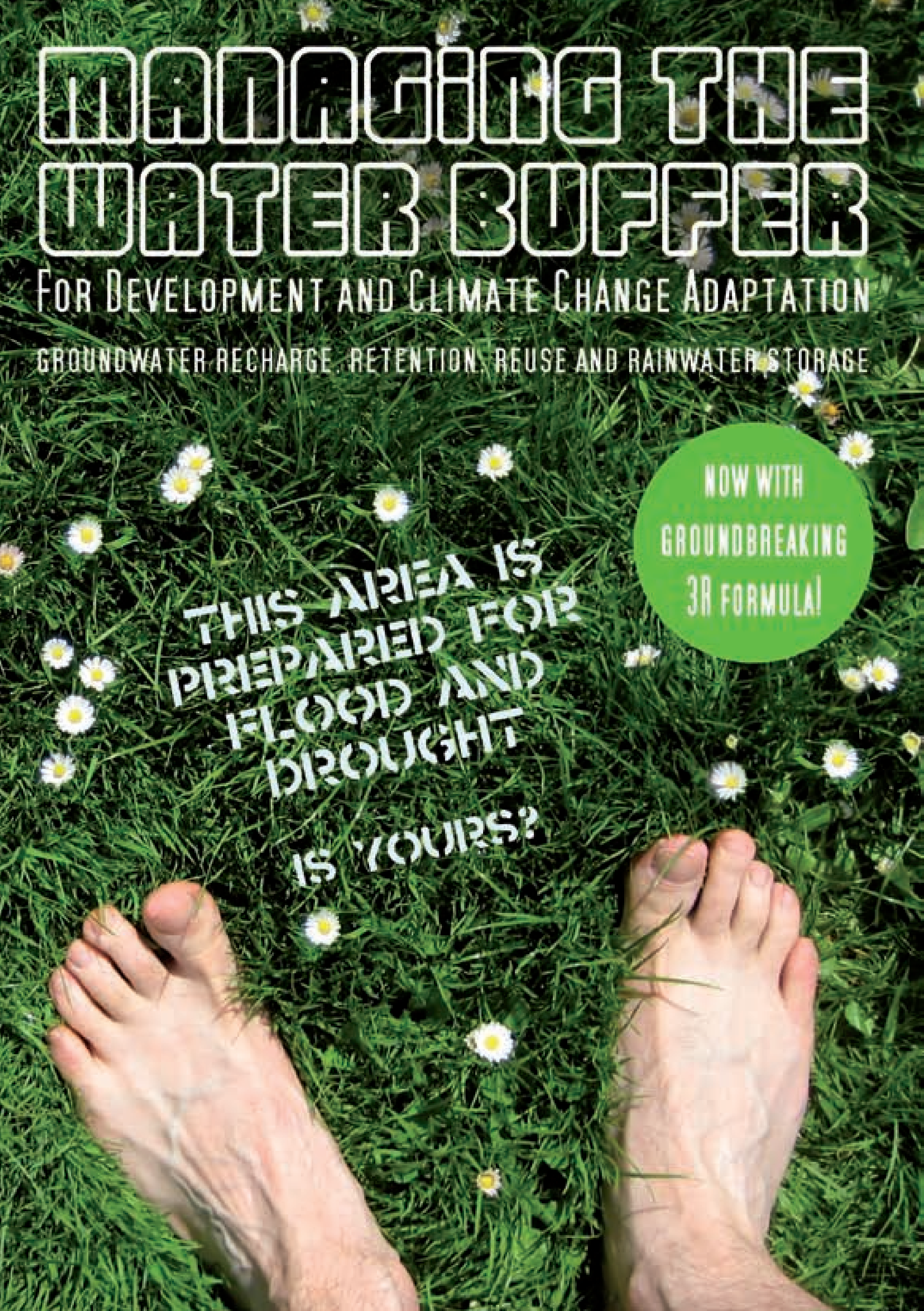
MANAGING THE WATER BUFFER

For Development and Climate Change Adaptation

GROUNDWATER RECHARGE, RETENTION, REUSE AND RAINWATER STORAGE



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Foreword

Scientific evidence has proven that climate change is a serious global threat that requires an urgent response at global, regional and local levels. Even at moderate levels of warming, all the evidence – from detailed studies of regional and sectoral impacts of changing weather patterns to economic models of global effects – points to serious impacts on the environment, on human life and on economics. All countries will be affected. Unfortunately, the population in the poorest countries, who are the most vulnerable, will suffer earliest and most severely. Adaptation to climate change is therefore essential – steps to build resilience, optimize buffers and to minimize costs are to be taken urgently. Optimizing the use of the storage options provided by both groundwater and local surface water is key.

The International Hydrological Programme (IHP) of UNESCO aims to help meet the UN Millennium Development Goals (MDGs) on environmental sustainability, water supply, sanitation, food security and poverty alleviation. The programme's mission is to strengthen the scientific understanding of the impacts of climate variability and change on water systems and to link scientific conclusions to policies for promoting sustainable management of water resources. Special attention is given to developing regions that are particularly vulnerable to climate change, with consequences that may have very serious social and environmental effects. Groundwater-related activities of the IHP include: assessment of impact of global change on groundwater resources and support to member states; improved understanding of groundwater in the global water cycle and the changes therein; assessment of the pressures on groundwater resources from growing population and economies and effects of global warming on recharge, sea levels and sea water intrusion and; raise awareness of decision makers, implementers, users and the public of storing freshwater.

The International Association of Hydrogeologists (IAH) has a longstanding cooperative relationship with UNESCO's hydrological programme. As an international organisation for scientists, engineers and other professionals working in the field of groundwater resource planning, management and protection, IAH aims to improve the understanding and management of groundwater worldwide. IAH harnesses the research, knowledge, expertise and enthusiasm of its members to promote the professional management of groundwater as part of integrated water resources management.

UNESCO and IAH work jointly to bring best practice techniques for the management of aquifer recharge (MAR) to the attention of a wider audience. Many of these techniques present economically and environmentally sound solutions that make better use of local water storage opportunities.

This publication on Recharge, Retention and Reuse of water (3R) focuses on managing buffer functions as part of basin management and climate change adaptation. While the benefits of strong and early action far outweighs the economic costs of not acting, proper groundwater management is akin to banking wisely: manage the storage account by taking advantage of economic opportunities, recharge the account in wealthier times and draw from reserves when surface water is scarce. In addition, there is a complementary range of untapped opportunities in local rainwater collection. It is in this framework that we welcome the 3R initiative of MetaMeta, Acacia Water, the RAIN Foundation and BGR.

We warmly recommend this publication to all managers of both surface and groundwater!

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Managing the Water Buffer for Development and Climate Change Adaptation

Groundwater Recharge, Retention, Reuse and Rainwater Storage

1. Introduction: 3R at a glance

1.1 3R: Recharge, Retention and Reuse of Water

This book explores how to maximize the use of groundwater and rainwater for development and climate change adaption in an approach called 3R. The vision of 3R is to give people the means and confidence to protect their livelihoods in response to climatic changes, and to improve local water management to ensure reliable access to water, economic development and the integrity of their environment. 3R stands for Recharge, Retention and Reuse.

This book is prepared for land use planners and catchment managers, for all those concerned with water management and climate change, whether working in government, water utilities, irrigation agencies, insurance and investment companies, private sector or civil society – in arid and humid areas alike.

The point of departure is the buffer function in a region – allowing one to deal with current peaks and lows and the larger variability that in many areas is expected to come with climate change. One important water buffer is the storage provided in the upper meters of soil and in shallow aquifers. In many places this groundwater buffer can be used to store rainwater and run-off, augmented by flows from rivers and irrigation, making it possible to re-circulate and re-use water. In addition to groundwater, local surface water storage adds to the water buffer in a region, such as harvesting and storing rainwater in tanks and local reservoirs. Managing the local water buffer is of vital importance – it determines livelihoods of people and the economy of an area.

The philosophy outlined in this book is to optimise the management of this buffer function through three subsequent steps – 3R, representing Recharge, Retention and Reuse. The larger idea is that tackling a local water crisis is not so much about allocating scarce water, but to catch water and extend the chain of water use and its reuse as much as possible within a basin, taking account of all people and the environment across entire basins.

Recharge

Retention

Reuse

1.2 The water buffer

This book puts the management of the water buffer functions centre-stage with a focus on groundwater and small local surface storage. Groundwater is already our largest reservoir of fresh water and stores more than 90% of the global fresh water, ice (polar ice and glaciers) excluded. Freshwater stored in rivers, lakes, large reservoirs and as soil moisture is less than 1%.

Groundwater can be found nearly everywhere. It covers half of global drinking water requirements both in rural and urban areas through centralized and individual systems; as well as 40% of industrial demands and 20% of water for agriculture, with strong variations from arid to humid regions. In addition, groundwater has a strong effect on soil moisture. High groundwater tables can provide security to rain-fed farming through augmentation of supplementary water to bridge dry spells. By allowing on-location supplies, groundwater is the driving force behind many of the quantum leaps in agricultural production and in provision of drinking water in locations that are remote from any stream. Groundwater is also a major source of water for rivers, lakes and wetlands.

The discussion on groundwater often focuses on overuse and control, which is indeed of great concern in many areas. The clear need for better groundwater management should include maximizing recharge and storing rainwater where possible, storing water from floods, managing water levels and ensuring water quality to make reuse possible. Water storage is analogous to savings in a bank, and has been the basis for the sustainable development of economies.

Local surface water storage is an important second dimension of the water buffer. Especially in areas, where groundwater suffers from quality problems, such as high salinity, arsenic or fluoride, or is hard to reach, storing rainwater and run-off in local storage reservoirs, will contribute greatly to areas being ‘buffered’ – with many small local solutions at hand.

1.3 The climate change dimension

In many parts of the world, both in dry and wet climates, Integrated Water Resources Management (IWRM) is a key challenge under the present, highly variable climatic conditions. Each region requires appropriate IWRM concepts that take both natural resources and socio-economic conditions into full account.

For the rain-dependent economies in many areas such as large parts of Sub-Sahara Africa, the GDP (Gross Domestic Product) is directly related to precipitation in any one year (figure 1).

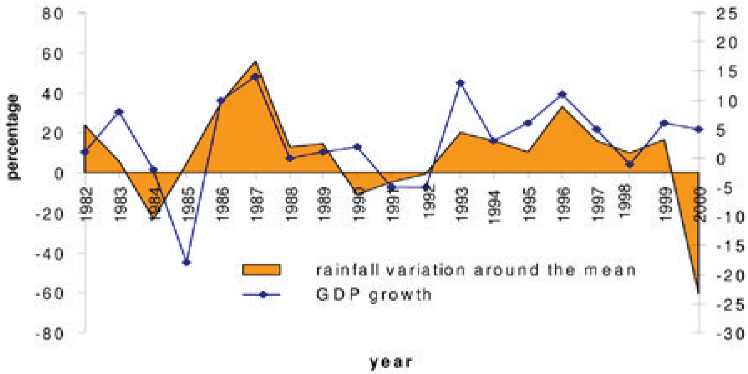

Figure 1. Rainfall and GDP for Ethiopia 1982 - 2000 (source: Grey and Sadoff, 2006)

Climate change will exacerbate the vulnerability of national, local and household livelihoods, economies and environments, and may jeopardise development including the achievement of the Millennium Development Goals. Droughts are expected to become more pronounced and rainfall events more intense; and the latter are expected to bring more intense and increased frequency in floods. Groundwater storage and rainwater collection can provide relief under these changing conditions. A larger capacity to absorb and store water is, therefore, a key factor in climate change adaptation.

In humid regions, climate change may cause monsoons to become more erratic, arriving later and with longer dry spells in between, and placing a premium on groundwater management, soil moisture management and supplementary irrigation. Managing groundwater, and the water buffer in general, is at the heart of climate change adaptation in arid and humid areas alike.

1.4 Making the 3R approach work

This book is written as a call to action for a worldwide 3R initiative to introduce buffer management on a basin-by-basin scale, rather than on a piecemeal basis. It brings climate change adaptation together with rain and floodwater harvesting and groundwater management. 3R is required in both dry and wet areas to adapt, sustain and promote improved water resources management to enhance sustained water supplies for people, food and environments.

The next section, chapter 2, provides more background information on the 3R approach, with a focus on management of the groundwater and local storage. It presents the techniques used for managed aquifer recharge, promoting natural recharge and retention, rain water collection and the 3R processes for water storage in the light of the challenges of climate change.

Chapter 3 of this book presents examples of existing 3R applications that have proven highly efficient. The cases explain the how-tos, the techniques used for groundwater, soil water and rainwater storage, and the results. The cases clearly demonstrate that many useful objectives can be achieved with a manageable level effort. Using 3R techniques can generate great benefits for water security, development and sustainability of livelihoods.

The infographic (figure 2) gives a graphic presentation of a hypothetical basin with an overview of the technical interventions, which are 3R elements that contribute to the improving the water buffer function in the entire basin or sub basin.

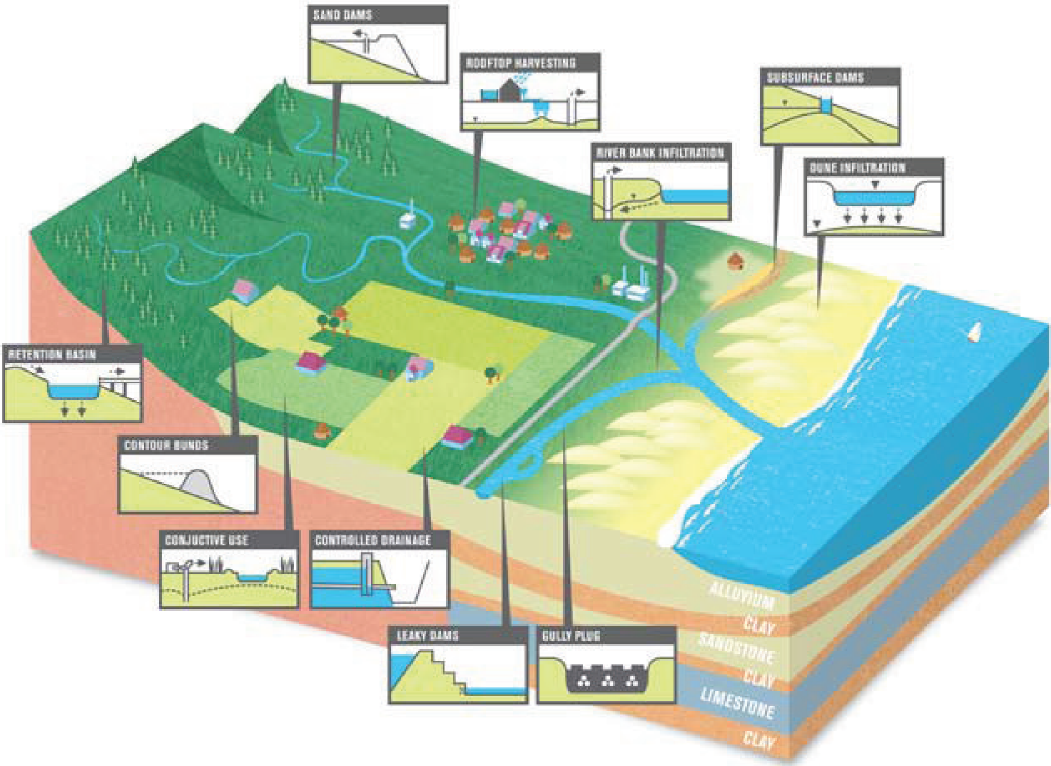

Figure 2: Infographic illustrating 3R applications within a river basin

2. BACKGROUND TO 3R

2.1 Managing local water buffers for development under climate change

There are at least four important arguments in support of 3R:

- Climate change adaptation using natural storage
- Scope for water quality improvement
- Recirculation in the water chain
- Support functions for ecosystems and agriculture

Climate change adaptation using natural storage

Climate change is expected to play out differently in different parts of the world (box 1). Storage of water plays a crucial role in adaptation. It is a key component to bridge temporal (ranging from overnight to annual) gaps between water resource availability and water demand.

