dams, and 171,278 ha of terraces and several vegetative measures were developed under the Rehabilitation Projects. The total cost of these two projects was USD 300 million. This is estimated to have reduced sediment load by 82 million tons.

Construction

The development of a warping dam consists of two stages: (a) the land development stage, and (b) the consolidation and management stage. The land development stage takes several years (on average 3-5 years, but sometimes more than 10 years). By then warping dams have collected enough sediment to start farming. After this consolidation starts. Stabilization is necessary when the dams are completely filled with sediment, in particular the creation of controlled water overflow structures. This can be done by changing the existing spill ways into a circular shape, redesigning the top of the shaft as spillway, constructing a side spillway, or designing an earth dam as overflow dam. There are many factors to take into account while constructing warping dams. The density of dams depends on natural factors e.g. slope, gully density and the possibility of retaining silt for farmland (Box 3). The number of dams depends on the slope and width of the gully. In the Loess Plateau, 2-5 dams can be found per km² in areas with a slope of 2-3% and a gully density of 3-7 km/km² (UNESCO, 2004).

Table 1: Classification of warping and key dams

Classification km	Gully Length km	Storage capacity 10^3 m^3	Height of dam m	Warping area ha
Small	0.3	10-100	< 15	<1
Medium	3-5	100-500	15-30	1-15
Large	> 5	500-5000	>30	>15

Source: UNESCO 2004

The development a warping dam requires an area approach. It is important to look at existing measures and natural factors in the area (e.g. cropping systems, slopes, upstream and downstream users, and rural road plans). It is also important to see the key dams and warping dams as a combined sediment management system.

Benefits

One part of the benefits of the warping dams is in the upper catchment. The sediment captured by warping dams, or warping land, is rich in organic matter and has soil moisture concentrations that are up to 80% higher than in the sloping land. Yields from warped land can be up to 2-3 times higher compared to terraced land and up to 6-10 times higher compared to sloped land (UNESCO, 2004). In the Loess Plateau warping dams are also used to connect roads in villages. This additional benefit enhanced the popularity of the warping dams.

In addition there are important downstream benefits. From an analysis of over 1000 warping dams from a typical watershed in the Loess region (UNESCO, 2004) it appeared that the average of retained sediment per dam is 2.78 km³. Data from Shaanxi Province show a decrease of 51% of sediment transported in the Yellow River after the warping dams were constructed.

The benefits of warping dams are usually shared by the ones who invested (financially or by labour) during the construction of the dam. The maintenance and management is mainly carried out by a village authority, but other forms of property rights occur, such as contractual agreements between households and local government and leasing arrangements to private companies.

Box 2: Three types of sediment control dams

1. Key dams are the largest dams (15-30 m high) - controlling catchment areas of 10-15 km^2. They are typically located close to the outlet of watersheds. Besides retaining sediment, key dams can be used to control small floods and to serve as water supply reservoirs as well.
2. Warping dams are smaller in comparison to key dams (around 5 m high). They are usually constructed in the wider parts of a gully downstream of a key dam. Their purpose is solely to intercept sediment and create flat arable land.
3. Check dams are small dams (1-2 m high) built of rock or brushwood. Check dams slow the flow of water in steep tributary gullies and prevent the undercutting of gully sides.

The sides of the deeply incised gullies in the Loess Plateau generate 50 per cent of the sediment run-off. Sediment control dams intercept this sediment at the source. To restore any loss in storage capacity due to sediment, the height of dams can be increased periodically.

Figure 2: Series of sediment control dams (Photo credit: World Bank Office Bejing)

There are opportunities to self-finance the sedimentation control dams. The argument has been made that if warping dams of required standards would be built with private funds and be paid USD 0.12 per ton of trapped sediment, then many village cooperatives and individual tractor owners would be encouraged to devote their labour and resources to the building of warping dams, without further assistance from the government. Under the same arrangement county governments would be subsidized for their rural road projects which usually involve high earth structures across gullies with sediment trapping functions.

Box 3: Examples of benefits

Inner Mongolia

Lijiageleng is a village of 26 households in Inner Mongolia near the Yellow River's northern bend. The villagers owned 17 ha of farmland which generated a per capita income of USD 60 - remaining at poverty level. After the development of a warping dam and 16 ha of terraced irrigated land, the per capita income rose to USD 276 in two years.

Northern Shaanxi, China

The construction of a 35 m high key dam - controlling a catchment of 3 km^2 and with a storage capacity of 800,000 m^3 - cost around USD 60,000. The dam can retain 150,000 m^3 of run-off and it traps 37,000 tons of sediment. A short overview of benefits:

- Clearing costs of coarse sediment (sediment that can not be flushed out to sea) is estimated at USD 0.24 per ton. As roughly half of the sediment trapped in the key dam is coarse, the dam saves USD 4,440 to the national economy annually.
- To transport one ton of fine sediment to the sea, 20 m^3 of water is needed. Reducing sediment by 18,500 tons per year saves 370,000 m^3 of river water which can be used for other purposes. This is in addition to the intercepted run-off by the dam, and gives a net gain of 215,000 m^3 in water supply.
- Direct agricultural benefits from the dam were valued at USD 6,000 per year.

Source: yellowearth.net

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3.5. Flood water spreading

Iran

Introduction

In the Fars Province in Iran an extraordinary programme of floodwater harvesting has been implemented since 1983 – changing the desert landscape into a verdant environment. Water and sediment from occasional floods in this arid environment have been utilized to:

- Recharge groundwater by spreading floodwater gently over a large area;
- Develop lands for spate irrigation – using the silt to build up soil and prepare land for direct irrigation;
- Introduce integrated farming systems of field crops, tree crops, honey bees and livestock;
- Develop *Eucalyptus camaldulensis* plantations on the newly-formed lands to function as windbreaks and shelterbelts, to sequester carbon, produce honey, and serve the urban markets with timber.

The floodwater spreading programme is a good example of turning a menace – silt-laden floods - into an asset. The floodwater carries high volumes of sediment – up to 5%, which is not unusual for ephemeral rivers. If storage dams were built in this environment their reservoirs would choke

Figure 1: Floodwater diverted to one of the infiltration basins during a rain fall event in 1983 (Kowsar, 2009)

rapidly. Instead, through floodwater spreading the silt is used as an asset by building up fertile land in a sandy desert that is under the constant threat of wind erosion. The floodwater is also used to recharge groundwater and to spate irrigate land directly.

A series of techniques are applied to spread the water and sediment over a large area - in particular combinations of conveyance spreading canals and level-silled channels (LSCs). The simplest version of a floodwater spreading system is a single, level-silled channel that receives the floodwater from one or more sources and allows the water and sediment to spread gently over the debris cone and alluvial fan. A full floodwater spreading system on the other hand may include a diversion weir, a conveyance canal, a wasteway, a conveyance-spreader channel (CSC), a number of LSCs, flood outlets (sometimes with masonry drops), trail dikes and a tail drain. If the system also functions for artificial recharge, an infiltration pond is added to the end.

The main feature in floodwater spreading systems are therefore LSCs. These are actually long stilling basins, closed at both ends, with the down slope edge exactly on the contour. The channel converts small, concentrated flows into sheet flows. The control section of the LSC is a level sill adjacent to its down slope edge, which allows the silt-laden water to spread gently before the sediment settles down. The soil excavated from the channel forms the bank immediately on its upstream side. Water enters the LSC through the gaps installed in the bank at 100 to 400 m intervals. The usually turbulent water loses most of its kinetic energy after entering the basin. When the channel is filled up, the surcharge spills along the entire length of the sill in a slowly flowing thin sheet. The LSCs are made with bulldozers, graders or front-end loaders. They are not intended to impound – only to briefly capture and to spread both water and sediment.

The dimensioning of floodwater systems depends on the expected normal flood levels and the use of the floodwater. There is no theoretical basis for determining the layout and space between consecutive channels, but two criteria are important. Firstly, the flowing water should not gain erosive velocity. Secondly, water should be distributed evenly over the space between the channels.

Box 1: Conveyance spreader channels (CSCs)

Conveyance spreader channels (CSCs) are larger than level-silled canals. The main function of the conveyance spreader channel is to convert concentrated flow from the upland to sheet flow. They can be kilometres in length. The CSCs receive floodwater from ephemeral or permanent rivers, drainage lines, depressions and watercourses, and surplus water from small reservoirs. As torrents with high velocities and heavy bed loads can hinder the functioning of the spreading channels, sometimes earth or rock buffers are added to retain the floods and send the reduced velocity, desilted water through gaps into the CSCs. Construction of the CSCs is similar to the level-silled channels, with one important difference. CSCs follow a very mild slope, their cross-sectional area is larger and usually they do not have bends or turns.

Box 2: Speeding up sedimentation

Assuming that a 30 cm layer of fine-textured soil is required to reclaim the sandy expanse in the Gareh Bygone Plain (3,000 m3 per ha), 18 Mm3 of sediment are needed to rebuild the land. Taking the average annual diversion at 10 Mm3, it requires about 90 years reclaiming the whole area. One idea to expedite the recovery is to break the marl and siltstone bedding on the watershed and generate even higher silt loads.

An integrated approach was involved – combining the development of new land from sediment, irrigation and recharge, and the planting of species to promote the development of agro-ecological niches. Another welcome development is the emergence of sowbugs – a crustacean that improves the infiltration of the land and builds up the soil structure (Box 3).

Knowing what to do where

In the floodwater spreading it is important to know what to do where. An important message is that – contrary to conventional wisdom – it is neither possible nor wise to always 'catch the water where it falls', as some catchments produce floods rather than recharge. Moreover, in some parts of the catchment recharge is undesirable as it would add to salinity. In the words of Professor Sayyed Ahang Kowsar, the lead scientist of the artificial recharge programme, 'Basins with impermeable outcrops are different from ones with permeable surfaces. Iran can consider itself fortunate to be blessed with flood-producing impermeable watersheds. Without this it would be impossible to live in such dry environments. The natural recharge for the alluvial aquifers materializes only by floods. The diffuse recharge is utterly insignificant.'

An example of knowing what do to where, is the Helleh River. The Helleh River has a drainage basin of 8,600 km^2, making it the second largest river in the Fars and Bushehr provinces. The discharge of the Shapur River, the most important tributary of the Helleh, however, is saline. This affects the use of the Helleh water for irrigation. At the source, the Shapur River is supplied by karst springs and is fresh. Salinity, however, builds up as a number of tributaries join the river course. Diverting the saline discharge of these tributaries through a pipeline system to the Persian Gulf was suggested at one stage but not taken up due to the high cost. For the same reason the construction of a large reservoir on the Helleh River to store floodwaters and dilute the saline inflows was rejected. Moreover, much precious water would be lost from evaporation from the reservoir and sedimentation would be an issue.

Instead of the reservoir and pipeline options, a more promising alternative is the careful management of the water buffer in the Shapur River so as to increase the baseflow of the Shapur River and eliminate the saline outflow. In general, in semi-arid, high temperature areas storing water in shallow aquifers is more cost-effective than constructing surface reservoirs.

An important portion of the Shapur's floodwaters originates in a 770 km^2 area upstream of the Tchegan Gorge. Promoting more intensive recharge in this part of the catchment would increase the freshwater baseflow of the Shapur. The floodwater spreading/recharge sites are best placed at a distance from the main stream of the Shapur River. This would ensure that the subsurface flow reaches the Shapur at a time when it is most needed. For example, if the recharge occurs in

December and the irrigation season starts in April, then the distance should be adjusted according to the aquifer parameters so that the recharged water would not reach the Shapur baseflow before April. This requires an understanding of faults and fissures that affect the shallow groundwater flow. The same method may be used for harnessing floodwater in other tributaries.

At the same time the saline outflows should be reduced. The flow from the saline springs in the Jareh and Dalaki tributaries should be diverted to leak-proof evaporation ponds to prevent this water from joining the main river. In addition to the evaporation ponds closure of the saline outflows may be considered. The Shekastian Drainage Basin is covered by an impermeable formation. In this area the saline discharge of these tributary rivers is not from local rainfall, but most likely from underground karstic streams flowing through local faults dissolving salt plugs in the process. Stopping the discharge of these saline springs may be achieved by diverting the flow of freshwater before they reach the salt plugs, for instance, by grouting and inducing new springs to issue freshwater.

Box 3: Tunnelling in fine sand: a brilliant feat of engineering

The sowbug, or *Hemilepistus shirazi*. common in the Gareh Bygone Plain, is a crustacean, 20-25 mm long and 5 mm wide, blackish gray and with seven pairs of legs. Like rain worms or termites in other places, sowbugs function as eco-system engineers in this arid area – keeping the flood recharge alive and gradually improving the quality of the soil deposits.

Sowbugs live in damp places, forage on vegetation and digest soil organic matter. They are also common in the arid flood spreading areas of Gareh Bygone. They prefer the moist subsoils and by burrowing they ensure the soil in the flood spreading area is not sealed with fine sediment.

Figure 2: The H. reaumuri (sowbug) entering his hole (Source: Kowsar, 2009)

Box 3 continued

Their burrows, 7 mm in diameter and up to 180 cm deep, serve to aerate and to punch the soil profile. In Central Asia, during its active life period of about three months, sowbugs will move not less than 1.5 tons of soil. This burrowed soil has more organic matter, a better structure and is more resistant to erosion than the soil from which it was derived. Sowbugs cement their burrows with body fluids. An extremely thin coating of a greyish material lines the narrow tunnels in very fine sand that would collapse otherwise. The organism lives for about one year. The white brood pouch under the abdomen of the female swells in March. The eggs form larvae in the pouch, and 60-70 sowbugs, very similar to their parents, are released from the pouch in May. They are very active in the spring and autumn. They come out of their burrows in the cool air of early morning and late afternoon. Sowbugs easily loose water through their skin. The digging deep into the soil is to reach a humid surrounding and prevent dehydration.

The emergence of the sowbug in the Gareh Bygone Plain helped to increase the infiltration rate of the topsoil layer in the artificial groundwater recharge zones. Sedimentation with silt and clay particles in infiltration basins often results in clogging of the top layers, inhibiting infiltration and drastically reducing soil moisture and recharge rates. The burrowing of the sowbug, however, results in large macropores and prevents such clogging. Instead, it increases the infiltration rate in the recharge zone up to 50 mm hr^{-1}, equivalent to 500 $m^3ha^{-1}hr^{-1}$.

The burrows of the sowbug are connect to a larger macro network – consisting also of the root channels formed by the decayed roots of the eucalyptus and acacia trees as well as the openings created in the very topsoil by dung beetles. Dung beetles are triggered indirectly by the presence of fodder trees and livestock. The manure produced by the livestock on site and carried by floodwater provides the ecological niche for the dung beetle. By loosening the soil the dung beetles initiate the start of the infiltration web. The typical infiltration rate found for the vegetative sites of the infiltration basins reached maximums of 93 mm/hr, the infiltration rates for the crusted non-vegetative sites in the infiltration basins were much lower at 4 mm/hr. A more detailed inspection of the soil revealed the high intensity of macropores around the tree, formed by the sowbug in the first metre of the topsoil and by decayed roots in the soil beneath. Further research reported by Kowsar and Pokpavar (2004) revealed average infiltration rates of 77 mm per hour in sowbug-infested soils and only 27 mm per hour in the controlled sites. The main conclusion of the study was that the macropores, formed by the sowbug and the decay of roots from eucalyptus trees, had stabilized and greatly improved the hydraulic conductivity of the top layer of the soil, therewith establishing the key structure in order to recharge the aquifer. In the Gareh Bygone Plain, no negative impacts of the sowbug have been reported, however the sowbug is reported as pest in other cases, for instance in saffron cultivation. As sowbugs consume living plant material and plant detritus, care should be taken if sowbug species are introduced in agricultural areas.

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3.6. Using natural landscapes

Turkmenistan

Introduction[1]

Natural surfaces – called *takyrs* – are used to harvest water in the extremely dry Karakum Desert in Turkmenistan. Takyrs are large stretches of desert landscape that are characterized by flat or gently sloping topography. They are deposits of clay material aggregated in local drainage zones. In Turkmenistan these areas cover a surface of 19,000 km^2. Of this 11,300 km^2 is occupied by takyrs that are larger than 1 km^2. Impermeable by nature, they have a low infiltration rate and, because of their sheer size, deliver substantial volumes of runoff even from the scarce amounts of rainfall they receive. Where the use of surface streams and aquifers is not an option, takyrs are effectively used to harvest water. It is thought that takyrs in Turkmenistan can produce 350-450 Mm^3 per year. Only a small part is utilized at present for productive use.

Buffer systems

The Karakum Desert covers most of Turkmenistan. It is characterized by a warm dry summer and by a short winter. Rainfall is usually 110-200 mm per annum - concentrated in the cooler winter months. The desert population has developed different buffer systems to save runoff during the humid periods and survive the long dry part of the season. Though the main activity is cattle

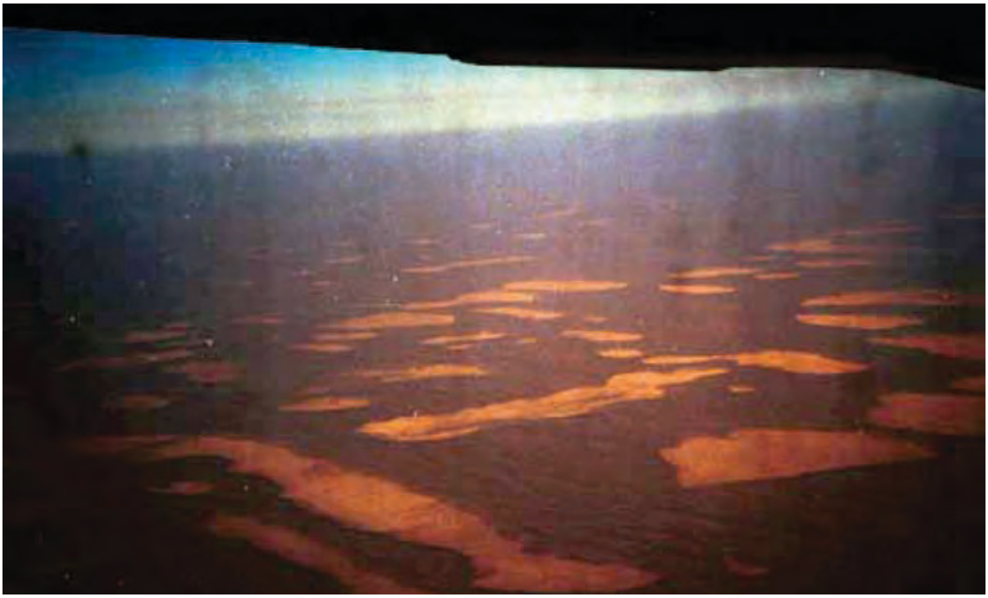

Figure 1:Takyrs from the air (Photo credit: W.P. Spaan)

1 This case is based on Fleskens et al. (2007).

herding, households also engage in small-scale farming for home consumption and supplementary feed.

The peculiarities of takyrs make them a perfect surface to produce excess water. Different techniques are used to store the run-off for later productive use: soils, shallow aquifers, closed reservoirs and open ponds. All the techniques make use of the low permeability of the natural landscape to concentrate the rainfall water. Often two or more methods are used conjunctively operated to gain the most out of the small amount of rain available. The main storage techniques are:

Khaks
These are artificially made depressions that collect water from takyrs during the rainy spells and store it in open-air reservoirs. They are mainly used to water livestock for 2-4 months after the winter. Due to the high evaporation rate of the environment these ponds can be used productively in the first part of the dry season only. They are not suitable to provide water for human consumption because the water in the open storage gets easily contaminated. The investment necessary to construct a small khak is around USD 350; a large system can cost up to USD 960.

Sardobs
Water can be alternatively stored in closed cisterns. These sardobs used to be built of lime mortar and bricks with a covering dome. Modern versions make use of concrete. Sardobs collect surface run-off. A typical cistern has a capacity of 500 m^3. When larger storage is needed, two or more structures are built in the same location. These constructions yield clean water, suitable for domestic use and in the drier months for livestock's watering. The freshwater obtained can be mixed with brackish aquifer water to water livestock for a longer period. The construction of one unit can cost up to USD 8750.

Chirle
An alternative is to store excess water in the sandy soil shallow aquifer underneath the takyr and to withdraw the amount needed with one or more wells. The run-off water is collected in a depression excavated at 2-12 m in diameter from where it recharges the permeable sandy layers underneath the impermeable takyr. The concentrated water is preserved in a freshwater lens above the saline aquifer and it stays separated from the salty water due to its lower density. One or more wells can be dug in and around the depression. Contrary to the other technologies used in the Karakum Desert, the storage capacity of these so-called chirles is flexible. When only one well for human consumption is in use, the structure costs USD 2500. When ten wells are dug, the cost increases up to USD 21,000. In case the wells are also utilized for livestock water or to improve the rangeland the cost rises to USD 36,500. Despite the first investment, maintenance costs are relatively low at USD 115-192 per year. The costs are usually shared by many households and the community maintains the chirles.

Oytak farming
Oytaks are natural takyr depressions covered with a layer of sandy soil that, during the rainfall, becomes moist and can be used for farming. Oytaks are traditionally used to produce fodder, but alternatively they can be used for crops and trees cultivation. Often oytaks gain water from the natural sloping surface of takyrs, but in certain cases the run-off water can be conveyed through furrows. When plants are growing, oytaks tend to act as sand traps and to decrease the surface area of the takyr. The construction of one furrow unit requires minimal structural work and has a cost of USD 24.

Modern takyr cultivation

Mechanized farming has potential in this harsh environment. A system of parallel furrows can be excavated perpendicular to the takyr slope to form a series of consecutive smaller catchments. Each catchment is confined in the lower side by a furrow in which the plants are grown. This system relies

Figure 2: Chirle well in Madau, western Turkmenistan (Photo credit: Luuk Fleskens)

Figure 3: Oytak after runoff event (Photo credit: Luuk Fleskens)

Figure 4: Oytak in Central Karakum (Photo credit: Luuk Fleskens)

on the fact that by reducing the catchment area a better runoff coefficient is obtained and the water is thus used more efficiently. In other arid regions similar farming practices are used to improve rangeland productivity, and typically an inter-furrow distance of 7-12 m is used depending on the climatic characteristics. When the climate is milder even fruit trees and melons can be cultivated using an interspace of 20-25 m. These modern systems require substantially higher investment and technological input than the traditional techniques, but they are potentially profitable.

Benefits

These different water buffer systems provide freshwater for human consumption and for economic activities in difficult desert conditions. Furthermore, with larger investments there is potential for larger-scale desert farming by using modern takyr cultivation. A household that has a directly available source of freshwater from one of the water harvesting techniques will save money otherwise used for trucking water or for pumping deep brackish water. In addition farmers will benefit from increased yields, healthier herds and lower dependency on piped water.

In a situation where herding is the main way of living, water brings potential for better conservation of the natural resources, but also some concerns. When water is concentrated in few spots, the animals tend to be concentrated in the areas immediately surrounding them. The risk of overgrazing and soil degradation is thus magnified. On the other hand without animal trampling around and breaking the surface crust, the soil tends to create a biogenic crust that can favor desertification processes. Nevertheless, pressure on natural resources caused by overgrazing can be decreased by augmenting the available sources of water and by spreading the herd on a larger area.

For agricultural production, modern takyr cultivation seems to always be profitable. High Internal Rate of Returns (IRR) were estimated: 130 for melon production, 38 for quince, 41 for grapes and 30 for pomegranates (Fleskens et al., 2007). When cultivating melons using oytaks the IRR is 99, based on average yearly conditions, assuming no external labor is hired and the average production of melons is 1200 kg.

For human consumption only sardobs and chirles can be used. Sardobs showed an IRR of 14. For chirles with a single well the IRR was 6.9, and when 10 wells where in use it was 8.6. These conditions refer to a situation where no external labor is needed and where the closest source of freshwater is 20 km away.

When the water harvesting techniques are used to create new rangelands in the central part of the Karakum, sardobs showed an IRR of 49, chirles of 61 and a small khak of 583. These figures are based on a number of assumptions: all the labor needed is provided internally and no rangeland degradation will take place. In case the water is used to create improved rangelands, the IRR always show positive values that guarantee a positive return.

Future

Investment in water harvesting from the natural landscape under a range options is profitable. Looking at the cost of water collected with the different methods, khaks appear to be the cheapest alternative in terms of cost of water per volume. Nevertheless, khaks can be used for only a few months per year and they produce contaminated water that is not safe for drinking. On the other hand, sardobs are the cheapest way to produce safe drinking water. This is particularly true when alternative sources of drinking water are more than 10 km away. The water harvesting systems for productive purpose all have very attractive prospects.

After the breakdown of the USSR, the central state investments in desert development ended and only few new structures has been constructed. There is a large unutilized potential – even in this inhospitable environment – to make more use of the natural harvesting basins. Local farmers associations may play an important role in managing the needed capital and in creating instruments to favor the construction of water harvesting structures.

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3.7. Fanya juu terracing

Tanzania and Kenya

Introduction

Fanya juu terrace systems have developed steadily in several parts of East Africa. One area where their spread has been spectacular is the Machachakos District in Kenya – where 85% of the land is now terraced. There are however several other areas where they are making an entrance. One area is the Makanya catchment in northern Tanzania. This catchment of 300 km2 is part of the Pangani Basin. Its population still largely depends on subsistence agriculture and the area is characterized by high rainfall variability – ranging from 400 to 800 mm annually.

Rain comes in two seasons. The long season (*masika*) lasts from March till May, whereas the shorter season (*vuli*) is from October to December. The maximum rainfall for any season is 400 mm. With the amount of water often heavily constrained, conservation measures are of crucial importance to raise yields and provide food security. Conservation measures in Makanya include hand-hoeing, terracing, intercropping, small flow diversions and irrigation from micro-dams.

Fanya juu: to throw it upward

Fanya juu literally means 'throw it upwards' in Kiswahili. The terrace systems are created by excavating a trench along the slope and applying the excavated soil material immediately uphill of the trench (Figure 1). This is repeated several times along a slope and as a result a system of benches and trenches is created. Next, nature is expected to do its work. The purpose of this system is to catch the flow of soil and water during run-off events before the benches and infiltrate water in the trenches. Over a period of 3-10 years terraces are formed with horizontal gradients.

Fanya juus can be developed on areas with slopes between 5 to 60% and climates similar to Makanya. As slopes get steeper the fanya juus become more costly to develop per surface area and less economical. Spacing of the trenches and bunds depends on slope and soil depth (Box 1). The construction by hand takes 90 days per ha on a typical 15% slope – or more (150-350 days/ha) in areas that are prone to erosion and have unstable soils. This translates in a cost of USD 60-460/ha. Bunds are best stabilized with grasses, which can be used for fodder too. Annual maintenance consists of building up the bunds from below and trimming grass.

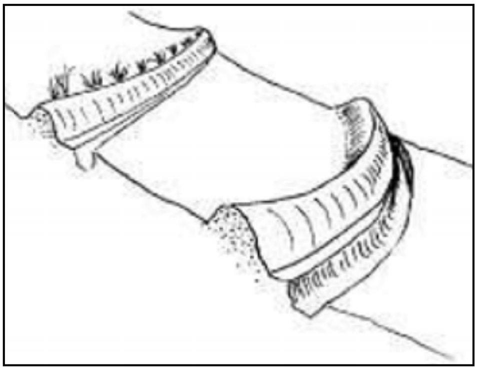

Figure 1: Diagram of a trench of a fanya juu terrace system (Source: WOCAT, 2007)

Box 1: Designing fanya juus

The spacing of fanya juu depends on slope and soil depth. It is usually between 5-20 m. On land with less than 5% slope it is 20-30 m, but terraces get smaller as land gets steeper: 15-20 m on land with a 5-10% slope; 10 to 15 m on a slope of 10% or more; and 5 m on even steeper slopes (10% or more).

- The height interval between two terraces is 1.7 m. As a rule of the thumb the distance between two terraces is 100 times the height interval between two terraces divided by the land gradient (in %).
- The infiltration ditches are typically 60 cm deep and 75 cm wide.
- The bund has a typical height of 0.4 m and a base of 0.5-1 m, and can vary to a height of 0.5 m and a base of 1.5 m.

On land that is very steep the bund is placed downhill from the trench. This practice is called fanya chine. It prevents that on very steep slopes the soil bund washes into the trench. The design of fanya juu also depends on the soil type. In sandy loamy soils an infiltration trench is useful. In 'black cotton' soil - with large water holding capacity - this is not required.

Figure 2: Fanya juus in Masingi, Kenya (Photo credit: MetaMeta)

Cost and benefits

Against the typical establishment costs of USD 60-460 per ha, fanya juu avoid uncontrolled run-off and improve the retention of soil moisture. This makes it possible to have earlier planting dates and a prolonged farming season, enabling higher yields of existing crops and providing opportunities for farmers to introduce new crops and new varieties. The fanya juu also help over dry spells. Crop yields typically increase by 50% (UNEP, 2000). Moreover, along the trenches horticulture crops can be grown: papaya, banana and fodder. Fanya juu protect against erosion and have the lowest soil loss of all soil water conservation systems. In a study of Kwalei, Tanzania soil loss from these systems was estimated at 2.7 ton/ha for the two seasons. In comparison to areas without protection, annual soil loss was estimated at 25 ton/ha, in grass strip areas it was estimated at 15 ton/ha, and for bench terraces 6 ton/ha. Fanya juu are economic investments in agricultural production – particularly when the land is not too steep or instable.