Box 1: Climate change predictions

Climate change is expected to change the hydrological cycle. The 4th Assessment Report of the IPCC presents the impacts on a regional basis and shows that the impacts will differ regionally and locally. In the Mediterranean region, for example, summer precipitation is expected to decrease by 5–20% by 2050–2100. This could decrease average runoff by 40% in this already relatively dry region.

Monsoonal climates are expected to experience more flash floods, especially in urban areas; and higher frequency of intense rainfall in mountain areas will increase the risk of landslides and floods, more intense cyclones and prolonged rainfall episodes, more coastal flooding and reduced yields and flow duration from decreased inland rainfall. These changes in runoff will affect water quality as well (Ludwig et al., 2009).

More accurate forecasts and outlooks on runoff impacts (quantity and quality) are expected to become available as understanding and forecasting capability improve. All indications warn, however, that the time to act has already arrived. Action can be undertaken on two levels: the level of 'no regret' measures (which are useful under any scenario) and the level of climate-specific measures. The 3R measures are important 'no regret' measures.

Making use of the groundwater buffer for storage has many advantages. Groundwater is usually available (or available nearby) at the point of desired use. The same holds for subsurface storage. For millions of households, hand pumps that draw on groundwater provide a reliable water supply. This local availability of water provides the greatest relief to women, who were previously exposed to risks in many areas as they travelled long distances with heavy loads.

The disadvantage of storing water in aquifers, rather than in surface reservoirs, is that it needs to be pumped. In addition, aquifers – depending on their characteristics – may fill slowly through infiltration over a relatively large area.

Scope for water quality improvement

Sub-surface storage has several advantages including low (if any) evaporation losses, relative protection against water pollution, and improved water quality. Suspended solids are absorbed by the soil, temperatures are moderated and with sufficient detention time in warm aquifers many pathogenic bacteria, viruses and unicellular micro-organisms (protozoa) are eliminated (Dillon, et al. 2009). Furthermore, the soil can reduce acidity, remove inorganic and organic compounds through adsorption, and chemical as well as biological processes can change and neutralize hazardous compounds. In addition, underground storage of surface waters and the purification potential of capturing rainwater where it falls have the advantage of providing a clean safe source of water, thus avoiding the need to purify water in the first place.

Recirculation in the water chain

There is a tendency in water resource management to regard the availability of water resources as the sum of precipitation, run off and storage. Consequently, water management is often limited to the paradigm of resource allocation, per head availability and water efficiency; and fails to take water circulation and 3R into account (box 2). 3R can contribute substantially to the increment of the quantity and the quality of water resources. For example in Bangladesh, induced riverbank infiltration allows water from the rivers to be reused for agriculture or domestic purposes. During this infiltration process, the arsenic burdened water from the river is filtered and storage in the aquifer makes water available for most of the year. In most cases, the use and reuse of water described in chapter 3 occur through short-term storage of water in the soil profile or shallow aquifer.

Box 2: Water circulation in the Nile Basin in Egypt

The Nile Basin in Egypt serves as an example of water recirculation (3R). On an annual basis, the amount of water available at Aswan is 55 BCM, but the water used and reused in Egypt (below Aswan) is most likely between 66 to 70 BCM. Taking into account irrigation conveyance efficiency, drops of water entering the system are circulated several times.

Support functions for ecosystems and agriculture

Finally, managing the water buffer has some important beneficial side effects. These are not always taken into account, but they can have a substantial impact. High groundwater tables assist in maintaining adequate soil moisture, thereby making an important contribution to 'green water management'. Green water management is the management of soil moisture (as opposed to the management of blue water which is the water in rivers, lakes and reservoirs).

Figure 3. Open well adjacent to check weir in Vanvasi, India

Guaranteed soil moisture is directly related to high productivity in rain-fed agriculture both in arid and humid areas. Green water management is linked to fertility as it also benefits from better tillage, composting and mulching, and physio-chemical and biological processes such as nitrogen fixing, nitrification and denitrification, and oxidation.

2.2 The 3R techniques

Several techniques, the main elements of which are the 3R's of Recharge, Retention and Reuse, can increase storage capacity at the scale of a sub-basin and improve its management. Some of these techniques are ancient and time-tested, others are new and innovative. 3R is required in arid and humid areas alike. It is important to recognize that water should not only be managed when it is scarce, as in arid areas, but also when it is abundant. The manner in which this fact is addressed may differ in arid and in humid areas, but better water management and climate change adaptation are necessary everywhere.

3R aims to design and integrate these individual solutions for the entire basin or sub-basin in a close link with all local planning activities including spatial planning, and the planning of local infrastructure, land development, irrigation and nature areas. The essence of 3R is to set things right at scale to avoid getting stuck in isolated improvements and interventions.

In Chapter 3 there are 19 cases in which the application of 3R techniques are presented. Grouped according the three R's, the cases illustrate that recharge, retention and reuse of water is interconnected at local as well as river basin scale.

Recharge

By adding water to the buffer, recharge contributes to water circulation. Recharge can come from the interception of rain and run-off water (natural recharge), from increased infiltration of natural processes by manmade interventions (managed aquifer recharge – MAR) or can be a by-product of some other factor (i.e. inefficient irrigation or leaking pipes in water supply systems). Recharge at scale, therefore, requires managing natural recharge, applying artificial recharge and controlling incidental recharge.

Recharge has been done at scale in areas of India, China, Kenya and Ethiopia – yet is uncommon in other parts of the same countries or other parts of the world. Where recharge was done at scale, large-scale degradation has been turned around and the resulting critical mass established a foundation for capacity building and local investments, as success breeds success.

There are many techniques for *managed aquifer recharge* – some ancient and time-tested, some very innovative (see figure 1 and cases). They range from individual rooftop rainwater harvesting systems, small storage solutions and recharge wells to water harvesting at catchment level, as in spate irrigation (box). Small-scale water recharge works best if it addresses local household or community needs. Many systems are suitable for installation and management at household level, community level or by catchment managers or private or government water utilities. Communities manage some of the larger systems. The spate irrigation systems (box 3) in South Asia rank among the largest farmer-managed systems in the world.

Box 3: Spate irrigation

Spate irrigation is a type of water management that is unique to semi-arid environments. It is found in the Middle East, North Africa, West Asia, East Africa and parts of Latin America. Floodwater from mountain catchments is diverted from ephemeral riverbeds (wadis) and spread over large areas to irrigate agriculture. Spate systems are very risk-prone. The uncertainty comes both from the unpredictable nature of the floods and the frequent changes to the riverbeds from which the water is diverted. Those whose livelihood and food security depends on the spate flows are often the poorest segment of the rural population. Substantial local wisdom has developed in organizing spate systems and managing both the floodwater and the heavy sediment loads that go along with it.

Table 1. Proposed classification of MAR systems.

Technique	Names used
Moisture conservation	Pre-season ploughing Tillage techniques Mulching Field bunds Composting
Spreading methods	Infiltration ponds and basins, Soil aquifer treatment, Controlled flooding
In-Channel structures	Incidental recharge form irrigation Percolation ponds behind check dams, sand Storage dams, Subsurface dams, Leaky dams and recharge releases
Well, shaft and borehole recharge	Open wells and shafts, Aquifer storage and recovery (ASR) Large basins Sometimes supplemented with injection devices
Rainwater and runoff harvesting	Roof top rainwater harvesting Field bunds, trenches, Spate irrigation
Induced bank infiltration	River bank infiltration Inter-dune infiltration

Source: IAH-MAR (2005) and IAH-NCC (2003)

A global inventory of recharge techniques and applications is available on the website of the International Groundwater Resources Assessment Centre (IGRAC, www.igrac.net).

It is equally important to manage the *natural recharge*. Natural recharge benefits from maintenance or construction of landscape elements that slow down and retain surface run-off such as terraces, low bunds, depressions, and cleverly designed roads and canal embankments. Natural recharge is also enhanced by ensuring that infiltration can take place in uncovered areas by avoiding the creation of impervious built-up areas. In agricultural areas, the preparation of land helps absorb a large part of the rainfall. In planning irrigation systems, the condition of the buffer underneath should be a prime consideration, because this allows for capture and reuse of seepage water. An important link also exists between natural recharge and the condition of streams and rivers. The capacity of rivers to store and buffer floods is not safeguarded by constraining them in narrow embankments or removing all their gravels and sands, but by reducing discharge velocity, enlarging surface buffer zones and enhancing the infiltration interface with the aquifer (commonly alluvial aquifers). Catchment management is required to balance the water needs of local communities with those downstream and the environment, in respect to volume and timing of water availability and flood mitigation.

Retention

Retention slows down the lateral flow of groundwater. This helps pond up groundwater and create a large wet buffer in the subsoil. Under such conditions, it is easier to retrieve and circulate water. Retention makes it possible to extend the chain of water uses. With retention, the groundwater table is heightened. Slowing down, or even controlling lateral outflow affects the water table and the soil moisture and soil chemistry. This has led to improved yields of rain-dependent agricultural areas. Some argue that in some cases it is better to control soil moisture from below than to provide surface irrigation water from above because of lower losses through evaporation and less development of salt crusts on the top soil.

An elaborate form of groundwater retention is controlled drainage whereby the groundwater tables are increased and decreased depending on the seasonal requirements for flood storage, agriculture or other uses. Groundwater levels and surface stream levels correspond closely, and a balanced matching of interests and stakeholders is required for success.

The many techniques for groundwater retention range from simple to sophisticated. On the low-cost end, earthen gully plugs in drainage canals can retain groundwater in large areas – a technique common in the eastern part of India and Bangladesh. Subsurface dams and sand dams have this same effect of retaining groundwater and creating a huge reservoir by increasing the outflow level. In Maharashtra in Central India, the so-called KG Weirs have shutters (called 'needles') that do the same, as they pond up the water and recharge the upstream aquifer. Controlled subsurface drainage systems – networks of collectors and distributors equipped with special valves and outlets that make precision groundwater level management possible – are at the top end.

Reuse

Reuse is the third element in buffer management. The biggest challenge of 3R is making water revolve as much as possible. Scarcity is resolved not only by managing demand through reduction in use, but also by keeping water in active circulation.

Three processes are important in managing reuse. The first is *management of (non-beneficial) evaporation*. Water that evaporates 'leaves' the system and can no longer circulate within it. This is an important concept. In some areas, for instance, 'efficient' irrigation reduces reusable recharge and results in the evaporation of a higher percentage of the water. This makes less water available for reuse and may jeopardize the water balance. One source of evaporation is from the soil – particularly from depressions and moist stretches. There is a fine balance between keeping good soil moisture (which is also achieved by agronomic practices, shade trees and the like) and avoiding evaporation losses from the soil. In fact, in some areas a reduction in groundwater table (from very high to moderate) reduces such non-beneficial evaporation.

The second process in managing reuse is ***managing water quality***. The possibility for reuse depends on the quality of the water, with different functions putting different demands on the water quality. Water quality management is an important element in buffer management. It entails avoiding the mixing of reusable water with lower quality water, and preventing up-coning or lateral flows from lower quality sources. Ensuring that repeated reuse of water and frequent circulation do not move water quality beyond safe thresholds requires significant effort. The fact that drinking water must be of higher quality than irrigation supplies, suggests the necessary sequence of reuse.

The third element of optimizing reuse is ensuring that water does not move to an area from which it is ***difficult to retrieve*** and reuse. The difference between wet and dry buffers is relevant here. Water which is recharged in a dry unsaturated buffer is difficult to retrieve and, though not lost, is difficult to bring back into circulation. When the buffer is saturated, on the other hand, it can be readily retrieved. The wet buffer or saturated zone is where intense hydrological interaction occurs between recharge and reuse, and between surface water and groundwater. In the saturated zone, reuse is rapid as water that seeps away is quickly picked up and circulated again. An important challenge in 3R is to increase the 'wet water buffers' and successfully manage the existing uses. By ponding up groundwater and slowing down lateral movement, retention can create or enlarge such saturated zones. These nuances must be appreciated in order to avoid the assumption that because a basin is a hydrological unit all water related processes in the basin are one and the same.

An understanding of 'what lies beneath', or the characteristics of the groundwater buffer, is essential to all of these techniques. Not all buffers are the same. They differ in size, in hydrological interaction, in storage capacity, and in vulnerability. The characterization of the groundwater systems in a basin requires the specialized input of a hydrogeologist who is qualified to map out the different aquifers and the key properties of the basin (figure 4).

There is no standard approach to determining 'buffer strategies', as different socio-economical and environmental conditions set different starting points. Much is to be gained, however, from tailoring 3R to local opportunities and preferences, as identified by the different parties living 'on top of the buffer'.