Box 2: Part of a large buffer management plan

Figure 3: Benedict Nbungi, chairperson Matuata WRUA. Priorities in the Matuata WRUA are awareness, creation and rehabilitation of small local storage, deepening of shallow wells, awareness creating, tree planting and fanja yuu terracing (Photo credit: MetaMeta)

The accelerated development of fanya yuu terraces is planned as part of sub catchment plans - that are being prepared by Water Resources Users Associations throughout Kenya. These WRUAs consist of prominent farmers and local leaders, a mix of women and men selected and trained by the Water Resources Management Authority and local chiefs. Their prime task is to enforce local water resource management - avoiding encroachment and unauthorized water diversions, protecting springs and river banks and promoting better buffer management. The WRUAs have registered as a Society. This provides the legal coverage to undertake activities, such as setting up nurseries, the development of sand dams, subsurface dams and local storage, terracing, and the promotion of roof top water harvesting.

Box 3: Optimizing soil moisture in the Fanya Juu systems

The soil moisture in fanya juus was investigated by Muharika et al. (2010). In order to assess the impact of fanya juu systems on the soil moisture content in the root zone around the structure, tubes were installed at gentle- and steep-sloped sites in the Makanya catchment (Figure 4).

Tube A represents the soil moisture in the 'controlled' situation, as no fanya yuu was constructed uphill. Tube B measures the moisture level, and so the impact, on the trench-site of the fanya juu. Tube C estimates the moisture level in the root zone in the middle section of the fanya juu, while the impact close to the bund is measured by Tube D. The research showed the following:

- Moisture levels in the rootzone around the fanya juu bench and trench structures are higher than those located at a distance. In the beginning of the rainy seasons, specifically, for the gentle-sloped areas (with large distances between the bunds) the moisture content around the fanya juu structure was around 17% and 12% in the area in the middle of the structures and upstream of those. In the dry spells the moisture level around the fanya juu structure was 3% higher than the other sites.
- At the steeper-sloped areas generally lower soil moisture levels were measured – but again the moisture levels closer to the structures were 3-5% higher. The distribution of moisture is critical as crops may move into the moisture-stressed conditions in parts of the fields.
- For moisture optimization the distance between fanya juu structures needs to be smaller (smaller than the distance recommended for the purpose of soil conservation) in order to enlarge the hydraulic potential of these structures. On steep slopes, particularly with shallow soils, the water of the trenches drains more as sublateral flows rather than adding moisture to the root zone.
- Another major conclusion is that in both sites with the fanya juu structures more than 50% of the water captured does not benefit local use as it is lost to deep percolation. This loss leaves room for other local water conservation structures, like micro-dams, to improve water retention in the area.

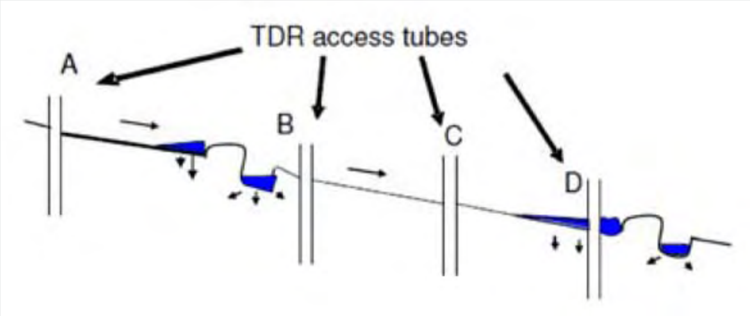

Figure 4: Placement of the TDR tubes along the slope (Source: WOCAT, 2007)

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3.8. Maximizing recharge with cascade check dams

Yemen

Introduction

Yemen is one of the five most water-stressed countries in the world, and within Yemen, Sana'a Basin – the seat of the country's capital – is the most precarious area. Yet Yemen is also a country with an extraordinary history of innovations in water management. One such innovation is the construction of cascades of check dams in wadis (ephemeral rivers). These check dams slow down the short-term flood flows in these dry rivers and maximize recharge. This enables the cultivation of very high-value grape farming in an area essentially dependent on only short floods.

Figure 1: High value grape farming, Wadi Qaradah Yemen (Photo credit: MetaMeta)

Cascade check dams

Wadi Qarada and Wadi Bahman are tributaries of Wadi A'ssir, located 30 km northeast of Sana'a. Like elsewhere in Sana'a Basin the climate is semi-arid. Average annual precipitation is 250 mm but evaporation is 2500 mm. Rainy days are few – 6 to 25 – spread mainly from March to August. In the dry catchment they transform into short-term floods, lasting a few hours. This is the main source of water.

The intermittent floods used to be either directly diverted to the land (so-called 'spate irrigation') or stored as surface storage in local reservoirs. Over the years agriculture has come to rely heavily on groundwater irrigation, but groundwater consumption far exceeds groundwater recharge. The difference is that Sana'a Basin is estimated at a factor four. Due to extensive irrigation and the rapid growth of Sana'a, the drop in groundwater levels in the main Tawilah Sandstone aquifer in the last fifteen years is estimated at 141 m.

Wadi Qarada and Wadi Bahman are famous for their grape farming and the production of high-quality and high-value raisins. Given the dry nature of the area this looks like a miracle – trellis grapevines stretch from mountain to mountain on either side of relative narrow dry riverbeds.

Historically, grape fields were spate irrigated by short-term floods, with supplementary irrigation practised from shallow open wells. These open wells were located near the banks of the riverbeds. Over the years, however, the shallow dug wells went dry or became seasonal. Many were abandoned and water abstraction from deep tube wells became the main source of water – resulting in lowered water levels to 350 m and reduced well productivity to less than half.

In Yemen in several places cascade check dams were built, for instance, in Wadi Qaradha and Wadi Bahman with the support of the Sana'a Basin Water Management Project. The cascade check dams consist of a series of low-elevation barriers (1-3 m high) built up from coarse stone pitching. Twenty-nine of these small structures were built in Wadi Bahman and 75 in Wadi Qaradha. The check dams are complemented by a protection wall along the riverbed, again made of stone pitching.

The cascade check dams serve two purposes: (a) to reduce the speed of flow in the wadi; and (b) to impound excess water during flash floods. The check dams divert water to spate irrigation canals on both sides of the wadi bed and increase the recharge of shallow groundwater. In semi-arid environments recharge most effectively occurs through riverbeds, as in these areas the alluvial deposits overlay sandstone and the cascade dams optimize the recharge effect.

Cost and benefits

An assessment was made of recharge efficiency of several water harvesting systems in the area: cascade check dams and different sized surface storage dams. Using a water balance model and flow monitoring values, the assessment concluded that cascade check dams have a recharge efficiency of 94%. This is ahead of the smaller storage dams and definitely much better than medium-sized dams. The cascade check dams are a major improvement over surface storage dams, because:

- Recharge through the riverbed is most effective. With cascade check dams there is an increase in the time for recharge and the areal spread of water, as floods are slowed down.

- Unlike in storage dams, sedimentation is not an issue: sediments are flushed by every subsequent flood. In storage dams on the other hand sediments accumulate at the bottom of the reservoir and obstruct the recharge of water.
- Check dams do not destroy the traditional distribution of water. Farmers along the wadi can continue to use the water for spate irrigation.

The value of incremental recharge due to cascade dams in Wadi Bahman was three times more than the incremental recharge at Beryan masonry surface storage dam. The cost of construction was only one fifth of the cost of construction of the gravity dam. The cost of investment in water storage per unit of check dams was calculated at USD 1.26 per m^3 and for recharged water it was in the order of USD 0.10 per m^3 (assuming a lifespan of 20 years).

Farmers in the area observed a marked improvement in water availability in the open wells near to the riverbed and a decline in the water level of tube wells. Fadhel M. Manea, Chairman of the WUA in Qaradha pointed out that 'one of the positive effects of check dams was diversion of run-off to spate irrigate grape fields on both banks of the wadi bed.'

Box 1: Designing cascade checkdams in dry river beds

The location and the height of the check dams are governed by the gradient of the stream bed, and the depth of waterway, respectively, while the cross-sectional dimensions depend on the expected peak flow. The design should preserve a proper speed of flow which ensures that sediment is removed at the upstream check dams providing clear water to the downstream part, which infiltrates more readily. A number of design criteria were adopted for the Wadi Bahman:

- The cross section of the check dam has mild side slopes to improve access to the wadi bed and to simplify the construction.
- A foundation key is preferred to improve dam stability against sliding and improve resistance to hydraulic pressure.
- For stream training purposes, the first dam of a check dam series should be constructed at the uppermost end of the valley. The first dam serves as the reference for calculating the distance to the second dam. It is rule of thumb that the height of the lower dam should be at the base level of the upper dam.
- To take into account the dug wells around the check dam site, the elevation of the crest of the check dam, and therefore the dam height, is set equal to the top elevation of the wells so that the upstream reservoir is extended to reach the wells, thus maximizing the dam's recharging capacity.
- The size of voids between boulders in the dam structure is selected so that sediments carried by the first flood will penetrate the check dam body and be deposited inside of the body of the dam, therefore improving stability and water tightness of the structure.
- The site of the check dam should not result in flooding behind the dam or create large shallow pools. Where back flooding does take place, protective embankments should be built.
- A protection wall along the wadi is added.

Box 2: Check dams

Check dams in Wadi Qaradha
Number of check dams: 75
Length : varying from 40 m to 100 m
Height of cascade check dam: varying from 1 m to 1.5 m
Crest width: 2 m
Upstream slope : 1V: 1H
Downstream slope: 1V : 3H
Total contract cost: USD 648,000

Check dams in Wadi Bahman
Number of cascade check dams: 29
Length : varying from 7 m to 57 m
Height of cascade check dam: varying from 1 m to 3 m
Crest width: 2 m
Upstream slope : 1V: 3H
Downstream slope: 1V : 5H
Total contract cost: USD 182,000

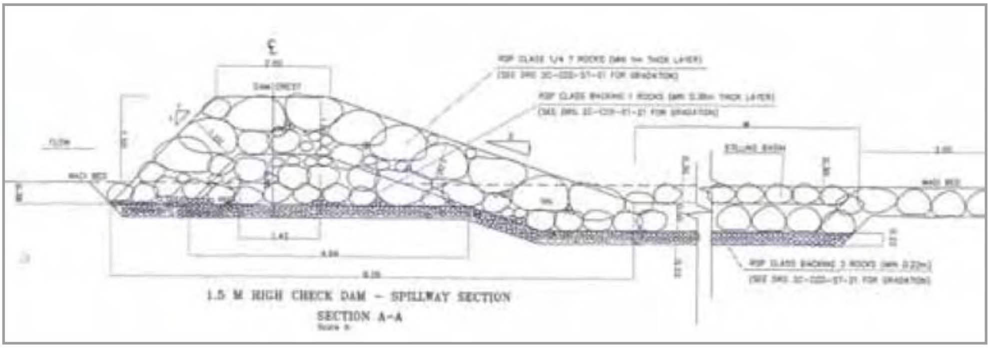

Figure 2: Features of a cross section of a 1.5 m high check dam at wadi Qaradha, Yemen

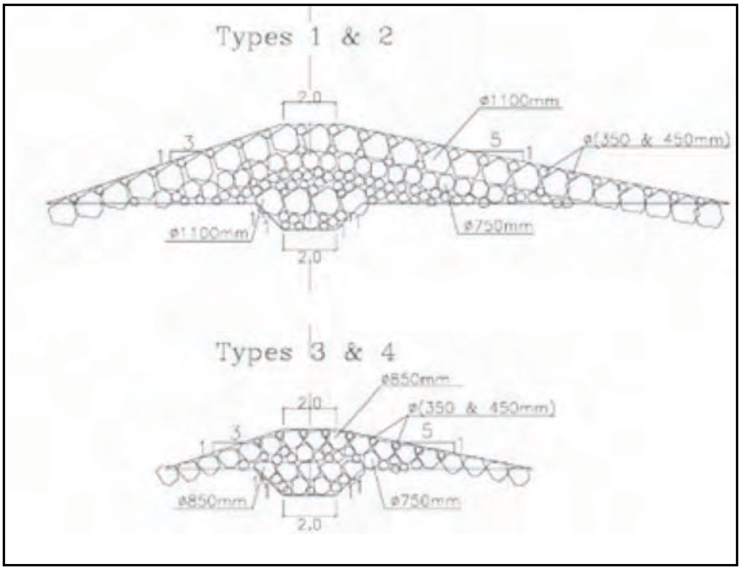

Figure 3: Typical cross sections of 3 m and 1.5 m high check dams at wadi Bahman , Yemen

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3.9. Groundwater retention weirs

Maharashtra, India

Introduction

Groundwater retention weirs, so called 'Kolhapur Type Weirs' (KTW), have been constructed by the Rural Development and Water Conservation Department of the Government of Maharashtra (India) under the Minor Irrigation Programme, Maharashtra (MIP-M). As far as irrigation structures go they are unique: the weirs do not divert water but rather they retain and head up the subsurface flow in the rivers, so as to replenish the wells upstream of the weir. The benefits are enormous: they create assured groundwater supply from the wells and improve soil moisture – contributing to substantially higher yields and making it possible to utilize a wider range of crops and benefit from higher crop intensities. They do not suffer from the operational problems of other irrigation systems as there are no channels to maintain. There are a recorded 131 medium-size KTWs in Maharastra, managed by the Rural Development and Water Conservation Department. A typical KTW has a command area of 100-250 ha. In addition there are thousands of smaller groundwater retention weirs under the authority of the local government.

Bolegaon KTW

A KTW is built across a river in order to store water in the riverbed within the banks upstream of the weir and the adjacent aquifer. For this purpose, a number of piers are constructed on top of the weir. Between these piers shutters are placed – known as 'needles'. This is done at the end of the

Figure 1: Downstream side of Bolegaon KTW (Photo credit: Olaf Verheijen)

Figure 2 and 3: Piers with installed shutters and bridge (upper) Reservoir area upstream of KTW (below) (Photo credit: Olaf Verheijen)

monsoon season so as to store water flowing in the river. These shutters are then removed at the start of the monsoon season in June, so that the monsoon flows in the river can pass the KTW freely. It is common to build a bridge on top of the piers for the placement and removal of the shutters and also allow traffic to cross the river.