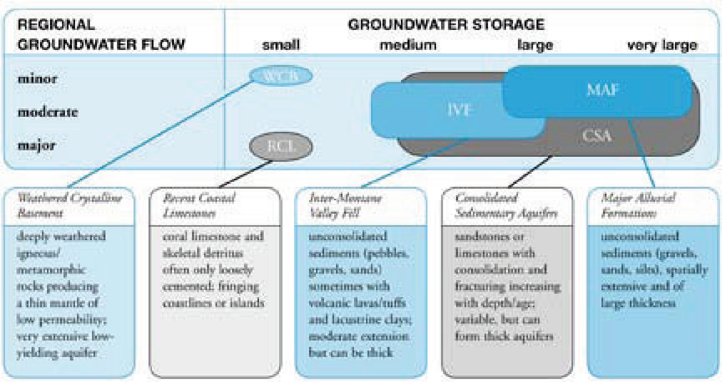

Figure 4. Summary of key properties of aquifer types (Source: Characterization of groundwater systems, GWMATE BN 2; www.worldbank.org/gwmate)

2.3 The 3R process

Assessing local needs

Buffer management must be derived from a thorough understanding of local livelihoods and the needs, priorities and potential of the people living in the area (i.e. from access to drinking water to the scope for economic development). 3R should be implemented at scale, be part and parcel of local development, and take into account local opportunities and constraints. The secure availability of water through better management of the buffer has different consequences for different people living in the area, which need to be well understood.

Feasibility assessment

The 3R Opportunity Maps are helpful for 3R investment decisions. 3R Opportunity Maps are based upon understanding of shallow hydrogeology and soil moisture processes (with the help of remote sensing – box 4), and decadal preferable downscaled climate change forecasts for the specific area and their projections for precipitation and run off. The 3R Opportunity Maps are assessments of hydrological and hydrogeological potential and include aspects such as governance and financing, not only of the particular 3R system, but also concerning the preconditions for proper 3R performance, including land use and possible changes. Thus, the assessment can lead to comprehensive feasibility and costs and benefits analyses.

Another useful tool for water management and 3R assessments is the yield-reliability risk assessment, which provides insight into the correlations between water management systems and mitigated impacts under current and future climate conditions. Risk assessments help to resolve debate about risk acceptance under uncertainty (with and without 3R under different conditions).

Climate information

For both 3R feasibility assessment and 3R operations, specific and tailored climate and weather information is available, and can and should be used. For a detailed description of the types of information and their use, see Climate Change Adaptation in the Water Sector by Ludwig, Kabat, Van Schaik and Van der Valk.

Time series analysis, stochastic (synthetic) hydrology and extreme value analysis are available for use in 3R feasibility studies. Table 2 gives an overview of climate information tools and the pros and cons of using them in water management (Ludwig et al., 2009).

Table 2: Climate information tools and remarks on their application in water management

Tool	Remarks
Time series analysis of climate variables	• Predictability: nature and amplitude of climate variability strongly vary on spatial and temporal time scales
Stochastic (synthetic) hydrology	• Trend detection: signal-to-noise ratio, as well as the availability of (long-term) homogeneous observational records, determines detection of a trend
Extreme value analysis	• Based upon rainfall and floods time series
Climate scenarios	• Climate projections: first 50 years of uncertainties in the initial conditions are more important than uncertainties in external forcing (GHG emissions)
Climate forecasts	• Correlations between sea surface temperatures and ENSO, PDO, NAO and IOD as a basis for seasonal forecasts • Land-atmosphere interactions, particularly soil moisture, as a basis for seasonal forecasts.
Climate models (GCM/RCM)	• Predictability determined by initial conditions and external forcing • Model scenario projections: from general circulation models to Earth System models • Uncertainty associated with imperfect modelling systems: can be covered by multi-models.

Implementation and financing

Significant amounts of buffer management can be achieved with more considerate planning and with the use of relatively low-cost techniques. As the examples of 3R in practice included in this booklet demonstrate, many techniques have very short repayment periods and some can be operated by local or community initiative. Given the impact of climate change on the long-term, there is a high end to 3R as well which makes implementation of 3R applications financially viable.

3R financing cannot be limited to a single sector–government, the private sector, or individual initiative–rather, a wide net must be cast that includes all sectors and considers who benefits most and who is best positioned to manage and operate the 3R facility. A 3R implementation and financing strategy systematically looks at the different functions served by buffer management, identifies the interests associated with these functions, and helps determine whom to involve in the different components.

A number of principles are involved in 3R financing:

- Mobilising action and investment – have the knowledge and incentives ready for individual families, firms and local communities to invest in recharge, retention and/or reuse. These incentives may come from direct benefits.
- Create matches with other investments – add buffer management to road planning, urban planning and land development programmes, so as to achieve high cost efficiency.
- Make use of special investment opportunities, for instance climate change adaptation funds, to leverage investment by others.
- Acknowledge and make use of the large interests involved in water and land development. In case of sand and gravel extraction, for instance, very serious money is involved in the mining concessions, which can be used to invest in rainwater harvesting, buffer management and water retention.

Box 4. Using new satellite information

A new generation of satellite techniques – such as the surface energy balance – make it possible to assess soil moisture, cropping patterns and estimated crop yields – in time series and with high accuracy. They make it possible to do a reconnaissance of the most promising areas and interventions. With the help of remote sensing, a water balance based on the same data set and methodology (as opposed to composites of different calculations) can be constructed to assess the evaporation of all land uses. Combining this information with stream flows and rainfall data enables construction of a water balance. This innovative technique makes it possible to estimate net groundwater use as a residual from the water balance. It can be used to infer a reliable estimate of net groundwater removal without identifying the features of individual wells. The data can also be used for calibration of groundwater simulation models, based on hydrogeological studies including: drilling, pumping tests, geophysics, hydrochemistry and isotopic methods, to characterise aquifers and groundwater flow systems.

Using the infrared of the spectrum, satellites make it possible to monitor precipitation in real-time on a global scale, even in areas that are located far from a meteorological station. This makes it possible to identify areas of high and low potential for rainwater harvesting and runoff management.

Institutional and social management

It is also important to integrate 3R development in river basin planning. River basins are globally accepted as the basis for water resource planning. This not only the on the basis of the European Framework Directive but also in the African continent where the AMCOW has recognized the River and Lake Basin Organizations as the building blocks to foster management of water resources including groundwater.

The livelihood perspective is also important – what does 3R and buffer management mean for the lives of women, men and children? The gender perspective is also significant as women traditionally take care of domestic water supply. In many areas, livestock keeping is also very much in the women's domain and women's role in small holder agriculture is increasing in many parts of the world. Involving women in 3R will contribute greatly to its success.

Knowledge base and information sharing

The 3R approach is still in its initial phase and will greatly benefit from sharing of existing information and from the exchange of best practices and lessons learned. Developing a shared knowledge and information centre will be considered in the near future. A website 3rwater.org is under development and will serve as the focal point for communication. Sharing information will also support formulation of a research and development agenda to refine the 3R approach and address specific technology development for testing and piloting.

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3. Cases

This chapter presents examples of water buffer management at work from a large number of areas. In the cases the three R's are used in different ways – depending on local priorities and potentials. In some cases time-tested indigenous techniques are used, sometimes modified. In other cases entirely new methods are introduced. The emphasis may be on recharge, retention (including making use of local surface storage) and reuse or a combination of them (see table). Several of the cases show that the systematic application of 3R can improve and optimize the buffer function for entire areas, not just for isolated places.

No	Case	Recharge	Retention	Reuse
1	Dune infiltration ponds, Atlantis South Africa	☐		
2	Small scale river bank infiltration – making use of river sediment storage, Bangladesh, India	☐		
3	Artificial groundwater recharge and protection zones in arid areas, Wadi Wala Dam, Jordan	☐		
4	Providing drinking water in areas with saline groundwater, Chaco, Paraguay	☐		
5	Sand storage dams, Kitui, Kenya	☐	☐	
6	Using floods for irrigation and recharge, Yemen	☐		
7	Diverting short floods to infiltration basins in extremely arid areas, Niger	☐	☐	
8	Seeking alternatives for sand mining in river beds, India, Sri Lanka	☐	☐	
9	Subsurface dams – intercepting groundwater flow for storage, Brazil	☐	☐	
10	Retaining water in very humid areas, North Bengal, India	☐	☐	
11	Creating a 'water bank' with surplus surface water, Namibia	☐	☐	
12	High altitude surface water retention dams, Peru		☐	
13	Harvesting the rain in dry areas, Sub-Saharan Africa	☐	☐	
14	Spring water harvesting, Tanzania		☐	
15	Rainwater harvesting in salt affected areas, Senegal		☐	
16	Multiple aspects of rainwater, Nepal		☐	☐
17	Controlled drainage, The Netherlands		☐	☐
18	Conjunctive use of groundwater and surface water in large-scale irrigation, Morocco	☐		☐
19	Making the most of road infrastructure for recharge, retention and reuse, Kenya, China, Brazil	☐	☐	☐

Dune infiltration ponds

Atlantis, South Africa

Sand dunes are favourable topographic features to store water because of the high permeability and often large storage capacity. Dune infiltration is widely used at different scales and for different purposes including provision of drinking water, water quality improvement through filtration, to maintain a strategic reserve, and as a barrier against saline groundwater intrusion.

Figure 1: Infiltration pond in dunes in Atlantis, South Africa.

Description

In Atlantis (South Africa), dune infiltration is used for drinking water supply and protection of fresh groundwater reserves against intrusion of saline groundwater.
The town of Atlantis, located 50 km north of Cape Town, along the semiarid West Coast of South Africa, has over 100 000 inhabitants. The water consumption without restrictions is around 7 MCM/year (in 2000).
Most of the 450 mm mean annual rainfall is received from April to September. Since the soils are mostly sandy, 15% to 30% of the rainfall recharges the groundwater. In the bare dune areas, recharge percentages are highest. Since its establishment in 1976, the town has been dependent on groundwater for its water supply. Groundwater supplies however are limited. To augment groundwater supplies, artificial recharge through infiltration basins was introduced shortly afterwards (figure 1).

Being a new development, the town was planned with fully separated residential and industrial areas. This fact contributed to the success of the artificial recharge operation, as it was possible to divert storm water (for infiltration in the basins) and the wastewater flows of inferior quality from the industrial area which was conveyed to a waste water treatment plant (figure 2).

Techniques used

To enhance natural recharge of precipitation to groundwater, infiltration ponds were constructed into the dune formations with high permeability. Ponds were either excavated or formed through enclosure dikes retaining the recharge water until it has infiltrated through the basin floor.

In the Atlantis area, surface runoff is generally low under natural conditions due to the high infiltration capacity of the soil. It was realized that large volumes of storm water runoff would be generated after urbanization and the associated hardening of land surface. However, the stormwater runoff was regarded a valuable water source to augment freshwater supplies in the region. Thus a stormwater collection system was constructed. As an added water source, treated domestic wastewater is recharged to the aquifer along with the stormwater.

Results and impacts

The artificial recharge system at Atlantis is a medium-sized scheme needing professional management which is provided by the Water Department of the City of Cape Town. The following have been some of the key experiences in maintaining and operating the system over the past 20 years:

- Maintenance of the recharge structure is important. The bottom of the pond must be inspected and treated regularly in order to minimize clogging to maintain infiltration rates and keep evaporation from open water to a minimum;

- Iron-related clogging of abstraction boreholes due to over pumping of the boreholes has proven to be an extensive and serious problem. From 1999 to 2002, boreholes were examined and rehabilitated using special treatment techniques;

- Managing water quality and, in particular, salinity has been one of the greatest challenges. Management actions to control salinity in the Atlantis water supply have included the launching of a detailed chemical investigation of the salinity sources, regular monitoring and the establishment of an early warning system against any potential uncontrolled spills;

- Awareness-raising and improved environmental practices have been initiated by some industries. Increased understanding of contamination threats allows these industries to improve their operational procedures to protect their water resource.

Some generic advantages and disadvantages of dune infiltration are:

Advantages	Disadvantages
- Expected flows can be accommodated by constructing basins of appropriate size.	- Not suitable on fill sites or slopes.
- Intermittent floodwater can be stored for later infiltration.	- Risk of groundwater contamination in very coarse soils (the basin should be declared a protected area).
- Clogging can be mitigated through proper basin construction techniques or operational procedures.	- Storage of surface water may increase breeding of surface water related disease vectors, and concomitantly increase the risk of diseases, such as malaria.
- Because infiltration basins are equipped with an intake system, intake can be stopped during periods when the water source is of poor quality.	
- They are integrated into the site's landscape.	

Concluding statement

The inhabitants of Atlantis (> 100 000) have access to good quality drinking water in a semi-arid region with little surface water resources and limited rainfall. With regards to the increasing erratic rainfall in Southern Africa, this method of capturing water in dunes is also considered as the most appropriate in coping with increased demand and adapting to climate change.

Artificial recharge through infiltration ponds can be applied almost anywhere, provided that there is a supply of clean fresh water available at least part of the year, the bottom of the pond is permeable, and the aquifer to be recharged is at or near the surface.

Besides natural rainfall, infiltration ponds could also be supplied with urban stormwater and treated domestic wastewater. The ponds do however require a relatively large surface area and are therefore only suitable where there is ample room for installation. Because infiltration ponds are very vulnerable to contamination, they should be located in a protected area.

Figure 2: Map of Atlantis artificial recharge scheme. (Source: Tredoux G. 2002).

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Small-scale riverbank infiltration - making use of river sediment storage

Bangladesh, India

Where rivers or streams flow, water is stored in rivers, riverbeds and riverbank sediments. This natural storage and groundwater flow can effectively be utilized through riverbank infiltration (RBI) systems. These systems and processes are exemplified with a case from Bangladesh, where high concentration of arsenic is found in water resources and a case from Maharashtra where there is high incidence of fluoride in groundwater. Other names used are induced riverbank infiltration or surface water infiltration systems (SWIS).

Description

River bank infiltration usually makes use of a gallery, a well or a line of (drilled) wells at a short distance from the river. Groundwater abstraction from the boreholes or gallery lowers the groundwater table adjacent to the river, increasing the natural infiltration of river water into the aquifer. During groundwater flow from the riverbed to the well, contaminants and pathogens are removed through physical, chemical and biological processes.

Figure 3. River bank infiltration well in Bangladesh for arsenic-safe water supply

An example of a successful application in a humid area is the river bank infiltration in Chapai Nawabganj, Bangladesh, where arsenic-free water is pumped from a well near the river (figure 1). The dugwell in Maharashtra (figure 2) shows river bank infiltration in a dry region from which fluoride-free water is pumped during the whole year to supply a nearby community.

Techniques used

River bank infiltration schemes are typically installed near rivers that are hydraulically connected to the aquifer through permeable sediments such as sand and gravel. An important design criterion for river bank infiltration is the guarantee of a minimal travel time of 30 to 60 days of the water from the river to the abstraction point in order to reach satisfactory purification.

A typical design of a river bank infiltration is shown in figure 1. The main component is the abstraction device, which is generally a drilled or hand-dug well with either vertical or horizontal screens, depending on the thickness of the aquifer.

Where the permeable sediments are thin, infiltration galleries can be installed at the base of the aquifer to allow greater recharge than would otherwise be possible.

A typical approach for the design of a small scale river bank infiltration system is:

- drilling shallow observation wells to check water quality, groundwater flow and the type/depth of sediments (including the thickness of the clay layer along the river bank);
- drilling a production well for a constant discharge test (72 hrs) during which the groundwater levels are observed in the observation wells;
- evaluation of the test and calculations with a (simple) groundwater model to design the abstraction wells, estimate the storage capacity of the aquifer and to verify the 60 days travel time of the water.

Figure 4. River bank infiltration well in Maharashtra

Some larger riverbank infiltration schemes are supplemented with infiltration ponds or recharge shafts to improve water quality and increase recharge (figure 1). An artificial deposit can be applied to the riverbed, creating a reduced environment to prevent the pollution of infiltrated water by organic material.

Many river bank infiltration schemes are operational, ranging from large schemes for supplying drinking water to cities like Budapest and Berlin to small schemes for local water supply consisting of a few wells along the riverbank. Where necessary, during periods of low river discharge, small schemes can use groundwater from the natural storage.

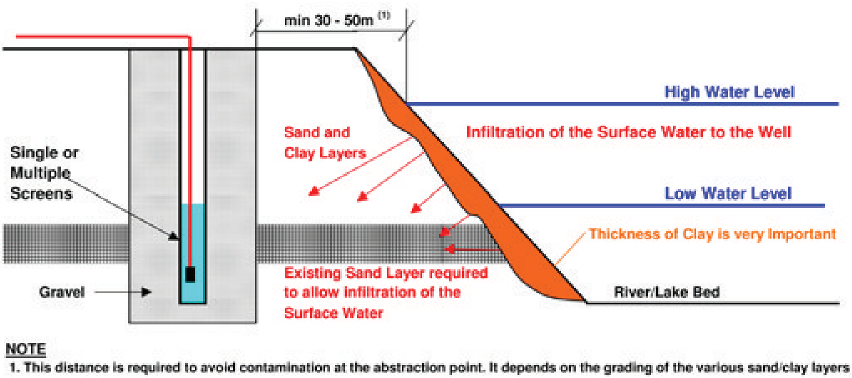

Figure 1. Typical design of RBI

Results and impacts

River bank infiltration provides potable water without expensive treatment and is a cost-effective solution compared to a surface water treatment or long distance water conveyance (box). For small-scale river bank infiltration there is the additional advantage that the storage capacity of the sediments around the river bed provide a source of water during the dry period when there is no flow in the river.

Quality improvement of the water (compared to the direct use of surface water) is the main advantage of river bank infiltration schemes. Also, the effects on the piezometric heads are limited compared to the abstraction of groundwater.

If the aquifer extends below the river, water supply is more certain during the period's limited flow. This is especially relevant for smaller systems which provide drinking water to villages or small towns.
Disadvantages are that the surface of the riverbed may need to be scraped during periods of low water level. If clogging of the river or lake bed is excessive it increases the resistance of the river water into the sediments. Long-term contamination of river water by persistent organic compounds (such as pesticides and pharmaceuticals) may contaminate groundwater, and is therefore currently the biggest threat to RBI schemes. Monitoring river water quality and quality of abstracted water should therefore be an integrated part of the operational routine.

Concluding statement

Small scale river bank infiltration is a cost-effective means to provide safer water with a year-round high quality, especially when compared to the usage of surface water. Storing surface water from rivers and lakes in adjacent aquifers also circumvents evaporative losses of a resource, which in many contexts is becoming increasingly erratic in time and space.

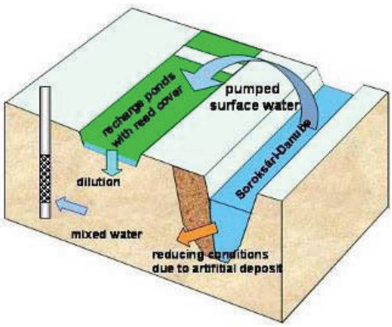

Figure 2. RBI with recharge ponds

Mwingi Town (Kenya): local river bank infiltration – versus - long distance conveyance

Mwingi Town is located along the ephemeral Thia River in the semi-arid Eastern Province of Kenya (rainfall 600 mm/year). The main source of water is the groundwater taken from the (temporary) dug wells in the riverbed. The municipality constructed a permanent dug well alongside the riverbed in 1983 from which the water was pumped to the town. The capacity was increased in 1993 with a new well (diameter 3 m). The water supplied 300 houses and a number of public water points for a flat rate of Khs 480/per month. A further extension was planned but never implemented due to the construction of a completely new water supply scheme.

A new system was then constructed in 1998, bringing water from the Kimbere dam (60 km away). The water is pumped into a 2,700 m^3 reservoir and distributed by gravity. The new system came into operation with a regional operator (TARDA) who charges Khs 170/ m^3 for the 300 house connections and Khs 2,5 per 20 litres for seven village kiosks. A surcharge for the water meter is also recovered. Since its construction, the new system has been out of order regularly for undefined periods which sometimes reached 1 month. During these periods water vendors (using donkeys) distribute water from temporary wells in the riverbed against a price of Khs 10–20 /m^3.

There is great dissatisfaction amongst local institutions and consumers about the high cost and low service level of the new scheme. They would prefer to reinstall and expand the old system, which was operated by the municipality and provided good quality water at an affordable cost.

Further reading

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Artificial groundwater recharge and protection zones in arid areas

Wadi Wala Dam, Jordan

Jordan is a country of extreme water scarcity with water resources availability of approximately 135 m^3 per person per year. The main factors which have lead to this situation are the high population growth rate and the influxes of refugees from neighbouring countries affected by war and civil unrest.

In Jordan rainfall occurs only during a short wet season (usually November to March) and is concentrated in the westernmost part of the country (figure 1). Since the late 1960s the Jordanian government has built a number of dams in order to store surface water during the wet period and use it mainly in the dry period. Until recently most of these dams were used for irrigation. However in recent years the government has built a number of large dams with the aim to increasingly make use of surface water for drinking purposes. Two of these dams are located in the central western part of the country and were completed in 2003: the Wadi Mujib dam with a maximum storage capacity of 31.2 million cubic meters (MCM) (safe yield: 16.6 MCM/yr) and the Wadi Wala dam with a maximum storage capacity of 9.3 MCM (safe yield: 17.7 MCM/yr). Both dams are located in the western part of the Wadi Mujib surface water catchment, close to the Dead Sea. The Wadi Mujib Dam is located in an area where the geological conditions and technical installations ensure that no infiltration into groundwater takes place. The Wadi Wala dam, however, has been built in an area where the stored surface water can infiltrate into the main aquifer used in Jordan, the so-called A7/B2 aquifer. Groundwater artificially recharged at the Wala dam is then abstracted in the downstream area, at the Wala/Heidan well field, some 8 km W of the dam. This well field comprises around 40 wells and has been used since the early 1980s. Since 1992 abstraction from the wells has been around 12 MCM/yr, varying between 8 and 14 MCM/yr.

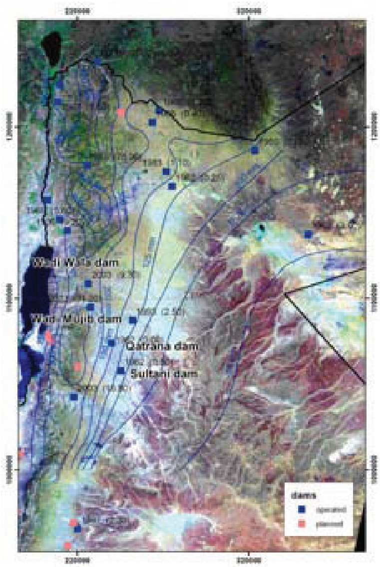

Figure 1: Location of Wadi Wala and Mujib Dams with Maximum Storage Capacities (MCM) and Average Rainfall Distribution

There are several water level monitoring wells downstream of the dam and in the vicinity of the well field. These show that in the immediate downstream area of the dam groundwater levels have risen by between 25 and 40 m after the start of operation of the dam (figure 2). Even in the Wala/Heidan well field groundwater levels have risen by between 16 m at the margin and 35 m in the central part of the well field.

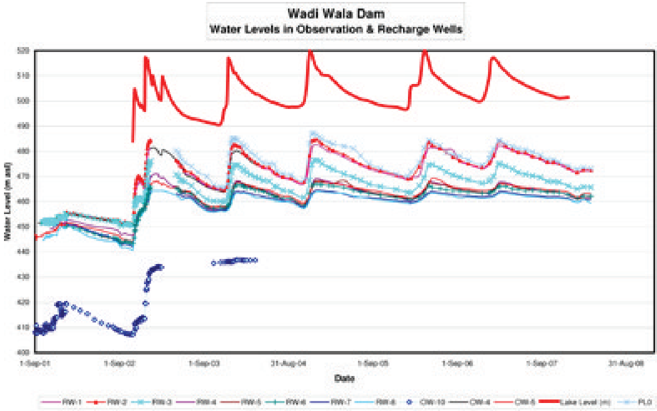

Figure 2: Monitoring Graphs of Lake Level and Groundwater Levels in the Downstream Area of the Wadi Wala Dam (maximum distance of monitoring wells from the reservoir: 2 km)

Techniques used

After six years of operation artificial groundwater recharge at the Wadi Wala Dam has so far proven to be effective. The injection wells, installed during dam construction, were until now not used. In the meantime considerable amounts of sediment have accumulated at the bottom of the reservoir (figure 3), which has led to a blockage of the lower draw-off pipe and the bottom outlet. Currently water can only be released from the upper draw-off pipe. When the reservoir fell dry during summer 2008 it was observed that a thin layer of sediment also covers the side walls of the reservoir.
The long-term water level monitoring data show that the sediment accumulation has not – or at least not yet – led to a significant decrease in artificial groundwater recharge. It is therefore assumed that current artificial groundwater recharge at the Wadi Wala Dam mainly takes place in the lateral direction and then follows vertical fractures. In the long term, however, artificial recharge is expected to decrease due to sediment accumulation and colmation, and injection wells will have to be used. This may also bring about changes in the hydrochemical composition in the reservoir as was observed at Wadi Mujib Dam.

It is therefore important that during the design and construction phase of dams the problem of sediment accumulation by sediment inflow and landslides is sufficiently addressed, especially concerning dams destined for artificial groundwater recharge. Sediment inflow into reservoirs could be reduced by installing large stilling basins in the upstream area, which need to be regularly emptied. It is important to mention that earlier attempts of the Jordanian Government to operate artificial recharge dams in the flat area at Qatrana and Sultani east of the Mujib and Wala Dams (figure 1) have failed because of siltation problems.

In the framework of a Jordanian-German technical cooperation project, surface water protection zones have recently been established for both the Wadi Wala and Mujib Dams (Margane et al, 2008 and 2009). As the most important criteria the slope angle near the dam was used for the delineation of protection zone 2 (Margane et al, 2007). In the related guideline zone 2 is defined as a buffer zone

Figure 3: Sediment Accumulation at the Bottom of the Wadi Wala dam has lead to the Closure of the Bottom Outlet and the lower Draw-off Pipe

of 500 m around zone 1, and zone 1 is identified as a buffer zone of 100 m around a reservoir. Zone 2 is measured from the highest possible water level if the slope within the zone is less than 2°. If the slope exceeds 2° at 500 m, zone 2 will be delineated up to the point where the slope is less than 2°. In the upstream area, zone 2 reaches a maximum of 5 km following the course of the main wadis discharging into zone 1. The protection zone for the Wadi Wala Dam is shown in figure 4. The main consequences of protection zone delineation for dams are that the Jordanian Government will have to establish wastewater collection and treatment systems for villages near the dams. In the case of the Wadi Wala Dam, the protection of the reservoir as well as the area between the artificial recharge facility and the groundwater abstraction facility, the Wala/Heidan well field (Figure 5), have to be considered because pollution can also occur along this flow path. The main hazards to groundwater in this area are related to agricultural practices, namely the abundant and frequent use of untreated organic and chemical fertilizers and pesticides. Following the establishment of both dams, cultivated areas have spread especially near and downstream of the dams. It is therefore important that the issues of surface and groundwater protection are addressed when selecting and designing dam sites. Only then can the protection of the water resources be effective.

Figure 4: Surface Water Protection Zones for the Wadi Wala Dam (according to the Jordanian guideline zone 2 for main wadis covers a buffer zone of 350 m to both sides of the center of the wadi)

Figure 5: Locations of Wadi Wala Dam and Wala/Heidan Well Field with Water Supply Network (the green areas between the reservoir and the well field indicate irrigated areas)

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Providing drinking water in areas with saline groundwater

Chaco, Paraguay

Introduction

Areas with saline groundwater are among the most difficult areas to deal with in terms of drinking water supply. Rain water collection and the careful management of fresh groundwater lenses provide a lifeline in such places. An example of a vast region with saline groundwater is the Chaco Plain in Paraguay.

Description

Figure 1: Location of the Chaco in Paraquay

The Chaco – with a surface of 240,000 km² – covers two thirds of Paraguay (figure 1). The area is scarcely populated and mainly undeveloped. Drinking water resources are limited. Much of the groundwater is saline, and there are no perennial rivers or lakes. The Chaco is a vast alluvial fan of sediment deposits from the Andes. The area of the Central and Western Chaco up to the Rio Pilcomayo covers the ancient delta of the Pilcomayo River. It is composed of medium to very fine grained sediments (sand, silt, clay and all transitions) with alternating aquifers and aquitards. Fine sand, silt and clay interchange both laterally and vertically. Following the gentle inclination of the old delta, groundwater flows slowly from west to east with a velocity between 0.6 and 1.8 m/year (Junker, 1996). In the central part of the Chaco, the shallow groundwater table lies at a depth of 3 m to 15 m. The groundwater in the area ranges from brackish to extremely salty with an electric conductivity up to 60,000 ppm (at 25 °C) (Echeverria, 1989; Godoy, 1990). The mean annual precipitation is between 800 mm and 900 mm, reaching up to 1600 mm in a peak year. The larger part of the rains occurs from November to March, when evaporation is also at its peak.