An example of a KTW is the Bolegaon Weir located in Gangapur Taluka in Aurangabad District. The climate in Bolegaon is typical for southern India: dry and dominated by an intense southwest monsoon from June to October. Average annual rainfall is 710 mm – but most of this is in this monsoon period. Dry spells in the middle of the rainy season lasting up to a fortnight are experienced in August and they can play havoc with the rainfed crops. A farming population of approximately 2700 people depends on the KTW, mostly farmers owning less than 2 ha.

In 2004-2005 the Bolegaon KTW was constructed across the Shivna River, which is a tributary of the Godavari River. Its length is 92 m and reaches a maximum height of 4.5 m. It counts 31 piers constructed on top of the weir. The metal shutters are placed in the openings between the piers towards the end of August in order to catch the receding monsoon flow. With a discharge of at least 6.0 m^3/s, it takes no more than two days to fill up the area upstream of the weir. The storage capacity is 1.04 Mm^3.

Costs

The total construction cost of the KTW was USD 425,000. With a command area of 159 ha, this works out to USD 2,660 per ha. A main advantage of the KTW is that no land acquisition is required for water storage as the existing riverbed and adjacent aquifer is used for this purpose. Initially it was proposed in Boleagon to install 3 or 4 lift irrigation systems to pump stored water to the fields on the left bank of the Shivna River. Farmers insisted that there was no need for this as the seepage from the stored water would sufficiently recharge the existing wells.

One of the basic concepts was the effective participation of the concerned farmers in the planning, design, construction and management of their irrigation scheme. Once completed, the responsibility for the operation and maintenance of the newly-constructed KTW was formally transferred to the farmers. For this purpose, a water users association (WUA) was formed and registered, taking over responsibility for the KTW in 2005.

To finance the operation and maintenance of the KTW, the WUA collects an annual irrigation service fee from all landholders irrigating their fields within the command area. For the 2009-2010 season, the WUA set the fee at INR 1,000 (USD 22) per ha for sugar cane and INR 750 per ha for all other crops. For the 2010/2011 financial year (FY), the WUA proposed to increase the service fee to

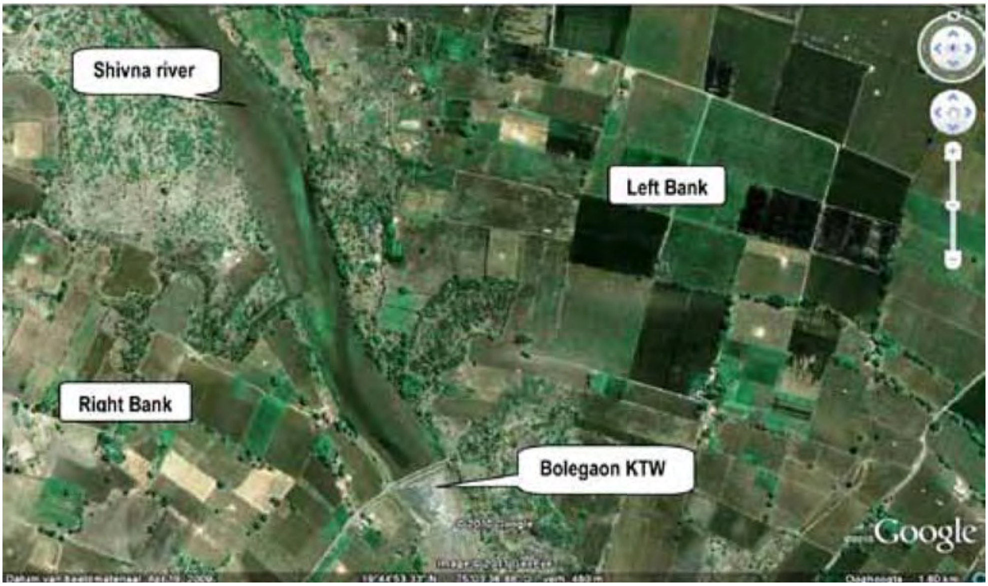

Figure 4:.Satellite image of the location of Bolegaon KTW. (Source: Google Earth)

INR 3,500 (USD 77) per ha in order to finance the replacement of the rubber seals of the shutters. An additional source of income is the lease of the fishing rights at a rate of INR 15,000 (USD 330) per year.

So far, the actual maintenance expenditures were modest: INR 63,000 (USD 1386) during the FY 2008/2009 and INR 53,000 during the FY 2009/2010, mainly for the replacement of bolts of shutters. One important advantage is that – contrary to conventional diversion irrigation systems – siltation upstream of the KTW is not a problem. When the shutters are removed from the KTW prior to the onset of the monsoon season, the first floods wash away any silt that has been deposited during the storage of water.

Box 1: The Water Balance at Boleagon

The catchment area upstream of the KTW site is 2,035 km^2. The total annual yield of the catchment area upstream of the KTW site is approximately 208 Mm^3. 162 Mm^3 is already allocated to 40 existing and proposed irrigation schemes upstream of the KTW site, so a net volume of 46 Mm^3 is available at the KTW site. As the Bolegaon KTW has a storage capacity of 1.04 Mm^3, downstream water users are not adversely affected as more than 40 Mm^3 continues to be available for utilization downstream.

There are three alluvial aquifers within a depth of 20 m at Boleagon. The thickness of each aquifer ranges from 1.5-7.0 m. These shallow aquifers are largely filled at the end of the monsoon season from natural recharge. Based on this natural recharge 4,000 m^3 water per ha can be abstracted for *rabi* (dry season) cultivation. This represents about 80% of the average irrigation requirement at 65% distribution efficiency. The remaining 20% of the irrigation requirement comes from the additional retention of water by the KTW.

Although the KTW itself is built on rock strata, the upstream riverbed and banks are comprised of sandy soils which are permeable. At full storage capacity, the daily seepage rate to the aquifers is estimated to be over 6,000 m^3, decreasing to zero when the KTW is empty and the ponded area decreases (Table 1).

It is estimated that approximately 20% of the total storage of about 1 Mm^3 recharges the aquifers through seepage from mid-September to mid-February. This is sufficient to allow the irrigation of 109 ha of rabi crop from groundwater as it will make up the 20% deficit that is not available in the aquifers from natural recharge. In addition, stored water is lifted by seven wells located in the riverbed itself with the capacity to irrigate about 50 ha. The water balance is lost to evaporation, leakage and deep percolation.

Table 1: Seepage rate as a function of water storage depth

Depth of water at KTW site (m)	Storage (m^3)	Surface Area (m^2)	Pond length (m)	Seepage area (m^2)	Seepage rate (m^3/day)
0.5	38,000	76,000	50	25	1
1.0	111,300	111,300	444	444	39
1.5	184,600	123,067	888	1,331	175
2.0	257,900	128,950	1,331	2,663	466
2.5	331,200	132,480	1,775	4,438	971
3.0	508,925	169,642	2,219	6,656	1,747
3.5	686,650	196,186	2,663	9,319	2,854
4.0	864,375	216,094	3,106	12,425	4,349
4.5	1,042,100	231,578	3,600	16,200	6,379

Benefits

The command area of the Bolegaon KTW is situated on both banks (although mainly on the left bank) of the Shivna River over a total length extending 2.5 km upstream and 1.0 km downstream of the KTW site, with a width of about 300 m. It is estimated that approximately 20% of the total storage of about 1 Mm^3 recharges the aquifers through seepage between mid-September and mid-February. This is sufficient to safeguard irrigated agriculture of 109 ha of rabi crop from groundwater as it will make up the 20% deficit that is not available in the aquifers from natural recharge. In addition, water is lifted by seven wells newly installed inside the riverbed with the capacity to irrigate about 50 ha. These are operated as soon as the river bed falls dry. The balance water is lost to evaporation, leakage and deep percolation. A total of 152 households own land in these areas. According to an inventory, a total of 45 dug wells and 9 tube wells were installed in the command area prior to the construction of the KTW. The wells are clustered along the banks of the river and in a defined 'strip' of land away from the river with a recharge connection from the river. Most farmers use 5.0 to 6.0 HP (electric) pumps to lift groundwater from the wells.

Figure 5 and 6: Dug-well (upper) and tube-well (below) in ICA on left bank, India (Photo credit: Olaf Verheijen)

Before the KTW was constructed, the wells had water for about 9 months per year until February/March – missing out on the large and vital part of the growth season. Following the construction of the KTW, all wells except three on the right bank have water throughout the entire year. The main limitation for the operation of the wells is the availability of electricity for only 8 hours per day.

The WUA has adopted a policy that forbids the installation of new wells within the command areas in order to avoid that the aquifers are overdrawn and the existing wells become dry. Further to improving water use efficiency, a total of 20 farmers have installed sprinklers on 50 ha and drip systems on 10 ha in the ICA.

Transforming lives

The agro- and socio-economic impact of the construction of the Bolegaon KTW together with the development of the WUA and the implementation of the agriculture development programme has been very significant. The main achievements are briefly described below (Table 2.).

First and foremost, the cropping pattern has changed considerably with the larger groundwater security and assured soil moisture. The range of crops has increased, the cropping intensity has gone up and so have the yields..

Table 2: Impact of the construction of the Bolegaon KTW , the development of the WUA, and the implementation of the agriculture development programme

Crops	Pre-Project Cropping pattern		Post-Project Cropping Pattern			
	2002/2003		2009/2010		2010/2011	
	Area (ha)	% ICA	Area (ha)	% ICA	Area (ha)	% ICA
Kharif						
Millet	68	43	41	26	10	6
Maize	16	10	7	4	20	13
Pulses	-	-	26	16	-	-
Vegetables	-	-	-	-	2	1
Rabi						
Wheat	-	-	24	15	20	13
Sorghum	24	15	12	8	6	4
Gram	33	21	27	17	1	1
Sunflower	10	6	-	-	-	
Maize	-	-	6	4	-	
Vegetables	-	-	12	8	2	1
Two Seasonal						
Cotton	48	30	48	30	98	62
Chilli	-	-	13	8	2	1
Sugarcane	-	-	11	7	27	17
Horticulture	-	-	6	4	-	-
Ginger	-	-	-	-	2	1
Total	**199**	**125**	**233**	**147**	**188**	**120**

Prior to the construction of the KTW, the farmers cultivated primarily dry staple crops. Five years after the completion of the KTW, a larger range of crops are being grown. This includes new cash

 

Figure 7 and 8: Cultivation of cotton and sugarcane (left) and ginger (right) in ICA (Photo credit: Olaf Verheijen)

crops: vegetables, chilli, sugar cane and fruit. During the 2010/11 rabi season, a number of farmers also started the cultivation of ginger, and the area under cotton increased from 48 ha to 98 ha.

The cropping intensity increased from 125% in 2002/03 to 147% in 2009/10, but it decreased to 120% in 2010/11 as a result of the cultivation of two additional seasonal crops – mainly because of the cultivation of two long duration crops, sugar cane and cotton.

Due to the larger groundwater security, better soil moisture and the agricultural development programme, yields have improved significantly. For instance, maize production increased from 3.0 t/ha in 2003-2004 to 5.8 t/ha in 2009-2010. During the same period, the yield of cotton improved from 0.5-1.0 t/ha to 2.5 t/ha.

According to data collected during the agro-economic impact assessment in 2010, the net return increased from INR 6,921 (USD 157) per ha in 2003-2004 to INR 36,401 (USD 824) per ha in 2009-2010[1]. In other words, the farmers' incomes improved by 425% and the payback to investment period is less than five years. The improved availability of soil moisture irrigation water in the wells throughout the growth season due to the construction of the KTW is the most important factor for this significant increase in farmers' income as it allows farmers to cultivate more irrigated land, to grow more high value crops and to achieve higher yields for the planted crops.

In addition to the benefits in crop production, the following positive impacts were highlighted by the Water Users Association:

- 50 to 60 landless households are employed as daily labourers throughout the year and wage rates for female labourers have increased from INR 30 to INR 150 per day.
- Access to better education as 15 students attend an English Medium School.
- Improved access to health care as more households go to the hospitals in the town of Aurangabad instead of the local health clinic in Gangapur, whereas all pregnancies are now supervised by medical staff.
- More families can afford the consumption of wheat in their daily meals.
- 25 to 30 households have replaced their mud houses by premises made of brick and concrete.
- About 100 households use LPG for cooking instead of kerosene burners, whereas most

1 Corrected for inflation by using the World Bank deflator indices.

households have purchased a colour television and satellite dishes.
- Almost all households with land use rights in the ICA have purchased a motorcycle during the last 5 years.
- 15 new tractors were bought by households having irrigated land in the ICA.
- Dowry for marriages has increased and weddings take place in wedding halls in urban centres instead of the village itself.
- Many households have been able to buy extra cows and buffaloes in order to increase the production of dairy products.

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Field survey by Olaf Verheijen

3.10. Controlled intensive grazing

Savannah Grasslands, Africa

Introduction

Cattle grazing is often singled out as the main cause of the loss of savannah grasslands. Overgrazing, it is said, causes degradation and makes savannah areas susceptible to desertification. To reverse this trend reduced livestock herds and area closures are recommended to restore grasslands.
Some experts – such as Allan Savory – are of a diametrically different opinion, namely that at least in xeric savannah areas land degradation would accelerate should cattle or wild grazers disappear. Perennial grasses die out when they are not being grazed or occasionally trampled. Instead planned grazing by bunched animals can restore grasslands and add to their productivity as well as biodiversity and capacity to sequester carbon. There are a now many experiences with this 'holistic management' approach that illustrate its merits.

When savannah terrain is grazed by large, tightly-bunched livestock herds, their trampling breaks the soil crust. This ensures that air can enter and more water infiltrate when it rains. The trampling also knocks down ungrazed leaves to provide a soil-covering mulch, while compacting soil to provide good seed-to-soil contact. Dung and urine provide fertilizer to feed the new grass plants that establish in the improved microenvironment.

Box 1: From an interview with Jody Butterfield, author of 'Holistic Management Handbook - Healthy Land, Healthy Profits.'

"We actively discourage fire – because of the pollutants it puts into the atmosphere (which in turn exacerbate climate change), and while overgrazing is a problem, the bigger problem in most of the savannah grasslands is 'overrest' – too much soil remains undisturbed, too many plants are left ungrazed. As a result plant spacing gets wider, bare ground increases and so does soil surface evaporation and rainfall runoff and 'droughts'. What we promote is holistic planned grazing, which bases herd moves on plant recovery times – so that animals don't remain for too long in one place, nor return to it too soon (before plants have regrown leaf and re-established the root sacrificed following the first grazing). We try to maximize the herd size and density so that more soil is loosened, so it can breathe and water can penetrate; and so that uneaten plants get trampled down to cover the soil and to expose growth points to sunlight in the following growing season (overrested perennial grasses – neither eaten nor trampled) will turn grey and remain standing for years in seasonally humid environments, and gradually choke out new growth altogether."