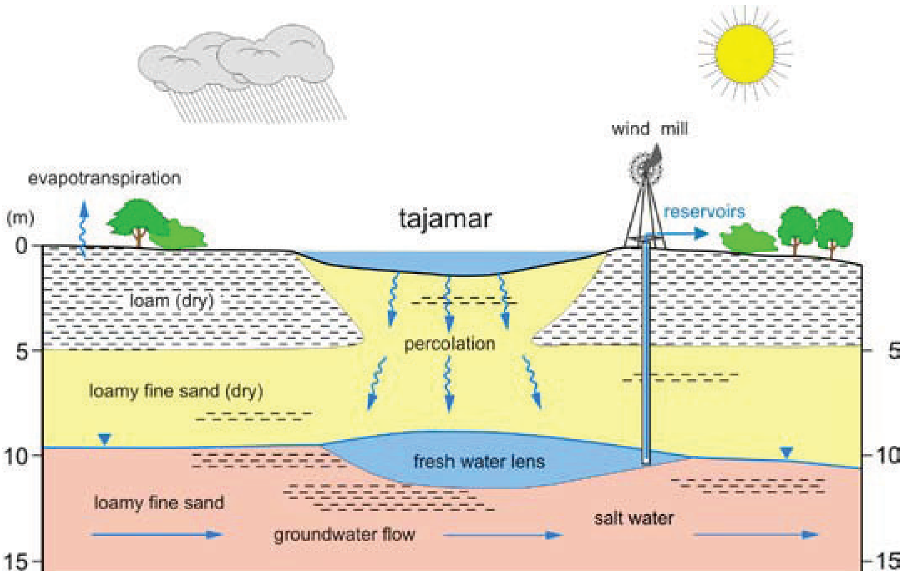

Figure 2: Formation of a freshwater lens as a result of rainwater infiltration

Techniques used

The use of rainwater during the rainy season is crucial to ensure domestic water supply. For this purpose, two different methods are employed in the Chaco region:

i. Rainwater harvesting. Rainwater is collected from rooftops and stored in underground cisterns. Water is lifted by hand pumps into buckets or pumped into overhead tanks with electric pumps (Keller, 1995). If the gutters and cisterns are kept clean, the water quality will be good.

ii. Surface water storage and artificial groundwater recharge by means of so-called *tajamares*. Some tajamares collect runoff of a large area and store it in a surface reservoir. Other tajamares are man-made depressions (figure 2) that together with natural depressions feed local freshwater lenses. These freshwater lenses float on top of the saline aquifer. They occur when the following conditions are met:

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

The tajamares systems are community-managed. They provide a water source under very difficult conditons and serve as a tool for climate change adaptation as they benefit from high intensity rainfalls. The water is pumped up into a reservoir by a windmill, as shown in figure 3. To avoid contamination by animals the tajamares should be fenced off. The general cost based on a tajamares was roughly 20,000 Euro – serving a community of 400 persons (60 houses). This cost involved the recharge structure, a windmill, five cisterns and handpipes, pipeline costs and labour costs. This amount is usually within the spending power of the local community. The tajamares can be planned and *constructed* by the local community themselves, thereby ownership will be developed and the transfer of technical know-how takes place. This is indispensable for guaranteeing that the water supply schemes are operated and maintained in the future.

Figure 3: A windmill pumps the water into a reservoir

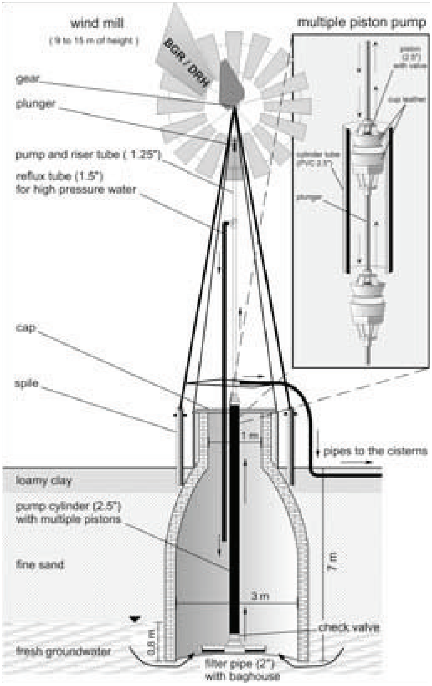

Figure 4: Schematic overview of windmill

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Kitui sand storage dams

Kenya

Introduction

Large-scale implementation of groundwater recharge interventions has many benefits over single systems. The stored volumes of groundwater are generally larger, and the ecological damage caused by a single, much larger water source is prevented. Social benefits are also numerous, as has been seen in the Kitui District (Kenya) where over 750 sand storage dams have been constructed.

Figure 1. A typical sand storage dam during the dry season in the Kitui District

Description

The Kitui District is situated 150 km east of Nairobi. The size of the district is approximately 20,000 km^2 including 6,400 km^2 for the uninhabited Tsavo National Park. The area is semi-arid, with rain falling in two wet seasons. The rains usually fall in a few intensive storms and are highly erratic and unreliable. Most rivers are seasonal, only flowing during the wet season. During the dry season, surface water sources are scarce or absent. Walking distances to the few water sources increased as the dry period prolonged. The response to these problems was the construction of sand storage dams.

In close collaboration with local communities, Kenyan NGO SASOL took the initiative in the 1990s to ensure water availability for rural communities in the Kitui District through the construction of sand storage dams. In the decade that followed more than 750 dams were built, successfully providing communities with water for domestic use and small-scale irrigation.

These dams were built in the riverbed to increase the thickness of the natural sand layer in the riverbed, thereby enlarging the storage capacity of the riverbed aquifer. Furthermore, the sand storage dam obstructs groundwater flow through the riverbed, preventing the loss of water from the catchments. The construction of a sand storage dam leads to larger volumes of water stored in the riverbed, ensuring higher water quality and availability (usually lasting throughout the dry season).

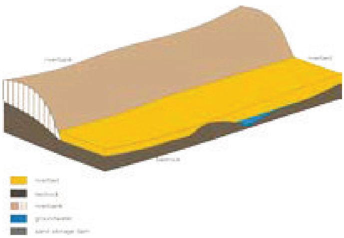

Figure 2. Riverbed without a sand storage dam during the dry season (Hoogmoed, 2009)

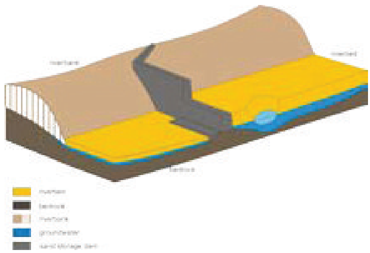

Figure 3. Riverbed with a sand storage dam during the dry season. Water availability is considerably larger compared to a river without a sand storage dam (Hoogmoed, 2009)

Techniques used

The first step in the construction of a sand storage dam is site selection. The following are general indications on the appropriateness of a riverbed as a construction site:

- the riverbed has a width of approximately 20 m and contains coarse sand;
- the riverbanks are steep at both sides and have a height of approximately 1 m to 1.5 m;
- the banks preferably consist of clayey material or rock outcrops;
- the presence of groundwater (scoop holes in river beds) a few months after the rains have ceased is a good sign (i.e. downstream of this location a natural flow barrier is present and an (semi)impermeable layer prevents leakage to deeper aquifers).

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

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

Communities are involved in siting and the construction of sand storage dams through sand dam management groups, providing knowledge, labour and raw materials. After construction, these groups ensure the maintenance of dams and protection of the water quality as well as promote ownership and thus sustainability.

Results and impacts

In the Kitui District, implementation of sand storage dams led to the availability of better quality water within short distances from the homesteads. Since less time is needed to fetch water, school attendance has increased significantly and more time has been spent on other income-generating activities such as household industries (basket weaving, sewing). Apart from drinking water security, sand storage dams provide enough water to develop small-scale irrigation (food and cash crops, tree nurseries) and industrial activities (brick making). After the introduction of the sand storage dams, the percentage of households suffering from malnutrition has demised from 32% to 0%, and incomes have increased significantly.

Vulnerability categories	Vulnerability indicators	Before dam construction	After dam construction
Agriculture	# of cash crops % irrigated crops	1.5 37	3 68
Special aspects	Domestic water collection (minutes)	140	90
	Life Stock water collection (minutes)	110	50
Gender	Average walking distance women to water (km)	3	1
Economic	Income (US$/year)	230	350
Health	% households suffering from malnutrition	32	0

Table 1: Measured social and economic impacts of sand dams in the Kitui region, Kenya (after Thomas, 1999).

In the Kitui District, sand storage dams have been implemented on a large scale, and frequently in cascades. The hydrological benefits of implementation in cascades are the reduced loss of water due to leakage of a sand storage dam (since the downstream dam will obstruct further downstream flow), and the groundwater levels are raised more extensively compared to the implementation of single systems (ensuring more water availability and generating vegetation in a larger area). Due to the construction of many sand storage dams (in cascades) communities are not dependant on a single water source, therefore limiting environmental impact. Also, implementing sand storage dams (and other water harvesting techniques) on a large scale enables communities to share experiences and knowledge, which promotes community participation.

Figure 4. Groundwater abstraction from the riverbed by means of a scoop hole in the Kitui District

Concluding statement

The implementation of sand storage dams has proved successful in ensuring water availability for rural communities in the Kitui District, not only for domestic use but also for small-scale irrigation purposes. Upscaling of the technology through the implementation of a large number of the structures has many benefits over the implementation of a single intervention, in relation to the availability of water and socio-economical benefits. Sand storage dams are a sustainable means to meet the increased water challenges in semi-arid areas due to the less reliable and higher intensity rainfall events as an effect of climate change.

Upscaling Across Country Borders

The successful implementation of sand storage dams on such a large scale as in Kitui District (Kenya) has inspired several new projects. Sand storage dams are now being implemented across District and country borders to provide rural communities of water, also with respect to climate adaptation. An example is the construction of sand storage dams in Mozambique, which was initiated through a knowledge exchange visit to Kitui.

Another good example is the pilot project in Borana Zone (southern Ethiopia). Here, the focus lay on making optimal use of available water resources in catchments to enlarging their water retention capacity. To this aim, 10 NGO's were trained by the Kenyan NGO Sasol, the Rain Foundation and Acacia Water on implementation of sand storage dams. AFD (Action For Development, an Ethiopian NGO) has implemented sand storage dams for the benefit of communities living close to riverbeds. For communities living far from rivers surface runoff water was harvested in underground water harvesting tanks. The combination of applying several water harvesting techniques within a catchment, and thus making optimal use of the natural resources, proved to be very successful.
Besides the sand storage dams built in the Borana Zone as part of the project, the on-job trainings and workshops resulted in several spin off projects by participating NGO's, in which community support and project funding was found to start implementation of sand storage dams in other regions of Ethiopia.

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Using floods for irrigation and recharge

Yemen

Introduction

Shallow aquifers are often the best place to store floodwater. Compared to surface reservoirs the cost of storing floodwater in the shallow aquifer and soil profile is minimal. There is very little evaporation loss and the water can be reused immediately or at the time preferred – with no conveyance loss. The capacity to store floodwater obviously varies from aquifer to aquifer.

There is also a second dimension to the link between floods and groundwater storage. If there is intensive groundwater development, effective flood storage capacity in the shallow aquifer will increase as the top layers are no longer saturated. As a result, floods will either not occur or, if they occur, they will do so later in the flood season and less frequently.

Figure 1. Spate irrigation in Tihama

Description

One of the best examples of combining flood storage, recharge and agriculture are the so-called spate irrigation systems. These systems have a long history in arid areas in Pakistan, Iran, North Africa, Sudan and Yemen. They are on the increase in the Horn of Africa and other parts of Africa. Spate irrigation is the quintessential adaptation to extreme climate events.
The central feature of spate irrigation is the usage of short duration floods that originate from

episodical rainfall events in highland catchments. Floods – lasting from a few hours to a few days – are diverted from dry riverbeds and spread gently over the land. The water is used in agriculture, with soil moisture often carefully preserved, as the floods usually arrive ahead of the cultivation season. The floodwater is also used for filling water ponds, for improving rangelands and tree stands, and for recharge. Spate irrigation systems have some of the most spectacular social organizations around. They require the local construction of diversion structures that are able to withstand flash floods and gently guide large volumes of water over large areas, thus slowing down erosion.
In Yemen the spate irrigated areas located on the Red Sea (the Tihama) and the Indian Ocean coastlines are the grain baskets of the country (see figure 1). Here agriculture is at its most productive. The high water productivity comes from the combined use of floodwater and groundwater, with the spate flows being the main source of recharge. Groundwater in the coastal plains of Yemen is mostly of good quality and hence can be easily reused. The result has been that the spate irrigation systems sustain not only extensive areas of staple crops and a large livestock population, but they have also made it possible to grow large areas of high value horticulture, such as banana and mango orchards. This has even reached the point that groundwater overuse is a real concern.

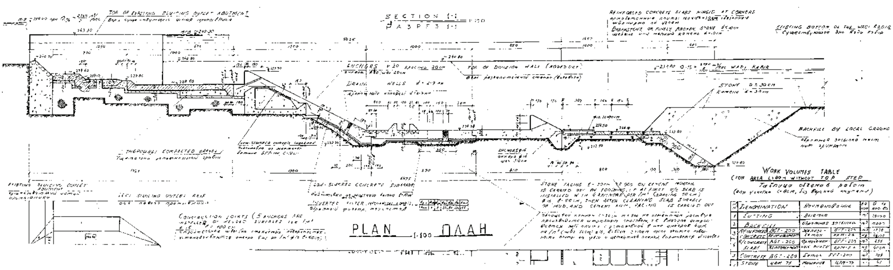

Figure 2. The Ras Al Wadi weir with weepholes provided

Techniques used

Most recharge in spate irrigation takes place through the riverbeds. Recharge from flood channels and farm fields is also important but is less significant. There are several ways to promote effective recharge. One is to keep the river bed armoured. Big boulders and stones will slow down the velocity of the floods and will enhance the replenishment of groundwater. A second action is to build structures that slow down the water. These are the regular spate diversion structures, but in some wadis in Yemen, such as Wadi Hadramawt, farmers have even built low weirs across the wadi specifically to increase recharge.

Since the 1980's a number of permanent concrete diversion structures have been built across some of the main ephemeral rivers in coastal Yemen. These structures were constructed to divert the flood flows to land, but some of them – for instance in Wadi Mawr or Wadi Siham – have inadvertently blocked the subsurface flow as well. These 'cut-off' weirs keyed into the bedrock or clay layers underneath the river. By doing so they had the unintended effect of increasing groundwater levels upstream of the weirs, and at the same time caused hardship for the users downstream.

A much better cut-off weir design was used in Wadi Tuban, where openings, so-called 'weepholes', were provided in the main body of the weir. These weepholes allow the subsurface flow to pass through the weir. Substantial flows emerge from these allowing the downstream wells to continue to function. Because of the weepholes, it is also possible to construct a relatively light structure. The Wadi Tuban weirs are relatively 'thin', which makes up for a substantial cost saving. If there was no underdrainage, the weirs would need to be much heavier to prevent them from 'floating away'.

Figure 3. Water emerging from weepholes

Apart from these modern structures, traditional structures – soil and gravel bunds and deflectors – also work very well. The traditional structures are typically built at a cost that is a fraction of the modern structures. Whereas a system provided with modern concrete headworks may cost 500 to 1800 Euro per ha, traditional structures may cost less than 250 Euro per ha. In many areas they work better: they provide more options to divert floodwater, they do not confuse the water rights and, because of their ability to breach in high floods, they are better equiped to keep such heavily silt-laden – and potentially damaging – big floods out of the command area. Smaller floods, however, are able to be utilized.

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Diverting short floods to infiltration basins in extremely arid areas

Niger

Introduction

Groundwater recharge by controlled flood diversion can safeguard and improve living conditions, even in extremely arid areas. Domestic water requirements, the needs of cattle watering and local irrigation can be met with low cost diversion structures and carefully sited infiltration basins. It makes it possible for settlements to develop even in the areas with the most fragile climate conditions.

Description

The oasis of Iférouane is situated in the Aïr Mountains in the central Sahara desert. It is located 1000 km north of Niamey, the capital of Niger (figure 1). With less than 50 mm of rainfall a year, Iférouane is extremely arid. In some periods even this low average is not achieved. For instance in the period 1940–1975 annual rainfall did not exceed 20 mm in this part of the Sahel.

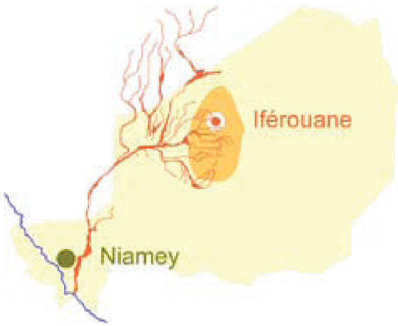

Figure 1: Location of Iférouane in Niger

The water demand in the oasis for human and agricultural purposes is met from traditional open wells. These are dug into the Quaternary sediments of the river valley that are intercalated by loamy material. The wells go down to a depth of 20 m. At a depth of approximately 10 m below the Quaternary sediments, there is a water-bearing granite/gneiss basement as well. The hydraulic conductivity of the sandy part of the aquifer system amounts to 3 to 5 m/day.

Until 1975, this groundwater buffer was only recharged by the occasional infiltration of surface water through the sandy bed of the local Kori Tamgak river during short flood periods. By 1974, after a stretch of extremely dry years, the groundwater table dropped and many wells fell dry. As a result, only one quarter of the gardens could be irrigated and the rest had to be abandoned. This threatened the very survival of the oasis.

Techniques used

Various hydrogeological investigations, including runoff measurements, groundwater monitoring, soil infiltration tests and numerical modelling, were carried out in order to identify the best suitable method for the improvement of local groundwater conditions.

Figure 2: Construction of diversion works

Among various scenarios, artificial groundwater recharge by diverting the occasional flush water from the Kori Tamgak into an infiltration basin was considered the most feasible measure. This infiltration basin was established upstream of the oasis in an area where infiltration tests showed the presence of highly permeable sandy and gravely material. Rock outcrops were also identified that could provide construction material for flood diversion works.

A low-cost barrage was constructed across the ephemeral river in 1975. The diversion works consisted of a ground sill, a diversion canal, protection walls and micro groins against flood erosion (figure 2). Low floods in the Kori Tamgak – below the level of the sill – are diverted to the infiltration basin, whereas the occasional high flood flush – that would cause damage and sedimentation in the infiltration basin - is allowed to pass over the sill and follow the original river bed (figure 3).

Impact

Consequently the groundwater tables started to rise immediately after the construction of the diversion works. After relatively 'high' rainfall of about 60 mm in 1976, the additional infiltration caused a remarkable rise of the groundwater level. In this year 13% of the flood discharge in the Kori Tamgak of 5.7 million m^3 was routed to the groundwater buffer through the infiltration basin. The rise of the groundwater level on the well adjacent to the infiltration basis is seen in the diagram.

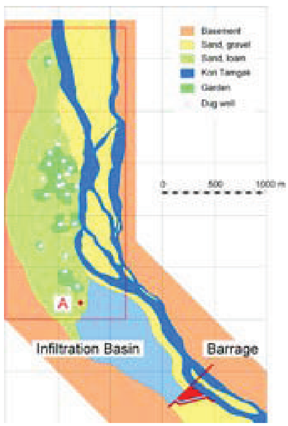

Figure 3: Schematic overview of the area after construction of barrage

During the last 30 years the groundwater situation has improved continuously and has created better living conditions and sustained agricultural development. Whilst only about 100 people were living in Iférouane in 1974, the population has grown from 1000 in 1984 to 3000 permanent inhabitants (Paschen, 2004). Currently, vegetables from Iférouane are exported to other markets.

Hydrogeological and engineering/geological investigations have made it possible to develop a workable concept of a low sill barrage and an infiltration basin. The decision to implement the infiltration basin in the extremely dry conditions of the oasis was further supported by model calculations, predicting the future effects on the groundwater table. By making effective use of the groundwater buffer, life in Iférouane changed from bare survival to a situation of growth and development.

Figure 4: flood flow entering the infiltration basin

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Seeking alternatives for sand mining in river beds, India, Sri Lanka

India

Figure 1. Kelani river bank erosion due to sand mining. A domestic water supply pipe line underneath the road got damaged and city water supply got disturbed for several days. (Photo: Badra Kamaladasa, Irrigation Department of Sri Lanka).

Introduction

Sand is a valuable resource and a main input in the construction industry. With rapid urbanization, the demand for sand in many areas increases manifold. River sand is often of high quality and therefore intensely harvested during low flow periods. In the process of sand and gravel mining, however, the riverbed is excavated until clay layers or rock material are exposed. With the removal of the sand and gravel the capacity of the river to store floods disappears and the hydrological interaction between surface and groundwater alters. As a result, wells are no longer recharged and floods are not absorbed in the riverbed. The increased hydraulic gradient in the adjacent lands lowers groundwater levels and wells fall dry. The buffer function is impaired and areas become more vulnerable to extreme climate events. There are other effects too. As the riverbed is lowered, irrigation inlets may fall dry, foundations of bridges become instable and base flows are reduced, leading to saltwater intrusion and drying-up of wells and nature areas due to lower groundwater tables (Gunaratne and Jayasooriya, 2005; Piyadasa and Naverathna, 2006). There is a need to find alternatives to the uncontrolled removal of sand and gravel from rivers near fast-developing cities.

Description

Kerala is one area that is very much affected by sand mining (Hemalatha et al, 2006). Unregulated sand mining caused the second largest river in the state, the Bharathapuzha River, with a length of 209 km, to lose much of its riverbed material. This caused wells on the banks of the river to fall dry, and during part of the year drinking water is transported into the area. The absence of a sand pack in the river to store high water has caused higher flood peaks during rainfall and salt intrusion by seawater from the Indian Ocean. The buffer function in the Bharathapuzha has been lost as well as the capacity to respond to extreme climate events – either floods or long dry periods.

Figure 2. Sand pit of 10 meter in Uttara pinakini river bed, Karnataka, 2003 (Hemalatha, A.C. et al. 2005)

Several measures have been announced by the local administration to put a cap on sand mining:

- restricting the time when sand is collected between 6 am and 3 pm;
- prohibiting trucks to be parked within a minimum of 25 m of the bank;
- permitting sand to be mined from designated areas only;
- specifying a maximum load to be excavated per day per licence.

These rules were difficult to enforce, however. Political will is limited and the lobby of the construction sector is strong. There is much money in sand mining, and sand mining labourers can make as much as 15 Euro per day. The price of a truckload varies between 15 and 50 euros, but may go up to 90 Euro during the monsoon when it is difficult to excavate sand.

What can be done

There are a number of practices that can avoid harmful sand mining. Some of these can even reverse the trend of falling groundwater and can stimulate groundwater recharge.

- In general, sand and gravel mining should be regulated. It can even be placed under the control of a central production board. In Sri Lanka for instance, the Geological Survey & Mines Bureau (GSMB) controls the market, but avoids completely dominating it. By providing enough sand to the construction sector it avoids the 'sand mafia' controlling sand prices;

- For small-scale sand mining, local committees can be formed which manage sustainable harvesting from the riverbed. Each river consists of an erosion, transport and sedimentation zone so that the suitable areas for sand mining practices can be identified. If limited quantities of sand are harvested, they will be replenished in subsequent high flood events. It has also been proposed to use sand dams for sand harvesting. If the top layer of sand is scraped off carefully and not excavated in pits (which would fill the sand dam with fine clays in the subsequent floods), the sand dams will continue to function and a certain amount of sand can be harvested every year;

- Large commercial operations should use safe alternative sources, such as off-shore resources, deserts, quarry-dust, rock deposits and old 'off-river' sand deposits. The environmental impact of such safe sources needs to be investigated;

- Aside from sand mining, sand pits can also have a second life as recharge ponds. If they are strategically located and supplied by streams and ephemeral flows these sand pits can fill with run-off and recharge the groundwater. Care is, however, required that such ponds do not fill with fine sediments, making it difficult for stormwater and run-off to infiltrate. Care is also required to avoid that the sand pits turn into unlined landfills with negative effects on groundwater quality.

Figure 3. Railway bridge foundation frequently being repaired due to sand mining across Uttara Pinakini river in Gauribidanur taluk, Karnataka, 2002. (Hemalatha, A.C. et al. 2005)

Figure 4. Public protesting against sand mining activity in Gauridanur town, 2002. (Hemalatha, A.C. et al. 2005)

The money involved in sand mining is substantial, which can fund better buffer management. There are many different sands with different characteristics and uses both in construction and elsewhere. The table below gives an indication of prices of internationally traded sands. This presents both an opportunity and a threat.

Mineral Sand	Mineral content	Industrial use	Global production (metric tons)	Price (Euro/ton)
Silica	95%	Glass production	126,000,000	22
Zircon	1-50	Abrasives and insulation	1,240,000	635
Ilmenite	10-60	Titanium production	4,800,000	58
Rutile	5-25	Titanium production	360,000	385

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Subsurface dams - intercepting the groundwater flow for storage

Brazil

Underground dams (subsurface or groundwater dams) are dams cut in the alluvial cover to intercept groundwater flow out of the area to create local storage, making it available during periods of drought (figures 1 and 2). Where the geology and groundwater flows allow, subsurface dams are an efficient and cost-effective way to intercept and store groundwater water for use during the dry periods. These dams are found in many countries in different sizes and numbers. In this case, an example in Brazil illustrates some generic features of the construction and performance of subsurface dams.

Description

Approximately 500 subsurface dams were constructed in the 'alluvial cover' in the Pernambuco state in north eastern Brazil in the 1990s. The programme consisted of:

- small structures (up to 3 m depth) were built under 'Government drought emergency and job generating programmes' at sites selected by the municipal committees without technical advice and follow up. They were manually excavated, incorporating plastic membranes and large diametrical concrete ring wells;
- similarly-sized structures were constructed at the initiative of local NGOs with specialist advice, and were filled with compacted clay and without a well for water abstraction;
- much larger dams (up to 10 m depth) were sited based on technical criteria and constructed to support small-scale irrigated agriculture. For these dams, mechanical excavators were used and incorporated impermeable plastic membranes, improved large diametrical wells and some technical monitoring.

Techniques used

Subsurface dams are impermeable barriers (clay, masonry or concrete) obstructing subsurface flow. Groundwater can be abstracted through wells, boreholes or a collector drain (figure 1). Typical small dams have a storage capacity of some 10 000 m^3 (average 4 m depth, 50 m width and 500 m length). Larger dams (for example in Yemen) may be 5–10 m in depth, have a width of 200–500 m or more, and be able to store 100,000–1,000,000 m^3.

When constructing a subsurface dam it is important that the dam is founded on impermeable bedrock. Several dams built in a cascade increase the total groundwater volume stored and limit the effects of leakage. In rural areas, community participation is essential to obtain maximum socio-economic benefits. For example, community labour reduces and enhances the efficiency, acceptance and lifespan of the dams (figure 3).

Results and impacts

In 2002, the use and performance of the subsurface dams were evaluated by a World Bank team. The evaluation of 150 dams showed that:

- 50% of the dams inspected in Brazil are in active multipurpose use for domestic water supply, livestock watering and small scale irrigation;
- about one-third were not in active use due to siting or construction problems;
- more than 10% were functioning well but the stored groundwater was not used due to the availability of a reliable surface water source, underlining the importance of involving the communities in such projects to discuss the needs of the community.

Investment costs for subsurface dams depend on the size and may vary from 3500 – 7000 Euro for small dams and up to 70 000 Euro for large dams with storage capacities of 100 000 m³- 1,000 000 m³. The investment cost per m³ storage volume is in the order of 0.35 –1.4 Euro/m³.

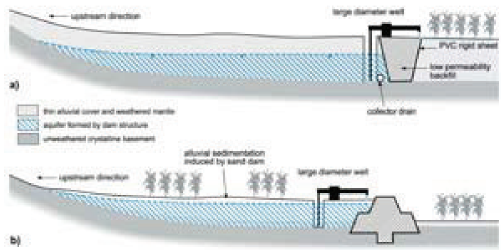

Figure 1. Typical design of subsurface dam (Source: GWMATE)

The evaluation in Brazil provided a number of key issues for successful dam construction:

- proper site selection to ensure sufficient storage potential;
- assurance that there is sufficient depth to reach relatively impermeable bedrock;
- availability of a soil type with sufficient infiltration capacity;
- avoidance of a soil type that could lead to groundwater salinization;
- proper design and construction to avoid low-yielding abstraction wells;
- address the landownership issue.

Concluding statement

Subsurface dams are a cost-effective means to store water for multiple use during dry periods. The main advantages are:

- losses from evaporation are much lower than those from an exposed water surface;
- the breeding of insects and parasites such as mosquitoes and bilharzia parasites is prevented;
- contamination of stored water, by people and animals, is greatly reduced, particularly as a well and hand pump are used to abstract water in a hygienic and controlled manner.

Large-scale subsurface dams can sustain water for small-scale irrigation in the dry season to generate income besides providing water for domestic use.

Essential factors for the success of small dams are the human factor (community participation and ownership), proper site selection and the use of low technology construction techniques and locally available materials. Successful involvement of the community and local labour is largely promoted by the provision of dedicated manuals and guidelines (figure 3).