Figure 1: Dimbangombe herd of cattle and goats being tightly herded on the river banks. Note herding mostly from front controlling speed of move as they graze and trample. (Photo credit: CJ Hadley, RANGE magazine.)

More cattle, more grass, more water

There are generally four recommended ways to keep perennial grass plants healthy: mowing, burning, resting or grazing them. The first option 'mowing' is impractical in most places as it is too laborious. Economics militate against this and even the resources to do this may simply not be there. Neither is fire recommended. It is now used on a large scale to manage African grasslands, basically due to the lack of animals. More than 800 million ha of grasslands are burned each year on the African continent alone, adding huge quantities of carbon to the atmosphere and drying out the soil.

'Resting' (or non-disturbance by livestock or fire) is conventionally proposed to restore perennial grasslands. This may result in an initial burst of growth in vegetation that was being overgrazed and can now grow freely. But within a few years, rested perennial grasses grow rank and start to oxidize, as indicted by their grey colour. The oxidizing mass of leaves prevents sunlight from reaching the growth points at the base of the plant, and it gradually chokes to death. When the soil surface is rested from 'hoof impact' it seals with the first rainfall and stays sealed so that very little water can infiltrate, and what does soak in quickly evaporates on flat land or, on slopes, runs off. Though resting soils and forage is perennially humid environments, it is damaging in semi-arid seasonally humid or 'brittle' environments.

By far the best option is to re-appreciate the role of livestock in grassland management. Root systems of perennial grasses react to above ground disturbances (grazing and trampling) of the grass. If perennial grasses are grazed by cattle (or for that matter by the bison, buffalo and other wild grazers that co-evolved with grasslands and their soils), the root system reacts with a survival mechanism: roots die back to provide energy for growing new leaf. However, if the animal that grazed the plant remains, it is likely to bite the tender new growth well before roots have had time to grow back and the plant will then be 'overgrazed'. On the other hand, perennial grasses properly grazed – i.e., given time to recover and regrow – can live several hundred years. In the process soil is built up and carbon is sequestered.

When properly grazed and impacted, grasslands act like sponges, storing humus and carbon, while the roots perforate the soil and open it up, which increase porosity and infiltration capacity. This is further aided by the trampling of the sealed soil surface, or soil crust, as well as the ungrazed vegetation. This then allows water to soak in where it can be used by plants, or eventually trickle down to feed springs, rivers, and boreholes or wells, thus increasing the residence time of the rainfall in the catchment and prolonging the hydrological cycle – or in 3R terms it 'extends the chain of uses'. The beneficial impact in semi-arid but seasonally humid environments is that a wetter ecosystem is created, capable of supporting more life and more economy. The wetter ecosystem is better for herbivores, because the native long life perennial bunch grasses green up sooner and stay green longer. This in turn feeds the grazing animals longer. It is also generally a much better bet than introducing exotic annual grasses. These annuals need to grow up, flower, set seed and die all in one season. In the next season they may not germinate at all if conditions aren't exactly right. Annual grasses are also shallow rooted and hence do not sequester carbon in the soil.

From a buffer management perspective, a main task for pastoralists and rangers is to reclaim the perennial grass component of their rangelands. This will help retain water, provide much better forage and mitigate erosion and soil loss. Holistic planned grazing works toward this end by timing recovery periods to the needs of perennial grasses, which then allows them to germinate and grow. Resilient, healthy grasslands are animal-maintained, rather than fire-maintained or rest-maintained grasslands. Although pastoralists may be seen as cattle farmers, it would be better to view them as grass-farmers working to harvest sunlight through green, growing plants that cover soil, feed animals and people, and, through well planned grazing also sequester water and carbon. The priority is to invest in developing animal-maintained grasslands in which perennials dominate.

Examples

On Dimbangombe Ranch in Zimbabwe, which is managed by the Africa Centre for Holistic Management, livestock (cattle, goats and sheep) is herded by day and placed in lion-proof enclosures at night, according to a holistic grazing plan. In the growing or rainy season the herd does not graze an area for more than three days and doesn't return to it for at least three months. Because the animals are herded, rather than controlled by fencing, they remain in a group throughout the day, providing good impact on soils and plants. In the long dry season, the timing is similar, but because plants are not growing- or growing very slowly – this can sometimes be a longer process. In the nighttime enclosure, remaining in one place from 3-7 days, the herd creates very high impact, which results in stunning growth in the months afterward (or when it rains). In agro-pastoral areas the nighttime enclosure is used to prepare crop fields for planting and results in maize yield increases of 3-7 times higher than those on adjacent conventionally prepared fields (Savory and Butterfield, 2010).

The improved forage on Dimbangombe, following almost a decade of holistic planned grazing and fire prevention, has enabled the ranch to increase livestock numbers substantially – currently 400

Figure 2 and 3:These pictures are taken at fixed points at one of the sites on Dimbangombe. The top picture is taken in 2006 and the bottom picture in 2009 after treatment once with very high animal impact. The top picture a shows the situation of this land as it had been for over thirty years. No matter whether the rainy season was good or bad - it used to be permanently bare and eroding for many years. (Photo credit: Savory Institute) per cent higher than when they began, and they say they could double the figure immediately if the funds and the livestock were available. The land has improved too. Once dominated by bare ground, fire-prone grasses and intermittent river flow, it is now difficult to find bare ground in the low-lying areas. In fact remnant patches are being preserved for wildlife. Grasses are becoming less fibrous and leafier resulting in an enormous reduction in fires, and the Dimbangombe River, though not yet perennial year round, has increased its length by 1.5 km higher up its catchment where it now has perennial pools with fish, ducks and other wildlife year round. The whole upper catchment area has become an ever-expanding wetland with new springs emerging as well as reed thickets. Furthermore, by keeping the livestock in lion-proof kraals, predators – lion, cheetah, leopard and hyena – are able to roam freely and help keep the wild grazing herbivores moving. In the absence of predators the wild grazers, like livestock, become static and damage soils and plants through overgrazing and overtrampling, especially in riparian areas.

Flexibility is a big part of the new grazing concepts. In another area in Zimbabwe, commercial farmer Johan Zietsman used cheap portable electric fences and strip grazing to create ultra-high densities – which had since been impossible to achieve other than by herding. During the dry season these densities – up to 3,000 cattle per ha – were used to trample the old growth and cover the soil. Over a ten-hour period the animals were moved ten times. Being so close to each other the hoof action of the animals is different, less gentle and able to disturb the area in a regenerative way – much as the tightly-bunched herd at Dimbangombe achieves. At night the animals were left to ruminate over a larger portion of the lane being strip grazed. The ultra-high density and good planning – still based on recovery time - achieved higher productivity of both cattle and forage. The large 'herd effect' resulted in a very effective impact on the land compared to herds that graze at low density. No trailing occurred and all animals grazed at the same time. They were still able to select their diets although the 'paddock' appeared to be more uniformly grazed. Zietsman was been able to double his stocking rate with this innovative fencing layout and good planned grazing against a minimal capital layout – i.e. the small costs of the movable live fencing. The results after one year were already significant: mature capping of the soil decreased from 43% to 1%; over-rested grass plants disappeared from 42%; palatable broad-leaved grass increased from 11% to 52% of the area, whereas unpalatable narrow-leafed grass decreased from 86% to 46% (Howell, 2008).

Holistic planned grazing is also practised in other semi-arid parts of the world with intense rainfall periods. On the large La Inmaculada Ranch, managed by the Aguirre family, in the Sonaran Desert of northern Mexico, planned grazing has resulted in a vigorous return of perennial grasses as well as ironwood and mesquite, the latter providing high-protein forage in the dry season. Rainfall averages 330 mm – most of it falling in the summer but this varies widely in time and space. During the summer growing season each paddock or grazing area is grazed only once, generally because growth is slow and recovery time for perennial grasses can be very long. They generally don't stay longer than two or three days when growth is fast, but can stay more than a week when growth is slow. Cattle never make a large dent into the new season's growth and sufficient forage is left to be rationed out through the long dry or winter season. Since beginning to plan their grazing, the Aguirres have increased soil litter cover 23% to 63% and the density of perennial grasses more than fourfold (Howell, 2008), again bringing together productivity and sustainability.

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3.11. Shallow tubewells in flood plains

Africa

Introduction

There is no precise estimate of the area under flood based farming systems in Africa – but a reasonable estimate is that it is upwards of 10 million ha. Flood recession farming occurs in the areas along the Niger, Zambezi, Senegal, Tana, Rufelji and Lufira rivers and their tributaries, around lakes, minor rivers and in natural depressions, such as dambo, as well as on the vast plains of South Sudan. So far flood recession agriculture has received as good as no attention, but there is large scope for applying a broad-based approach to improving the productivity of these systems and the livelihoods of the people depending on them.

Flood plains in Africa are excellent natural wet buffers. Groundwater is usually available at shallow depth and is replenished annually. Moreover any water that is diverted and not used ends up inside the 'wet water buffer' – from which it can be easily retrieved. The inundation also carries sediment that revives the land annually. However, compared to Asia the density of population, livestock and agriculture in African flood plains is still very low.

Techniques

There are several opportunities to explore the potential of the flood plains:

1. Better water management – use of dikes, inundation canals and drains to better guide and control water

Flood based farming systems occur in different parts of the world and can sustain large populations. A prime example is Bangladesh, where over centuries a sophisticated system of bunds, dikes, canals and drains has developed, spreading the inundation over a large area, avoiding standing water and generally retaining the water for a longer time. Elsewhere raised beds are made to start cultivation earlier and use the inundation water (Mexico), or in the dry season crops are transplanted to chase the falling moisture table (India).

2. Transformation to flood-rise agriculture

Crops can be grown in the residual moisture after the flood plains have fallen dry, but in some areas the rising flood water can also be used, particularly for the cultivation of fast-growing rice species which keep apace with the rise in inundation levels.
The recent transformation from flood recession to flood rise culture around Lake Tana in Ethiopia has permitted double cropping: growing rice on the rising flood and, subsequently, other crops,

such as chickpeas, on the residual moisture. Such transformations are possible for other areas too depending on the pattern of flood rise. In such areas the introduction of floating rice varieties may be considered – very fast growing varieties that keep up with the speed of the rising flood and can reach 3-5 m in height. Floating rice varieties grow in areas as varied as Mali and Cambodia.

3. Use shallow groundwater

Most flood plain areas are areas with ample shallow groundwater resources. As they are continuously recharged from the floods and the river flow, they constitute a highly dependable resource that is relatively easy to exploit. It requires the use of shallow tube wells – that can be sealed during the flood season – rather than dug wells that will inevitably be damaged when inundated. Irrigation from shallow tube wells will allow starting supplementary irrigation soon after the floods have receded. There are several techniques (Box 1) that are low cost and can be mastered artisanally. Unlike Asia the skills in manual drilling of shallow wells is not yet as widespread in Africa.

4. Diversification - fishery, livestock

Flood based farming system provide the basis for diversified livelihood systems – not just farming, but also fishery and livestock keeping. Fish for instance can be promoted by finger-ponds. Also the wetlands in and around flood based systems often offer opportunities for non-timber products, medicines and other products. Market chains are however not well developed.

Figure 1: Developing high value horticulture on the Lake Koka floodplain, Ethiopia (Photo credit: MetaMeta)

Table 1: A quick guide to manual drilling techniques

Technique	Description	Advantages / disadvantages
Hand Auger	Consists of extendable steel rods, rotated by a handle. A number of different steel augers (drill bits) can be attached at the end of the drill rods. The augers are rotated into the ground until they are filled, then lifted out of the borehole to be emptied. Specialized augers can be used for different formations (soil types). Above the water table, the borehole generally stays open without the need for support. Below the water table a temporary casing may be used to prevent borehole collapsing. Drilling continues inside the temporary casing using a bailer until the desired depth is reached. The permanent well casing is then installed and the temporary casing must be removed. Augers can be used up to a depth of about 15-25 m, depending on the geology.	Advantage: Easy to use above groundwater table; cheap equipment. Disadvantage: It may be difficult to remove the temporary casing. Geological application: Sand, silt and soft clay.
Sludging	Uses water circulation to bring the drilled soil up to the surface. The drill pipes are moved up and down. On the down stroke, the impact of the drill bit loosens the soil and on the up stroke, the top of the pipe is closed by hand (or valve), drawing up the water through the pipe and transporting the cuttings to the surface. On the next down stroke, the hand (valve) opens the top of the pipe and the water squirts into a pit, in front of the well. In this pit, the cuttings separate from the water and settle out, while the water overflows from the pit back into the well. The borehole stays open by water pressure. Thickeners (additives) can be added to the water to prevent hole collapse and reduce loss of working water (drill fluid). Water mixed with cow dung is a often used for this matter. Sludging can be used up to depths of about 35 m.	Advantage: Easy to use and temporary casing is not needed. Disadvantage: Working water has to be maintained during the drilling process. The level of the water table is not known during drilling. Geological application: Sand, silt, clay, stiff clay and softer- consolidated rock formations weathered laterite
Jetting	Based on water circulation and water pressure. As opposed to sludging, water is pumped down the drilling pipes. The large volume of water has an erosive effect at the bottom and the 'slurry' (water and cuttings) are transported up between the drill pipe and the borehole wall. A motor pump is used to achieve an adequate water flow. The drill pipe may simply have an open end, or a drill bit can be added and partial or full rotation of the drill pipe can be used. Thickeners (additives) can be added to the water in order to prevent hole collapse and reduce loss of working water (drill fluid). Jetting (with rotation) is generally used up to depths of 35-45 m.	Advantage: Rapid in sand. Disadvantage: A lot of working is needed at once. The level of the water table is not known during drilling. Geological application: Limited to sand and thin layers of soft clay.

Development of the fadama flood plains

The fadama are the extensive flood plains and low-lying areas underlined by shallow aquifers, found along Nigeria's river systems. The alluvial aquifers are formed by the deposition of suspended material over the low gradient plans and its poorly defined canals. Silt and other materials are suspended in stagnant ponds. Over time, these accretions form layers of silt, clay, sand and silty loam overlying the original sandy material – in no obvious order. The low water transmissivity and storage properties of the heavy alluvial material and its uneven distribution result in pockets of aquifers throughout the floodplain. Through experience and trial and error, water users excavated wells where local aquifers occurred. Hence, traditional shallow dug wells – with depths of less than 5 m - are often clustered in groups along the fadama. Areas of local occurrence of clay are revealed by failed wells and become preferred sites for brickmaking. The climate is semi-arid with rainfall in the order of 700 mm, with a peak in August. In the past irrigation started in November, after the plains were sufficiently dried to allow the re-excavation of the dug wells (Tarhule and Woo, 1997).