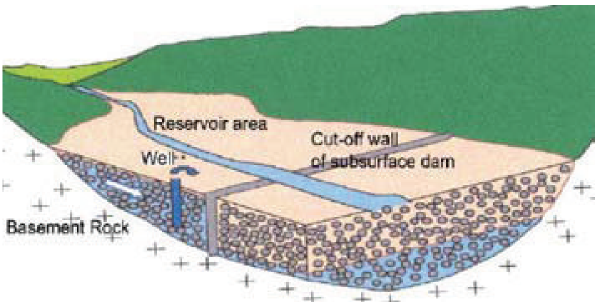

Figure 2. Conceptual diagram of a subsurface dam (Source: Vétérinaires sans Frontières, 2006)

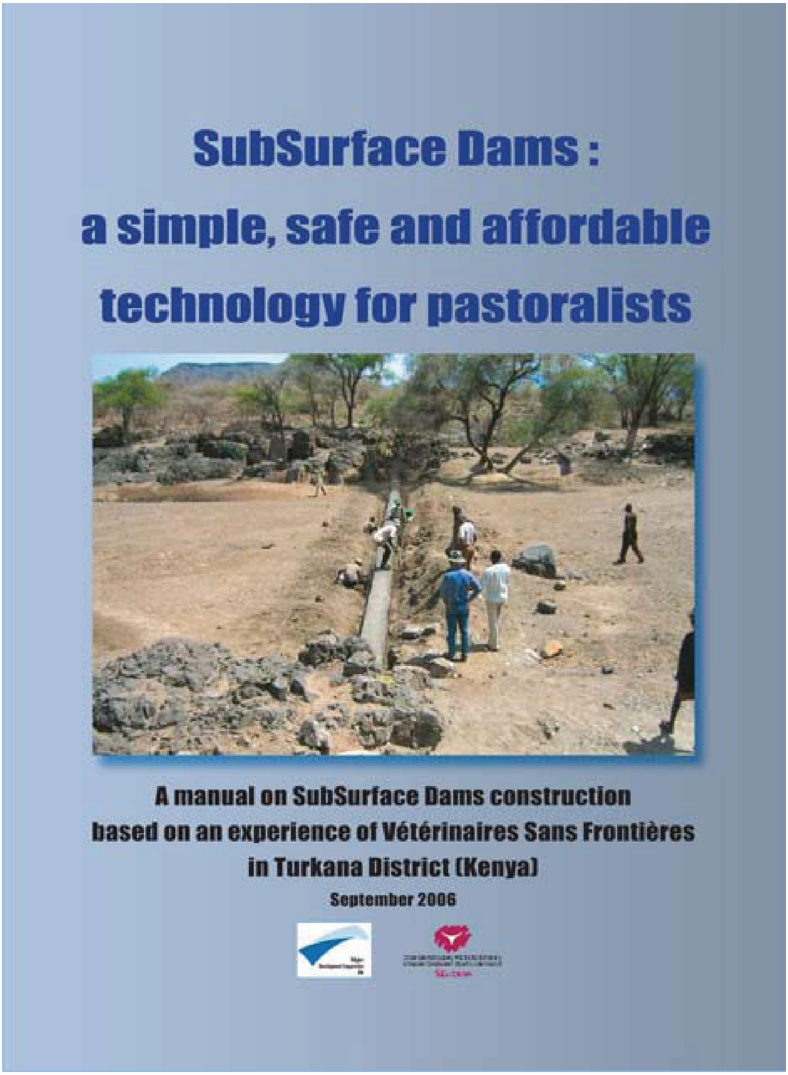

Figure 3. Example of a subsurface dam manual (Source: Vétérinaires sans Frontières, 2006)

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Retaining water in very humid areas

North Bengal, India

Introduction

Sometimes it is assumed that where water is abundant it need not be managed. This assumption is not correct. Water management in humid areas is as important as it is anywhere else. In humid areas the main cropping season is usually entirely rain dependent. The late arrival of the rains or unusual dry spells in the main season can play havoc with the most important agricultural season. Climate change may make the wet season more erratic or may delay its onset. Water retention can provide the adaptation to such climate change. Groundwater management is important in humid areas by securing soil moisture and providing supplementary irrigation.

Description

In the Terai region in North Bengal in India, a large range of interventions were undertaken to recharge and retain groundwater. The Terai is the extensive area that borders the Himalayan region – stretching from Nepal to Assam. Rainfall is between 2200 mm and 3500 mm and almost of all it is concentrated in a five-month period. Soils are generally coarse due to the proximity to the Himalayas. Loamy soils only develop in the top layers. The main crop is the rain dependent *amon* paddy.

Figure 1. Gullying playing havoc with soil moisture

A consequence of the coarse soil is that excess rainfall is relatively quickly absorbed, disappearing in a number of days, particularly in the early period of the monsoon when the soils are not completely waterlogged. Much of the lower lying areas are only very temporarily inundated and large volumes of water are drained away through gullies and as sheet flows.

By improving drainage patterns runoff can be slowed down, water can be retained, recharge encouraged and scouring avoided. This is done by a series of landscaping measures that break the speed of runoff, spread water over a larger area and avoid deep surface drainage. These 3R measures serve two objectives:

i. They reduce the velocity of sheet flow and runoff. This avoids the loss of fertile topsoil and the deep scouring of drainage gullies;
ii. They retain the water table at a high level, improving the reliability of cultivating rain-fed paddies. This is the essential difference with watershed improvement in dry areas. In wet watersheds the objective is to avoid over drainage from gullies, slow down runoff and retain groundwater at a high level, whereas in dry watershed runoff infiltration is a prime purpose.

Figure 2. Constructing a gully plug to retain groundwater

Techniques used

The main repertoire of measures consists of four elements:

i. Gully plugging – this is done by blocking gullies with earthen bunds or by constructing small overflow weirs in natural drains. Gully plugs cause runoff water to be impeded and spread. They prevent local water tables lowering because of deep gullies in the freely draining sandy soils;

ii. Graded bunds and barrier bunds – these are used in areas where controlled removal and retention of large quantities of sheet flow is of prime importance. They are build in a series and serve to spread water or retard sheet flow and prevent the formation of gullies and the lowering of the water table and the drying of the phreatic zone. Whereas the natural land slope is 2% to 4% in North Bengal, the graded bunds aim at a grade of 0.2% to 0.4%. This makes it possible to dispose of water at a non-erosive velocity. The graded bunds are placed at a slight angle with the contour lines. The height of the bunds is relative to the slope of the land and the area to be inundated. This impounded area is not to be more than 15 cm deep. In relation to the land slopes in the area, as a thumb rule bunds are usually made at 60 cm height. Their onward slope is usually 2:1 and downward slope 1:1. The bunds also ultimately channel the sheet flow to diversion canals and drains;

iii. Field bunds – raising field bunds avoids that water gushes from field to field but instead fills a field basin before it neatly topples over to the next field basin. These bunds are typically 60 cm high with a 1:1 slope on both sides. Like other soil structures they are preferably made in the middle of the dry season to allow the bunds to settle under the impact of cattle and human movement and be strong enough before the new monsoon starts;

iv. Protection bunds – built along rivers and gullies. The protection bunds have two functions: firstly to prevent uncontrolled flooding from the streams, and; secondly, to avoid that water gathers in the rivers and gullies too quickly and in large quantities.

Impact

The impact of these water retention measures can be very significant. An evaluation of several sites where such water management improvements was undertaken (Kundu and Soppe, 2002), and suggest very high returns against modest investments of 70 Euro/ha:

- Average cropping intensity in each site increased by more than 40%;
- Soil moisture availability during typical dry spells in the monsoon increased from 2 days to nearly 11 days due to the highly-controlled water table. The interventions also reduced soil erosion and thus gradually increased water retention capacity by increasing the organic content of the soils, among others;
- On average the gross value of production increased more than four-fold- it was 280 Euro/ha on average after the recharge and retention measures;
- Land value increased from 480 Euro/ha to 910 Euro/ha.

Figure 3. North Bengal (India) planning the management of the local buffer

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Creating a ‘water bank’ with surplus surface water

Namibia

Introduction

By storing surface water in aquifers a ‘water bank’ can be created through the combination of three elements: recharge, retention and reuse. Excess water from surface reservoirs is stored in aquifers – thus creating a bridge between years with high rainfall (when there is surplus to be stored) and drought years – making the water supply system resilient to climate variability and, in the long term, climate change.

Description

Windhoek, the capital of Namibia, has around 270,000 inhabitants (2005). Subsequent to the expected continued rapid growth (3.25%) due to the influx from rural areas, water supply will run short.

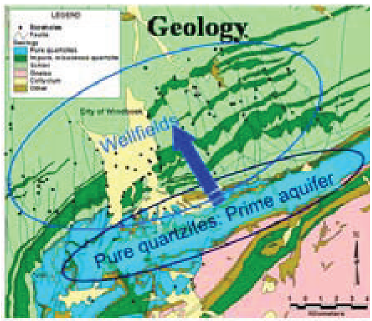

Figure 1. Geological characteristics and target areas for artificial recharge

The current annual water availability for the city (22.3 MCM, including 1.3 MCM for irrigation) is based on:

- bulk water supply from three dams (Von Bach Dam, Swakoppoort Dam, Omatako Dam), located respectively at 50 km, 100 km and 200 km from Windhoek, totalling 17 MCM per year;
- groundwater abstraction from 50 wells in the Windhoek area, approximately 3.8 MCM (exceeding the safe yield of the aquifer);
- minor sources including treated surface water from the small local Goreangab dam, reclaimed wastewater and emergency groundwater supplies from the Berg Aukas mine (420 km from Windhoek).

South of Windhoek is the so-called Windhoek Aquifer that consists of highly fractured quartzites. The amount of water stored in this buffer is 35 MCM – less than capacity because of overdrafts in the past. By injecting treated surface water from the abovementioned dams during times of surplus, the amount could increase to 66 MCM. The groundwater could then be used during drought periods to bring about a secure water supply system. Storing more water in the groundwater buffer would also address the high evaporation losses from the dams (currently around 70%).

Techniques used

NamWater, the public water supply company, together with the City of Windhoek are implementing the following strategy to cope with future water demand:

- artificial recharge (AR) of the Windhoek Aquifer using surplus water from the central area dams, see above;
- conjunctive use of water, by relying on surface water during periods of ample supply whereas groundwater is used as a backup system during drought;
- implementation of water demand measures, which would lower the unrestricted water demand by approximately 30% as well as the annual increase in consumption to less than 2.5%;

The water bank project of the Windhoek Aquifer started in 2004 and full implementation of the programme will take 15 years. During the initial phases of the project four injection boreholes were installed. According to the project plan, five exploration boreholes, ten injection wells and nine monitoring wells will be put in place. In the long term, treated surface water will be blended at a ratio of 3:1 with reclaimed waste water from the Goreangab Water Reclamation Plant, using advanced treatment techniques.

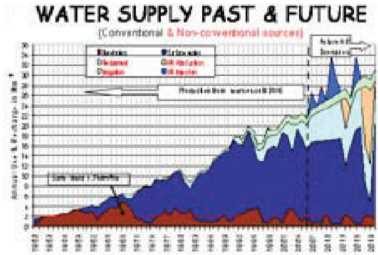

Figure 2. Historic and proposed future annual water production amounts for Windhoek

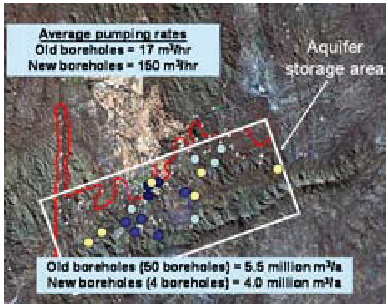

Figure 3. Location of the Windhoek Aquifer artificial recharge sites and wells used for water supply

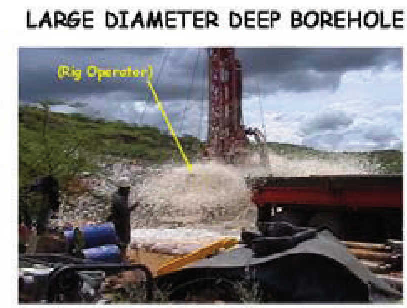

Figure 4. Drilling of large diameter deep borehole

Impact

The cost for the fifteen-year Windhoek Aquifer artificial recharge scheme amounts to 19.8 million Euro. The programme does not pay for itself and is not financially viable. However, it provides assured water supply to Windhoek and a number of other benefits:

- It does not lay claim to scarce water resources in the country but instead improves the efficiency of existing sources;
- Other planned supply augmentation schemes can be downsized significantly;
- Demand measures are more viable as small savings can be deposited through injection in the water bank;
- Upgrading of storage infrastructure can be postponed;
- Environmental impacts are minimal compared to other alternatives.

High altitude surface water retention dams

Ocoña Basin, Peru

Introduction

Climate change can trigger the development of new approaches in water management. Retention of stormwater runoff will augment water availability throughout the year and improve living conditions. In regions with a distinct dry season, the retention of stormwater runoff during the wet season can make a big difference to local agriculture and the livelihoods of the rural population. An important element is safeguarding the interests of land and water users in the entire basin.

Description

In high-altitude catchments in the Ocoña Basin of Peru, streamflow is intensively exploited and no other water resources are available in the dry season. Here medium-scale retention dams located high in the catchment area are used to increase water availability throughout the year for local agriculture.

Figure 1. A retention dam at Lago Palcacocha, near the Coropuna Glacier

The Ocoña River Basin lies in the Southwestern Andes in southern Peru, and forms a fertile barrier between the Sechura and Atacama Deserts. The uppermost limits of the catchment basins are delineated by the Huanzo mountain range, containing a number of high-altitude glaciers, including the Coropuna (6445 m), Solimana (6095 m) and Firura (5500 m). The population of the Ocoña River Basin is approximately 70,000 people, mostly living in poverty or extreme poverty (less than $2/day or $1.25/day, WB - International Comparison Program 2008). In several high-altitude catchments such as Arma-Chichas and Churunga, farming activities are sustained by irrigation systems that use meltwater complemented by rainwater. Groundwater resources are inadequate or currently unexploited.

According to the Tyndall Centre for Climate Change Research, Peru will be one of the three countries hardest hit by climate change because of the country's high dependence on glaciers as a source of water. The most important effect of climate change in the Ocoña River Basin is retreat of glaciers. The consequent reduction in baseflow during the dry season severely affects the agricultural potential of the area. Stormwater runoff during the wet season and excess baseflow can be retained by dams placed at strategic locations in the catchment. The stored water can subsequently be used in the dry season to supplement the irrigation water supply in the region.

Techniques used

The Ocoña River Basin contains three sub-basins. User commissions are active in each sub-basin, with the exception of the Arma sub-basin which has an irrigation commission coordinator. These commissions have formed the Platform for Integral Water Management for the Ocoña Basin,which aims to coordinate the integrated management of the water resources in the basin.

The user commissions coordinate actions to create surface water storage in order to increase availability of water resources during the dry season. The medium-sized Palcacocha dam has been constructed at the Churunga catchment close to the Coropuna Glacier. Behind the dam an artificial lake has formed and water from this lake can be released into a stream leading to an intake point for the three major irrigation systems of this sub-catchment.