Since 1992 the World Bank has supported the development of agriculture in these areas. An important component has been the construction of over 40,000 shallow tube wells, equipped with small engine-driven water pumps, a new technology at the time. This made irrigation more reliable, covering a longer period and allowed for the cultivation of vegetables for instance. This was part of a larger package – increased supplies of farming inputs and extensive infrastructure improvements – from local storages to roads. To sustainably increase the incomes of different groups (farmers, fishermen, hunters, pastoralists, gatherers) grants were provided for small-scale productive and/or economic infrastructural sub-projects, such as fishponds, cold stores, feed mills, harvesting equipment and feeder roads, small bridges, culverts, rural markets, rural electrification as well as training and skills development. The accelerated development also created tensions between different users groups, particular farmers and sometimes militant outside pastoralist groups, concerning access to land caused by the degradation of grazing land elsewhere. Another issue is that, as wells are used intensively for irrigation in the morning, they are sometimes not yet recharged in the afternoon when they are used for livestock watering. The Fadama Development Project takes a community-driven development

Figure 2: Dugwells in flood plains: prone to collapse and vulnerable to lowered water tables (Photo credit: MetaMeta)

approach, which places beneficiaries in the driver's seat. Local community members, under the umbrella of Fadama Community Associations and Fadama User Groups, oversee the development of local development programmes and are empowered through skills and capacity-building to improve their livelihoods by increasing income generating activities.

Table 2: Inputs for manual drilling of shallow tubewells

Method*	Equipment (USD)	Labour (Days)	Maximum depth (m)
Hand auger	200 - 600	1 - 4	15 - 25
Percussion	300 - 1200	2 - 8	< 25
Rotary jetting	800 - 1400	1 - 2	35 - 45
Rotary sludging	600 - 1000	1 - 3	35

* The choice of drilling method and number of labour days is dependent on the geological strata and the depth of the well
To this the costs of the well casing (bamboo, PVC, GI) and packing should be added

Source: PRACTICA Foundation. 2010. Manual drilling series - Technical training on affordable manual well drilling

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3.12. Plastic mulches, biodegradeable alternatives

China and US

Introduction

In the last twenty years plastic mulching has made a meteoric rise – very much so in China, where in some areas entire valleys glisten as they are partly wrapped up in plastic mulch. In 1999 already the area under plastic mulch was estimated at 9.5 million hectares (Brown 2004). This area has by now at least doubled. Especially in drought prone provinces in North West and South West China, such as Xinjiang and Yunan, the technique is very common. Plastic mulching is popular because it creates a microclimate allowing better control of water, temperature and nutrients. It allows earlier cultivation and requires substantially less weeding. The plastic mulch prevents unproductive evapotranspiration of water. Instead water is kept within the reach of the crop roots. Besides its effective internal water circulation in the top soil, the plastic cover increases nutrient uptake (through prevention of nutrient leakage during occasional showers), and increases or decreases soil temperature (allowing earlier germination).

Figure 1. Plastic mulch mulch is very popular in China (photo credit: MetaMeta)

Different colors of mulch are used: transparent (clear), white, black, each having different impact on crop growth factors. Transparent sheets support early season plant growth and cropping, as sunlight shines through the sheets. Black sheets are used to control weed growth, as sunlight is unable to pass, blocking photosynthesis. White (or silver or aluminum) sheets are used to re-direct sunlight that has passed the leaf canopy, to the leaves again, allowing higher yields. Simultaneously white sheets cool the soil allowing crop cultivation during high temperatures. The sheets also differ in thickness and porosity – with different impacts on water circulation, nutrient uptake and longevity. The plastic sheets are placed manually or mechanically and holes are punched in the sheets to allow the growth of plants.

Application and removal of plastic mulch requires additional labour and costs, but this is outweighed by the increase in crop production – that under normal circumstances is 50%, but in exceptional cases can be even a factor 4 or 5 (Sanders, D.C., 2001; Osiru and Hahn, 1994; Ashrafuzzaman, M. et al. 2011). The increased cost for the mulch is partly compensated by savings on labour and energy costs for removal of weeds, fertilizer application and irrigation. For instance drip irrigation system widely used in combination with plastic mulch uses "much less energy and water than do methods such as furrow irrigation or overhead sprinklers" (Kovach et al. 1999).

Challenges in the plastic mulch are financial and environmental. The price of plastic mulch is high – at approximately 0.14 USD per square meter or USD 700 per hectare (not the entire area all is covered). Environmental challenges concern the disposal of the plastic after its life cycle is over – typically between one to ten years – depending on thickness and use.

Biodegradable alternatives[1]

The concern regarding plastic mulch residuals in the soil and the costs of plastic mulch usage have resulted in a search for biodegradable alternatives. Costs of mulch removal and disposal in the US were estimated at USD 250 per hectare in 2004, a costly disadvantage (Schonbeck, 1995; Olsen and Gounder, 2001). Biodegradable plastics were introduced to agriculture in the 1980's. However, they did not degrade sufficiently (undergo a significant change in chemical structure resulting in a decrease of physical and mechanical properties, [per ASTM D883-11, 2011]) and instead fragmented into small pieces (Riggle, 1998). By the 1990's, inaccurate claims for these products caused confusion about the term 'biodegradable' (Yabannavar and Bartha, 1994), and nearly twenty years later, grower skepticism remains. Further, biodegradable products that are commercially available for agriculture are generally two to three times more expensive than standard black plastic mulches.

To be considered biodegradable, products should decompose into carbon dioxide, methane, water, inorganic compounds, or microbial biomass (Song et al., 2009). Biodegradation is generally initiated by abiotic degradation followed by microbial degradation (enzymatic hydrolysis of polymers), first to low molecular weight oligomers and finally to carbon dioxide and water. The American Society for Testing and Materials (ASTM) and other agencies worldwide have outlined protocols for assessing the biodegradability of plastics – e.g. ASTM D6400 (2004) which specifies that in compost

1 Contributed by: C. Miles, D. Hayes, M. Brodhagen, J. Lee, A. Wszelaki, J. Moore-Kucera, R. Wallace, T. Marsh, and D. Inglis. Washington State University, University of Tennessee, Texas Tech University, Western Washington University, and Texas A&M University; USDA SCRI Project No. 2009-02484.

at 58°C, 60% of a plastic's organic carbon molecules must be converted to carbon dioxide within 180 days. However, these methods fall short of definitively quantifying the degradation of polymers at the molecular level (Krzan et al., 2006; Roy et al., 2011; Yabannavar and Bartha, 1994).

For a biodegradable mulch to be considered successful, it should perform equal to black plastic mulch in regards to weed control, moisture conservation and temperature modification, and crop growth and yield. Additionally, it should be sufficiently degraded near final harvest to allow for burial and further biodegradation in the soil without increasing labor costs (or other inputs). Mulches that are labeled as 'biodegradable' are commercially available (Table 1). Paper mulch made of cellulose is 100% biodegradable in the field, while other mulches that contain polymers derived from non-renewable petroleum have been shown to be biodegradable, but under composting rather than field conditions. Biobased (derived from renewable biological starting materials such as starch) and biodegradable polymers, such as polylactic acid (PLA) and polyhydroxyalkanoate (PHA) are also available commercially, and have good potential as agricultural mulches (Vroman and Tighzert, 2009). PLA is derived from microbial transformation of corn starch, and has numerous applications in biodegradable or compostable materials. Production of PLA mulch is increasing, and costs are more competitive with polyethylene mulch (currently only approximately 15% higher) (http://www.cupdepot.com). PHA is produced by bacteria, and is significantly (three times) more expensive than PLA. Both PLA and PHA biopolymers can be brittle and PHA is susceptible to thermal degradation.

The overall effects on soil health and microbial ecology of incorporating biodegradable mulch into agricultural soils are unknown. One concern is that conventional plastics can form microplastics (particles smaller than 5 mm in diameter) that adsorb toxins present in the environment, thus concentrating them (e.g. Zarfl and Matthies, 2010; Teuten et al., 2007; Mato et al, 2001). It is not known whether biodegradable mulch fragments will also adsorb and concentrate toxins (e.g.

Figure 2: Black plastic mulch used in pineapple plantation, Kenya (Photo credit: MetaMeta)

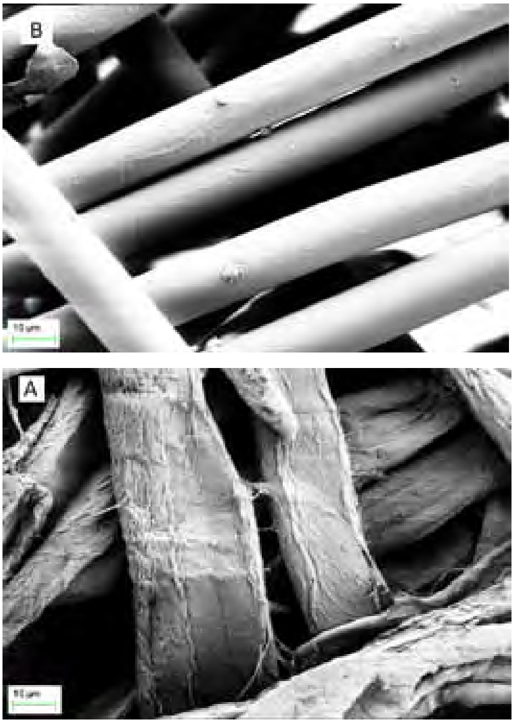

Figure 3: SEM photomicrographs of cellulosic (a), SB PLA (b) and MB PLA (c) specimens initially at 1000X

pesticide residues) sometimes found in agricultural soils and what effect this process could have in an agroecosystem. Also unknown is the rate at which soils will promote biodegradable mulch breakdown – rates will likely differ by region and cropping system. For example, in an ongoing field study, selected commercially available biodegradable mulches (two starch-based and one cellulose-based) and an experimental spunbond PLA mulch were tested for tomato production in three diverse geographic locations of the United States (northwestern Washington which is cool and humid, northeastern Tennessee which is hot and humid, and northwestern Texas which is hot, dry and windy). At the end of the first year, all commercially available biodegradable mulches showed evidence of increased degradation (compared to polyethylene mulch) in all climates, and degradation was greatest in the hot, dry windy climate. The cellulos-based mulch degraded the most at all three sites while the spunbond PLA mulch showed no evidence of physical breakdown.

Small squares of the biodegradable mulches were subsequently buried over the winter at each site, and during the following spring, native soil bacteria and fungi that were capable of growing with only the biodegradable mulches as a carbon source, were isolated in the laboratory. Additionally, the area of each mulch piece was measured after six months of soil burial, and compared to the original size. For the starch-based biodegradable mulches, post-burial surface area ranged from 100% to 71% of the original, while for paper mulch, post-burial surface area ranged from 95% to 0% (none detectable). Overall, soil microbial biomass, and carbon and nitrogen mineralization potential were highest in soil around the paper mulch. At all sites, the PLA-based mulch showed very little visible degradation. The possible relationships among climate, soil microbiology, soil biochemical processes, and biodegradable mulch breakdown is currently studied.

Agricultural mulches can influence soil physical properties, including soil temperature and moisture, which also greatly affect crop growth and yield, and soil ecology. In the same field study, maximum temperature at the soil surface under starch-based mulches was 3-4 °C higher than under black plastic mulch. This trend continued to the 15 cm soil depth. Soil moisture content at 15 cm and 46 cm depths did not differ under the biodegradable mulches as compared to black plastic mulch, however. In the Washington part of the study (cool climate), tomato fruit yield was greater with mulch as compared to bare soil, whereas in the relatively hot climates of Tennessee and Texas, there was no difference. These results suggest that in a cool climate, soil warming from mulch use can increase tomato yields. At all three locations, tomato yield with biodegradable mulches was comparable to that of black plastic mulch. The effects of black plastic versus biodegradable mulches on tomato root diseases are still under study.

Prior to the field study to understand the current status of grower knowledge of plastic and biodegradable mulches, a key informant survey was conducted targeting leading and innovative farmers in Washington, Tennessee and Texas (Miles et al., 2009). Three quarters of those surveyed (n=34) had used plastic mulch, and were satisfied with the results. However, plastic mulch removal and disposal were the primary concerns, especially since recycling was not available in most areas. Almost 25% of farmers had tried biodegradable mulches. Of that number, 28% felt biodegradable mulches provided adequate weed control and water/moisture conservation, but 60% were dissatisfied due to unpredictable and incomplete mulch biodegradation and added cost of removal of un-degraded fragments. These survey results and our field study research results indicate that today's biodegradable mulches are still not satisfactorily biodegradable. While one third of the farmers believed biodegradable mulches are suitable to the crops they grow, barriers to adoption include high cost, lack of availability, and general lack of knowledge about biodegradable mulches, especially with efficacy and potential impacts on soil health and quality. Continued work on biodegradable mulches should provide answers to some of these concerns.

Table 1. Commercially available agricultural mulches labeled 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
Biobag Agri	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 Agri	Starch, vegetable oil derivatives, and undisclosed biodegradable synthetic polymers	Dubois Agrinovation, Waterford, Ontario, Canada
WeedGuard Plus	Cellulosic	Sunshine Paper Co. LLC, Aurora, CO

1 PBAT = poly(butylene adipate-co-terephthalate)
2 PBSA = poly(butylene succinate-co-adipate)
3 PLA = Polylactic Acid

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4. The costs and benefits of buffer management

The preceding discussed the transformation of landscapes for better lives and vibrant rural economies. It documented a number of examples where landscapes and the associated water buffers were transformed – at scale and making use of well-known and innovative techniques.

At present buffer management investments or integrated landscape development projects are not yet mainstreamed – unlike investments in infrastructure, such as irrigation development, roads or water supply. No uniformly accepted method exists for calculating costs and benefits and translating these into investment plans. This comes partly from the more complex nature of investments, the tailor-made nature of landscape development, the novel character of some of the techniques and the multi-purpose composite character of the benefits, but also from a tradition of employment generation programs, with economics and private initiative taking a back seat.

There is also a history in many governments and external funding agencies of investments in agricultural production, poverty alleviation and natural resource management being spread over different disconnected departments. As a result buffer management and systematic investment in landscape improvement remains often elusive. Investments are often partial and a critical mass for transformation is not reached. As a result scale effects with processes reinforcing another and landscapes and economies systemically changed are not achieved.

This is all in spite of evidence that in many cases investing in buffer management makes very good sense. This chapter intends to bring together information on costs and benefits and the factors that underneath these.

The costs of buffer management

There is a wide range of techniques in buffer management – some very common, others in spite of their potential not well known outside the area where they were developed. What works is determined very much by the area where it is introduced: its climate, hydrology (arid or humid), geology and soil (opportunities to buffer), current land and water use (agriculture, pastoralist, forestry, wild life, urban, hydropower), availability of material (stones, clay, geo-textiles) and very important the local organization and priorities. The experience of the zai planting pits in Niger and Burkina Faso underline the value of local experimentation and experience sharing. To get it precisely right is not a given but relies on local innovators.

The other specter is the economy. This determines what is feasible in terms of investment and running costs and whether there are resources to mobilize. If there are markets and road connections high value land uses are possible that may provide the economic base for sustainable land management. There is a 'unborn chicken and unhatched egg' dilemma – there are unutilized opportunities that need to be triggered before they can mobilize substantial investment.

Table 1 is an overview of the costs and benefits of a range of buffer management techniques – described earlier in diagram 3 and 4 of chapter 2. Investment costs of buffer management differ – with investment costs ranging from extremely modest to medium-high. Figure 1 gives an overview of the costs per hectare and cost per cubic meter storage of selected water buffer techniques – from water harvesting and soil conservation measures on individual lands to water retention and storage measures that are applied directly at landscape level. The cost in a particular locality depends on a variety of factors – local labor and material costs being very important. The costs and benefits in the table hence indicate the order of magnitude. The figures come from this publication and earlier 'Managing the Water Buffer' as well as other sources such as the WOCAT data base (Critchley et al 2007). A more detailed list of the latter is given in the Annex.

At the lower end (less than 150 USD ha) there are individual investments that are part of agronomic or pastoralist practices and at the same promote water recharge and retention and better sediment management. Examples are grass strips, controlled grazing, planting pits, improved trash lines. Much of these costs are in labor or farming inputs – making them independent of the availability of cash to implement.

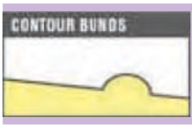
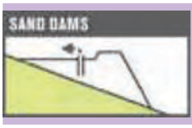
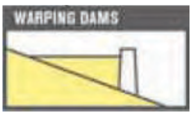
Moving up the cost ladder from 150 USD onwards, there are first medium cost interventions that require cash investments – stone bunding, terracing, wind breaks, agro-forestry. The return to some of these investments takes time to mature or has longer payback periods. Some of the top-end land management practices – such as plastic mulch – are in this bracket too and are sustained by higher value agriculture.

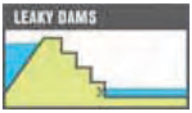
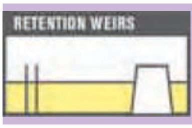
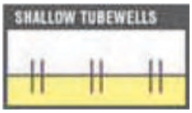
Within most of the techniques there is a (wide) cost range – with top end investments going up to USD 2500/ha. A number of techniques are interchangeable – with low cost and mid-cost techniques suitable in similar settings, but with different outcomes in terms of effectiveness and longevity – for instance grass-strips or stone bunds or infiltration ponds or recharge wells. If costs are low, the chance of a technique being adopted as part of farmer's repertoire of land investments becomes higher and the prospect of turning it into a movement becomes better. The benefit in terms of productivity or other wise maybe significantly lower and the recurrent costs higher in case of relatively low cost application.

Apart from the individual or local land based investment there are buffer investments that are directly done at landscape level and that have costs that cannot immediately be attributed to a single user group – adjustment to roads, the protection of bed loads in local rivers, retention measures in main streams, spring grouting, gully plugging and hill-top reforestation.

The main point is that all things being equal many investments in water buffers per hectare affected can be modest – ranging from nearly zero to a top of USD 2500/ha. By way of comparison this range is distinctly lower than in irrigated agriculture (FAO, 2011). Irrigation investments range from USD 300/ha to USD 8000/ha – the lower cost investment usually for larger systems with minor modification and the top end systems being relatively small-scale systems.

Table 1: Orders of magnitude: investment costs (including labor) and benefits of different 3R buffer management techniques (in USD)

Technique	Costs per ha	Costs per m^3 storage	Overall costs	Prime benefits	Overall benefits
	900-1200 (plastic)		30-200 (organic)	Yield increases with factor 2-4 (plastic)	Increased infiltration, reduced erosion, increased soil moisture
	75-250			Yield increases with factor 4-18	
	275-2700			Yield increases with factor 4-18	Steady base flows, reduced erosion
	10 -1000			Stocking rate increase 2-8	Better water buffers
		10	335-2385	3-90 m^3 water	Strategic storage
		3.4-10.2			Strategic storage
	240	0.35-1.4	1576	8282 m^3 water	Storage in riverbed and riverbank
		1.79	5380	3000 m^3 water	Storage in riverbed and riverbank
		0.075	60,000	Yield increases with factor 6-10	Reduces downstream sedimentation
	250-1800			Yield increases with factor 2-5	Stabillizes the landscape
	140-200			400/ha/yr	

Technique	Costs per ha	Costs per m^3 storage	Overall costs	Prime benefits	Overall benefits
		0.1 (ground-water) 1.26 (surface)			Secures groundwater tables
			1200		
	2700			650/ha/yr	Storage in riverbed and riverbank
			30-150		More secure access to groundwater

(This table is based on references, see reference list)

Benefits

Direct benefits from many of the better buffer management techniques are substantial. Terracing, contour bunds, mulching and other improved field management techniques can cause crop yields or animal stocking rates to increase dramatically with a factor 2 to 6. These amount to very spectacular transformation in areas that are often neglected or degraded to start up with. Better water buffers moreover reduce the risk of failure and allow the cultivation of new crops – such as fruits – 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. These are 'down stream' and accrue to people and organizations elsewhere in the landscape: less disruptive sedimentation and more reliable base flows and higher groundwater tables. In case of retention weirs – see the example of Maharashtra described in Chapter 3 – the benefit may be even be upstream – raising the water in the wells. Then there are the off-stream benefits – that benefit all, even those outside of the catchment; general stability and security, bio-diverse ecosystems as well as the sequestration of carbon. Figure 1 summarizes the most important benefits. To capture these benefits and set them in the centre of investments requires different mechanisms and business models, also described in Chapter 5.

From the costs and benefits perspective there is also a strong case to work at scale. This is the experience in Niger and Burkina Faso (regreening), in Tigray Ethiopia (soil and water conservation) and China (plastic mulching). Working at scale reduces costs – new supply chains, broad-based knowledge and skills and in general changed economic systems. Working at scale also affects

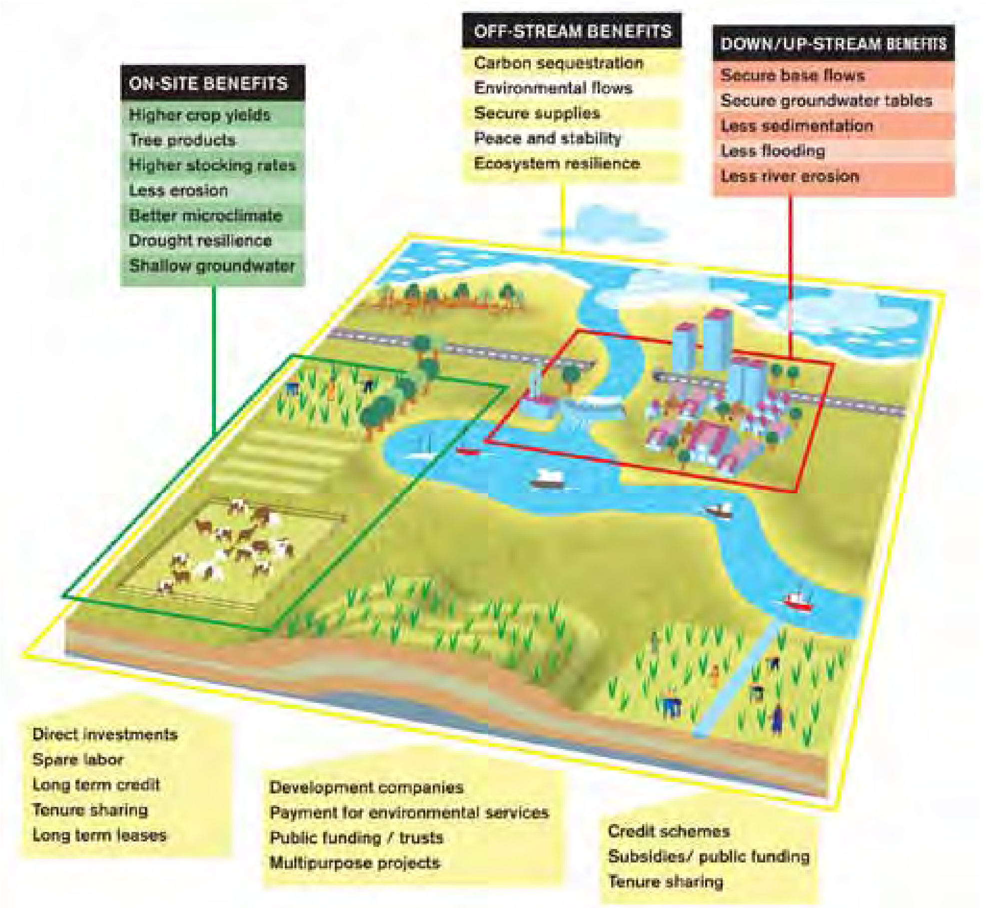


Figure 1: Most important benefits from buffer management

benefits – significantly changing microclimates, sedimentation processes and secure water buffers. Achieving scale is particular important for down-stream and off-stream benefits – better base flows and accessible groundwater tables, more carbon sequestration. In general improved integrated landscapes are less vulnerable to climate change and to calamities in general. Moreover – there is the effect of scale begetting scale and better land and water management practices having significant effects so they become the routine and the norm rather than the innovation and exception.

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5. Business models

Special challenges

The financial challenges in buffer management follow on from the previous. First, some investments take a long time to mature. Second, benefits do not necessarily only accrue to the persons who invested in better buffer management: there are likely to be significant downstream and upstream benefits.

The first financial challenge in sustainable buffer management is that of long payback periods. In many instances the payoff is substantial but returns do not come immediately. This is a classic case of needing to bridge the gap with special long-term credit. However, most financing mechanisms in developing countries, including micro-financing, provide short-term credit only. Currency losses and the perceived risk of instability stand in the way of long-term financing modalities. For many decades agricultural terms of trade worsened too, making investments in rural land management unattractive. Fortunately prospects have reversed here and the prospect for rural 'green growth' looks better than they ever did.

In the absence of long-term financing mechanisms, investments in buffer management have often been paid for, either by:

- Public funds and subsidies – safety net programmes and publicly-funded watershed programmes – have been major sources for funding landscape improvement.
- Spare labor – land users have applied their own labor to invest in land improvement, recharge wells or tree development. The regreening in Niger, for example, was mainly undertaken by land users protecting trees that sprouted naturally after the stone bunding programmes. This was done with off-season labor that had no or low opportunity costs.
- Off-farm income – remittances or income from other activities have been usesd to pay for investment. The surge in fanya juu terracing in Machakakos in Kenya was largely funded by off-farm income. The same applies for the wave of earthen storage dams developed in Yemen before 1991. These were largely paid for by remittances of migrant workers.

A second challenge is related to scale of buffer management: land and water use at one place affects water availability, sedimentation and local climates elsewhere in the landscape. These 'downstream' [1] or 'off-stream' effects may be local or they may extend throughout the landscape. To accelerate the investment in natural resource management the concept of Payment for Environmental Services (PES) was developed – or specific to 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 (see also Chapter 4). The example of warping dams (Chapter 3) suggests that private investment in sediment interception would work, provided adequate compensation was paid. In spite of efforts, however,

1 The term downstream effect may be misleading, particularly where it concerns groundwater availability. The case of the retention weirs in Maharastra are a prime example of upstream impact.

PWS is still not taking off in a major way (Porras et al., 2008). There are a number of explanations:

- PWS involves complex transactions – there is the challenge of the valuation of services from one party to the other and setting in place the actual mechanism for payment. The transaction costs involved may be high. 'Services' can also be fuzzy – it may not always be possible to assign an environmental service to one benefactor and one beneficiary in one specific time period, and it is often hard to quantify the benefit. In fact PWS programmes have been most promising where they are implemented on a larger and more general scale, and not as transactions between individual users that are nearly impossible to calculate.
- PWS assumes the existence of a party that has the finances to pay for environmental services, e.g. a city, a hydropower station or major agro-industry. These may not always be there. In many situations downstream benefits may be with many small and marginal land users who lack the resources and priorities to pay for environmental services.
- In PWS the economy may take second place. If the emphasis is on paying for direct environmental services, economic opportunities may be overlooked.

There are by now, however, also examples of promising large PWS systems. One example - based on the presence of large parties, investment in direct economic benefits and simplified transactions - is the Green Water Fund, developed for the Tana Basin in Kenya. Preparation of the facility included assessing and quantifying the cost and benefits of upstream land management, bringing the different parties on board and creating a financial mechanism at an intermediary organization, in this case the largest bank in Kenya (Box 1).

Figure 1: Tea plantations have often been promoted to retain water and serve as a buffer against forest encroachment in 'water tower areas' - combining development and protection.

Box 1: Green Water Credits in Kenya

Figure 2: Tana Basin, Kenya (Photo credit: MetaMeta)

The Tana River Basin covers an area of 126,028 km² in the south-eastern part of Kenya. The upper basin is formed by the Aberdare and Mt. Kenya mountain ranges. Rain-fed cultivation of tea, coffee and maize cultivation is common in these high rainfall areas. Coffee and maize, in particular, cause erosion as the ground cover is poor. The lower and drier areas in the basin are used as rangeland mostly – but a number of important large water users are also found. The largest users of water in the Tana Basin are five hydropower stations, operated by KenGen (Kenya Electricity Generating Company Limited). Together these provide between 40 to 64 per cent of the national demand. Municipal water supply is the second largest user, managed by the Nairobi Water Company (NWC). The capital city draws three quarters of its water from Ndakaini and two other reservoirs in the Tana River Basin. Municipal water demand moreover is expected to grow rapidly at 6% annually. The third largest user is irrigation, with schemes totalling 68,700 ha. In addition to these consumptive uses, sufficient base flow is required in the delta area to preserve the mangrove and reef systems near Kiunga Marine National Reserve.
The combination of high rainfall in the upper basin with erosive farming and significantly large downstream water users (with increasing demands) sets the scene for the implementation of the Green Water Credits Fund. Better soil moisture management by upstream farmers through, for instance, mulching, conservation tillage, tied ridges and terraces would lead to higher yields for the upstream farmers. At the same time it reduces erosion, increases recharge and regulates base flows. In this way the likelihood of devastating floods – such as in 2002 - may be reduced. The controlled run-off and reduced erosion also decreases the high sediment loads currently deposited in the reservoirs of the hydropower stations. This increases the lifespan of reservoirs, and reduces dredging costs and damage to the generators. It would sustain water volumes for Nairobi. A higher base flow during the dry months (June-October) would further provide more water for the irrigation sector (increasing the growing season) and the environmental flows at the delta.
Under the Green Water Credit Project, supported among others by IFAD, these benefits were quantified and validated by the stakeholders in the Tana Basin. The benefits of better soil and water management in the uplands far outstrip the costs (Figure 1). In summary even at 20% coverage, annual downstream benefits for hydropower facilities and urban water provision would amount to USD 6-48 million annually, whereas costs would range from USD 0.5-4.3 million. In addition several benefits were not taken into account in this equation – higher production for upstream farmers, reduced flood damage, impact on the delta and carbon

sequestration. The hitch is the start up cost, which may amount to USD 10 million annually for the first five years – at which time the downstream benefits do not yet accrue.

Key in this whole design is the development of a mechanism that will fund better green water management practices in the upper basin. Equity Bank, one of Kenya's largest banks, will lead this process and will manage the Green Water Fund. This fund enables transactions between approximately 150,000 farmers in the upper catchment and the downstream parties KenGen and NWC. The fund is to be ultimately furnished by contributions from the large downstream parties as they generate profits and savings from better upstream land and water management. For KenGen these consist of higher electricity production (because of more reliable base flows) and lower maintenance costs (reduced sediment inflows). In return Equity Bank provides financial means to enable the farmers in the upper basin to implement the green water management practices. One part of the finances is used for the development of organizational capacity and includes strengthening of local communities and educational programmes for leaders and farmers – especially in the initial years. Another part is used to enable farmers to actually make investments in better practices. This is done through low-interest loans or through vouchers for equipment. Investments at community level are possible too, such as the construction of schools or hospitals. As the benefits of green water investments take time to materialize, the stream of transactions to and from the Green Water Fund will only come in effect after five years. In order to kickstart the 'engine' an initial injection of USD 50 million is to be pre-financed by institutions including governments, international financial organizations and developments agencies.

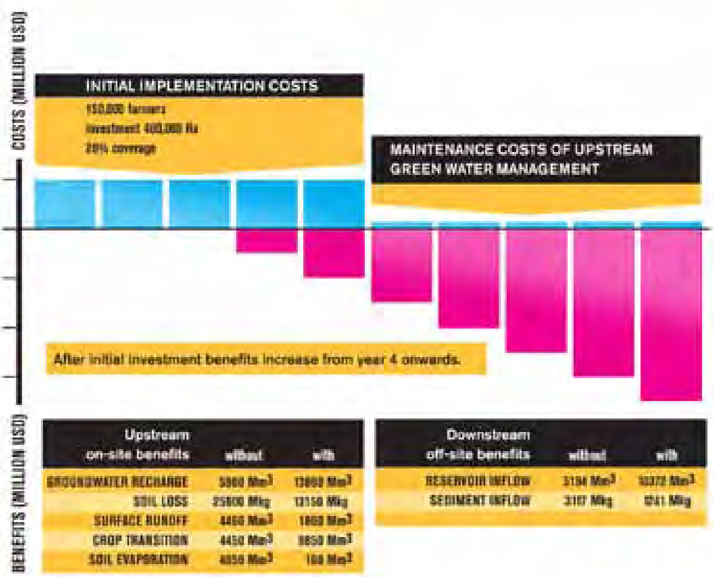

Figure 3: Green Water Credits (Source: ISRIC, 2010)

Source: ISRIC, 2010

Figure 4: Commercial bamboo plantation protecting watersheds , China (Photo credit: MetaMeta)

Special business models

While it is important to continue with all the financing mechanisms above – including PWS – it is also important to widen the menu of business models that support sustainable buffer management. In addition to the mechanisms above – public or private subsidies or payment for watershed services - more opportunities may be used for local investment that exploit business opportunities directly associated with sustainable land and water management. This will create jobs and incomes and at the same time improve land, water and vegetation. Several such mechanisms are in place in different localities and they need to be nurtured and further developed. Below several examples are given.

Promoting local tree and water business

There may be local business opportunities in land management that make good financial sense and at the same time safeguard the environment. In Tihama in Yemen private 'charcoal' plantation enables local investers to plant acacia ehrenbergania trees – which upon maturity are converted into a charcoal. A side product is qataran - a cresote which among others cures animal skin diseases. The acacia plantations generate local business and also take the pressure off the natural stands of acacia in the area suffering from uncontrolled cutting.

Setting up land improvement companies

Land improvement companies acquire degraded land and invest – sometimes with public money - in the improvement of it before they lease it out or resell it. This was common in Europe in the early part of the twentieth century. The Grontmy obtained large concession of 'waste land', improved the water management, replanted the areas and then released them at a profit.

Exploiting 'hidden' financial benefits

There are many 'hidden' values in resource management systems – that are not always exploited for the benefit of sustainable buffer management, yet have the potential to generate substantial revenue. An example is the development of waterfront property or other scenic property – capitalizing on an otherwise unexploited value. The revenues from selling water front property can be used to pay for investment in improved water systems. Other examples are water storage ponds being used for recreation, fishery or others – or planting hedge-rows for moisture protection as well as sources of timber or fuel wood. Selling 'excess' soil for reuse in house construction, land improvement or others is another example of creating revenue from 'other benefits'. These secondary benefits often justify larger investment in landscape transformation and buffer management than the primary benefits.

Starting long-term leases in local forestry

Long-term investment can be coupled with long-term savings. In Indonesia small town investors pay farmers in surrounding villages to plant and maintain trees. For this a small contract is drawn up. At harvest time the returns from the mature trees are divided between the landowner and

Figure 5: Large field bunds in spate irrigation developed by co-owning tenants (Photo credit: MetaMeta)

investor. For the small town investors the arrangement means profitable long-term returns, securing a retirement payment or a large future investment – the construction of a house or the expenditures for a wedding. For farmers it means a source of steady income.

The same system is emulated in banking in eastern Uganda. Farmers are paid for the planting and upkeep of trees for the years that it takes the trees to mature. At harvest time the Bank retains 70% of the return and farmers keep the remainder.

Co-tenure for land development

Traditionally to reclaim wasteland landowners in the spate areas of Pakistan would give their land to so-called 'hereditary' tenants (bazgar marousi). These would build up the land and in particular develop the large field boundary bunds that are essential in developing new soils and maintaining moisture. For these services the bazgar marousi became co-owners. Their shared ownership, however, is conditional and lasts as long as they maintain the fields and the bunds. If they cultivate the land themselves they receive a far larger share of the harvest than a common tenant, but they can also lease out the land themselves. If the landowner decides to sell the land he is bound to give part of the proceedings (usually 40%) to the hereditary tenants who, for all practical purposes, are conditional co-owners.

Swapping land rights

A variation of the bazqar marousi co-ownership was applied to develop the very costly horizontal well systems (qanats) in Balochistan, Pakistan. A crew of specialized qanat diggers would approach a community with a proposition to develop a qanat in the area. If it was successful part of the shares in the land and water would be transferred to the excavation team.

A similar transfer of tenure became popular in Gambia. In areas with potential for rice cultivation the traditional large landowners ('founding fathers') were encouraged to give up their titles to areas of uncultivated land as part of the Lowlands Agricultural Development Programme of IFAD. This land was then transferred to women who reclaimed the lands and converted them into paddy fields. To compensate the 'founding fathers' under the project local infrastructure – roads and flood protection dikes were developed – which substantially increased the value of all land in the area.

There is scope to promote such mechanisms and link it with long-term sources of capital – from pension funds or institutional investors that want to spread risks. Mechanisms need to be fine-tuned so that the investments give regular dividends after maturity – in line for instance with the requirements of a pension funds. This may require packaging with immediate mechanisms – for instance micro-finance.

The enabling conditions matter very much and it is important to work on the enabling conditions. In some countries live trees cannot be cut officially – precluding the development of charcoal plantations for instance whereas at the same time the uncontrolled removal of natural stands continues unabatedly. In other areas ownership of wells and trees is with the landowner – and not with the land users who would like to develop a shallow well or a tree stand. Tree tenure would need to be reformed then. This can be done as some cases show.

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Annex

Table 1: Establishment and mantenance costs soil and water conservation techniques

Technique	Country	Total establishment costs / ha (USD)	Total maintenance costs /ha (USD)
Conservation agriculture			
No-till technology	Morocco	600,00	400,00
Conservation agriculture	UK		
Small-scale conservation tillage	Kenya		93,00
No-till with controlled traffic	Australia		111,00
Green crane trash blanket	Australia		543,00
Manuring / composting			
Vermiculture	Nicaragua	122,00	60,00
Composting associated with planting pits	Burkina Faso	12,00	30,00
Improved trash lines	Uganda		30,00
Vegetative strips / cover			
Natural vegetative strips	Philippines	84,00	36,00
Green cover in vineyards	Switzerland	15000,00	2300,00
Vetiver grass lines	South Africa	140,00	25,00
Agroforestry			
Shelterbelts for farmland in sandy areas	China	125,00	11,00
Grevillea agroforestry system	Kenya	160,00	90,00
Popular trees for bio-drainage	Kyrgyzstan	920,00	30,00
Multi-storey cropping	Phillipines	1390,00	490,00
Intensive agro-forestry system	Colombia	1285,00	145,00
Shade-grown coffee	Costa Rica	2535,00	330,00
Conversion of grazing land to fruit and fodder plots	Tajikistan	2690,00	570,00
Orchard-based agroforestry	Tajikistan	550,00	210,00
Water harvesting			
Sunken streambed structure	India	240,00	5,00
Planting pits and stone lines	Niger	245,00	35,00
Furrow-enhanced runoff harvesting for olives	Syria		88,00

Technique	Country	Total establishment costs / ha (USD)	Total maintenance costs /ha (USD)
Gully rehabilitation			
Check dams from stem cuttings	Nicaragua	190,00	35,00
Gully control and catchment protection	Bolivia	110,00	16,00
Landslip and stream bank stabilisation	Nepal	2925,00	70,00
Terraces			
Stone wall bench terraces	Syria	1460,00	20,00
Rehabilitation of ancient terraces	Peru	1400,00	125,00
Traditional stone wall terraces	South Africa	1270,00	160,00
Fanya juu terraces	Kenya	320,00	38,00
Small level bench terraces	Thailand	275,00	45,00
Orchard terraces with bahia grass cover	China	1840,00	376,00
Zhuanglang loess terraces	China	1290,00	35,00
Rainfed paddy rice terraces	Philippines	2700,00	40,00
Traditional irrigated rice terraces	Nepal		840,00
Grazing land management			
Ecograze	Australia	10,00	1
Restoration of degraded rangeland	South Africa	230,00	32
Improved grazing land management	Ethiopia	1035,00	126
Area closure for rehabilitation	Ethiopia	390,00	90
Other technologies			
Sand dune stabilisation	Niger	1450,00	50
Forest catchment treatment	India	400,00	50
Strip mine rehabilitation	South Africa	212,00	37

Source: WOCAT 2007: where the land is greener - case studies and analysis of soil and water conservation initiatives worldwide.Editors: Hans-peter Liniger and William Critchley.

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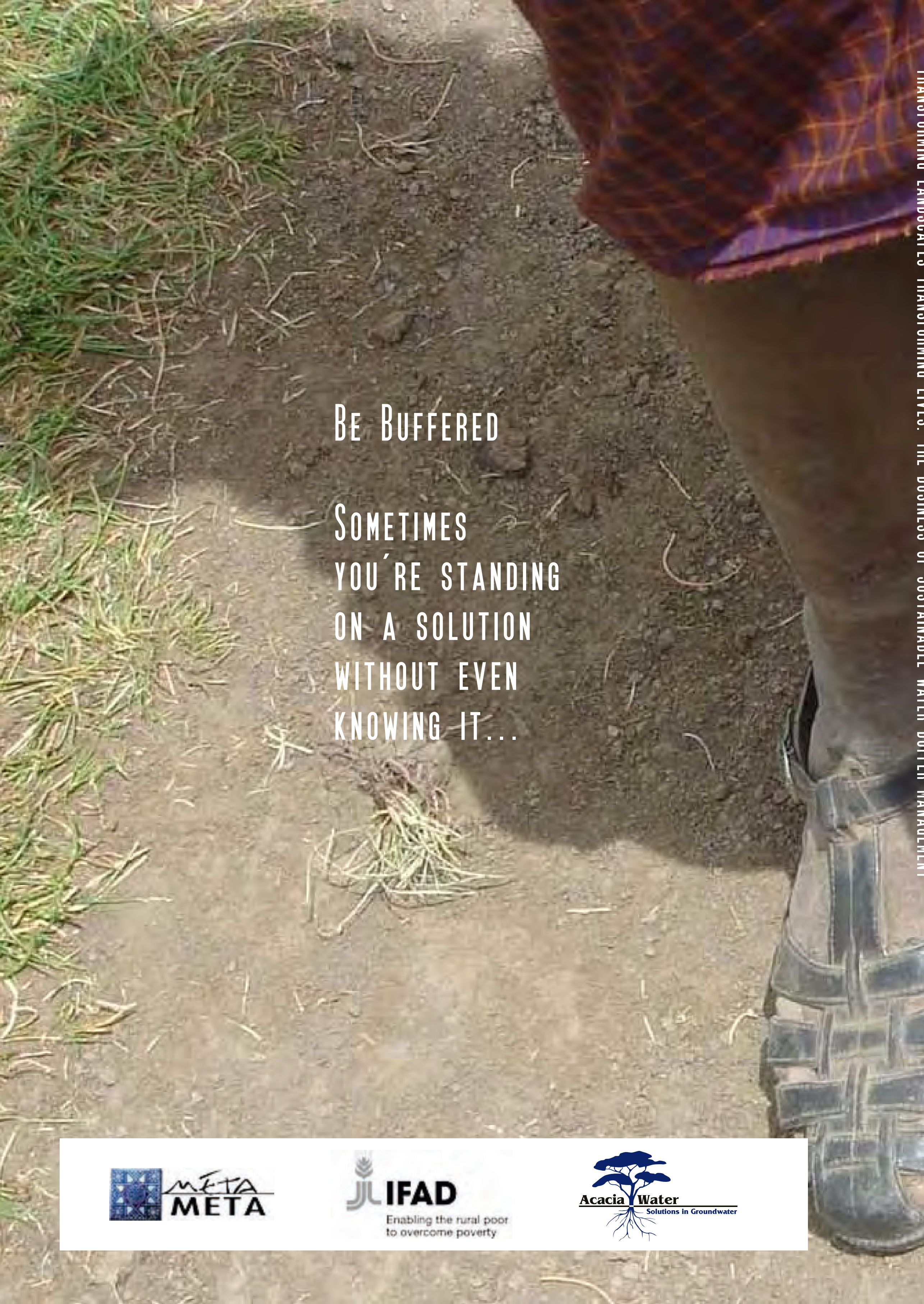

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