A bigger storage dam has been planned for construction in the upper part of Arma River in the Arma-Chichas sub-catchment (project Arma). Water from this dam will be guided by gravity through a series of canals to a nearby sub-catchment for agricultural purposes. Because of the high elevation of the dams, evaporation is relatively low.

Impact

Although impacts of the Palcacocha dam are yet to be thoroughly evaluated, stormwater runoff already collects in the dam, from which subsequently throughout the year the irrigation systems in the catchment are fed. It is strongly suspected that the lake behind the dam recharges groundwater as well.

Water availability throughout the year for irrigated agriculture in the Ocoña Basin is being severely threatened by glacial retreat due to climate change and the subsequent diminishing baseflow. By capturing and retaining excess water resources high in the catchment through the construction of dams, water can be distributed more evenly throughout the year and the region.

The integrated approach in the Ocoña Basin ensures that all activities aiming to improve water availability in the Basin are carefully coordinated. It also safeguards sustainable water use for all upstream users without creating negative side effects or compromising downstream users.

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Harvesting rain in dry areas

Sub-Saharan Africa

Many areas in Sub-Saharan Africa such as Burkina Faso, Mali and Senegal are severely affected by water shortages. Often groundwater is polluted (due to geological layers) or too deep to be a feasible water supply. Women and children in particular invest many hours per day in fetching water, walking long distances and/or queuing in line at boreholes, which often have limited capacity, are depleting or are even non-functioning. This reduces their time for agricultural, economical, educational and social activities. In some areas people do not have access to boreholes and collect water in the traditional way, i.e. from an open pond, which is usually also used by their cattle.

Health problems due to limited and contaminated water affect many people all over the world, not to mention the burden of fetching this water. A general misperception is that most areas in Sub-Saharan Africa receive very little rainfall, while in fact annual rainfall can be sufficient to cover the annual water demand. The challenge lies in how to substantiate the long dry season based on short and intense rainfall periods when most of the water is lost through runoff. If the rain could be stored, sufficient water would be available for drinking water, and many other uses such as livestock, agriculture and other sustainable activities.

The potential of rainwater harvesting

In areas where other water sources are not available or unreliable, rainwater harvesting can provide a simple and effective option for safe and sufficient water supply. An example of the potential of rainwater harvesting at household level is given in the box below.

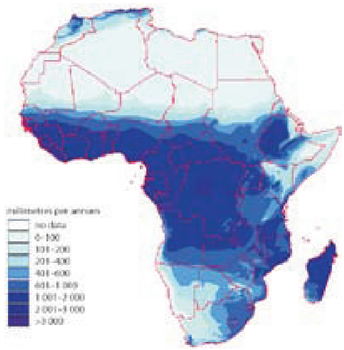


Figure 1. Annual total rainfall in Africa (source: UNEP)

Rainwater harvesting can provide sufficient water, especially in areas where little or no water sources are available, and reduces pressure on groundwater resources. The family living in Tonka will not only benefit from the water itself, but also from the fact that it is available at their doorstep, thus reduces time and the daily burden of fetching water. Especially women and girls would have time to spend on other activities, such as women's groups or school. The calculation given is for one household only, while there are also families living in larger compounds, which increases roof size and therefore rainwater harvesting potential.

Roof area = 30 m²
Annual rainfall = 650 mm
Household size = 10 people

Water per person during 7 months dry period = 7,4 litres per day

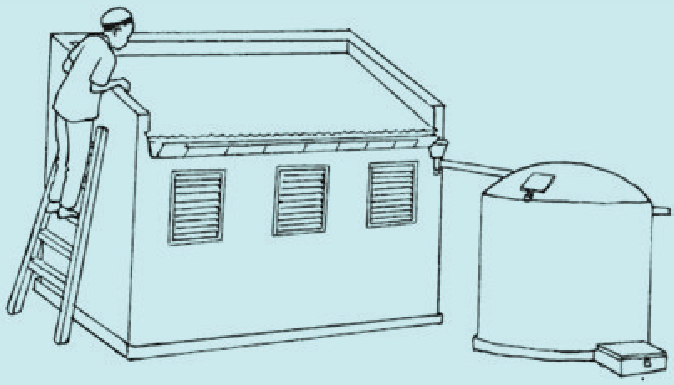
In the village of Tonka in the Koulikoro Region, Mali, a household of 10 family members spends three to four hours per day to fetch water from a distant borehole, which is often not functioning due to groundwater depletion. They mostly use water from an open pond formed during the rainy season, which is also used by animals. What could this family gain from harvesting rainwater?

Annual rainfall is approximately 650 mm per year (rainfall period between May and October) and their roof area is approximately 30 m^2.

Rainwater harvesting potential = 0.8[1] x (30 m^2 x 650 mm)/1000 = **15.600 litres per year**

With an average dry season of seven months, 15.600/ (7 x 30) = 74 litres of water are available per day. The family consists of 10 people, which means that each family member could have 7.4 litres of water per day from rainwater harvesting.

Studies have shown that rainwater collected from corrugated iron roofs, are very applicable for drinking if operation, management and maintenance is carried out. If water is needed for other purposes, like livestock breeding, kitchen usage and gardening, water quality is not much of issue. In this case the family could have a rainwater harvesting tank for drinking and an additional pond for catching surface runoff for other purposes.



[1] here the runoff coefficient of a corrugated iron roof is approximately 80%, taking into account 20% water loss.

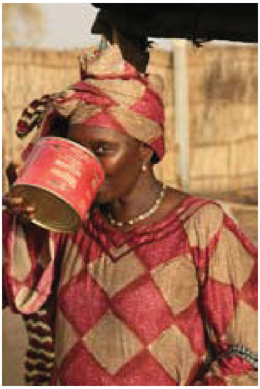


Figure 2 and 3. Beneficiaries in front of their tank and drinking the water in the village of Sébi Kotane, Senegal

Keep it simple!

Rainwater harvesting systems are decentralized, meaning they are fully managed and operated at household level, providing people with great independence. Households are responsible for maintaining, managing and conserving their own water source. As people invest in their own system, through cash, materials and/or labour, the sense of local ownership is high, which increases sustainability of the system. There are many ways to store water at different scales. Roof water harvesting at household level is one option that delivers water at the doorstep.

Roof water harvesting systems are simple and straightforward: the rainwater is collected on a (preferably corrugated iron) roof and led through a gutter- and filter-system into a storage system or infiltrated into the groundwater for recharge. If the water is used for drinking purposes, the piping system towards the storage system is equipped with first flush and filters, to prevent contamination (like dirt or debris from the roof) from entering the storage system. A first flush system helps to divert the first millimetres containing most potential contamination. Studies have shown that a properly operated and maintained first flush is often sufficient to provide water of potable quality. In the storage facility, it is important that no light enters the system, because this could lead to bacterial growth. It should also be protected from people and animals entering the system. Water stored in a closed system is known to enhance bacteria die-off, improving water quality.

Rainwater harvesting can also be used for irrigation, livestock and groundwater recharge. High water quality standards are not applicable for these uses, and other (and often cheaper) techniques can be employed. Depending on the water needs and the rainwater harvesting potential, an integrated plan can be made for the optimal use of rainwater.

Some results and impacts of roof water harvesting

- water source at the doorstep;
- better quality and quantity of water compared to existing sources;
- higher school attendance by children, especially girls, due to time saved in fetching water. Children are also more healthy and able to participate in classes due to the availability of safe and sufficient water;
- more time for agricultural, economical, educational and social activities, not only through saving time in water fetching, but also as there are less occurrences of water-related diseases, especially amongst children.

Collect, store and use

There is a huge potential for rainwater harvesting in Sub-Saharan Africa, especially in areas where other water sources are insufficient, unavailable and/or unreliable. The only task is to collect the rainwater, store and use it. The challenges are to upscale the successes already achieved, to provide low-cost and durable storage options and to reach out to people who still depend on unreliable water sources.

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Springwater harvesting

Tanzania

Introduction

With a constant discharge and good water quality, springs are a reliable and often preferred water source. A spring can be captured and water conveyed to areas with difficult access to a high-quality water source. In Tanzania, such a system was constructed to supply the community of Kwemakame, which was previously using the unreliable and often low-quality water from (seasonal) rivers.

Following a severe cholera epidemic at the end of the 1980s, a project was started which identified springs in Dindira Valley as having enough discharge to supply downstream communities (including Kwemakame village) with water. To capture the springwater nine trenches (3 x 15 x 1.5 metre) were dug uphill of the spring location and made watertight on the sides. Connecting to the same aquifer as the spring, the bottom of the trenches then allowed outflow into a covered storage tank and subsequently the water distribution system. The distribution system supplied 27 water points, and served around 90 people each, in total 2430 people.

However over the years two major problems concerning water security have arisen:

i. decreased groundwater levels due to climate change and deforestation, resulting in less groundwater recharge;
ii. increased water consumption as consumers use more tap water for irrigation and watering cattle.

Techniques used

To overcome these problems the Pangani Basin Water Office (PBWO) was established and measures were taken to increase intake yield through the enlargement of groundwater recharge. The measures consisted of diverting and collecting surface runoff water in a small dam from which water is recharged to the groundwater via a recharge pit upstream of the spring intake. Furthermore by collecting this quick surface runoff and infiltrating it in the permeable aquifer of the spring, peak surface water discharges are avoided. The measures eventually ensure increased and continuous high-quality spring water discharge, making the dependant communities less vulnerable to the effects of the changing climate. Finally the PBWO plays an important role in providing and sharing knowledge amongst similar projects, overseeing the consequences of projects and the effects on downstream users and optimizing the use of resources and safeguarding its long-term availability and sustainability.

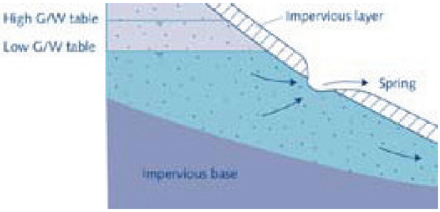

Figure 1. Example of an artesian depression spring (Wijk-Sijbesma et al, 2002).

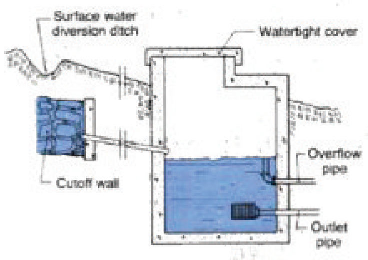

Figure 2. Cut-away view of a concentrated spring (Jennings,1996)

Figure 3. Plan of the Kwemakame village and surrounding communities (Source: Chamavita)

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Rainwater harvesting in salt-affected areas

Senegal

Almost half of Senegal's population is considered poor, and the Government has made the reduction of poverty a central objective in its national policy. Water is considered essential in fighting poverty and is therefore high on the agenda. For years, the Government has been working on providing sufficient water to cover basic needs by building water infrastructures, such as boreholes, water towers, dams, ponds, etc. However, many areas in Senegal are known to have high saline content in their groundwater or the very deep groundwater makes it unfeasible to drill boreholes. Desalination is an effective technique to purify groundwater, but this is a highly technical and expensive technique and not easily accessible to the average population.

Figure 1. Salt mining in Senegal

Salt ponds in Senegal

In Senegal, areas like Casamance and Sine Saloum are known for their high saline groundwater. Due to the depletion of freshwater resources, the groundwater is becoming more affected by the intruding saltwater from the sea. The salty groundwater affects people's health, has a negative impact on the taste and it also damages iron materials used for boreholes.

An option for safe water supply is rainwater harvesting (RWH), which is relatively low cost, context appropriate and sustainable. Since 2007, the Rainwater Harvesting Implementation Network (RAIN) has been working with Caritas Kaolack and the Regional Centre for Water supply and Sanitation (CREPA) in Senegal on the islands of Sine Saloum to construct rainwater-harvesting systems of various sizes at the household and community level (health centres and schools). The objective is to provide sufficient potable water for at least 3 to 4 months to overcome the critical dry period. Until now, the projects implemented have resulted in more time availability, safer and better-tasting water and a decrease in health risks. Below is an overview of the rainwater harvesting systems

Figure 2. A hangar built by partner organization CCF as no appropriate roofs are available for roof water harvesting

constructed through the RAIN programme in Senegal. Up to now 2,229 m^3 of RWH storage capacity has been constructed in Senegal, providing more than 7,500 people with safe and sufficient water to overcome at least the critical dry period.

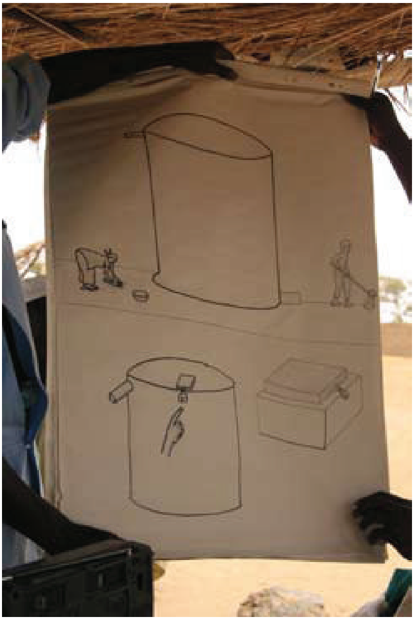
RWH storage capacity (litres)	Number of RWH systems constructed through the RAIN programme		
	2007	2008	2009
10,000	40	34	65
12,000		39	
15,000		7	26
16,000		1	

Water for Diogane Island

On the islands of Saloum, access to safe water is a challenge due to the high concentration of salt in the groundwater. This situation has been improved for the people living on the Diogane Island with support from the Senegalese NGO Caritas Kaolack. Today, more than 50 households have their own RWH system, ranging in size from 10 m^3 to 15 m^3 which collect rainwater from rooftops. This provides people with sufficient potable water during several months of the year, especially during the dry season.

Figure 3. A rainwater harvesting tank being maintained in the village of Diogane

The people benefiting from the RWH systems participate and contribute during the whole project both in kind and in cash, totalling approximately 5% - 10% of the total investment cost. Total investment cost for hardware (this excludes supervision, communication and overhead) is approximately 600 Euro. The average lifespan of a rainwater harvesting tank is 15 to 20 years, resulting in 40 Euro per year to finance a rainwater harvesting system. As this is a low-cost, effective and sustainable option for water supply in salt-affected areas of Senegal, the challenge is to upscale this technology to other areas which suffer water quality or quantity problems.



Drawings are used during the training to show examples of proper and miss-management of RWH systems.

Figure 4 and 5. Beneficiary in the village of Simal, Senegal showing drawings that are used during the training (photo: RAIN)

Awareness- raising on water quality

RAIN's partner organization Caritas Kaolack focuses strongly on water quality issues concerning rainwater harvesting. At each village where RWH systems are to be constructed, detailed training is given on preventative measures during the collection and extraction of water in and around the RWH tank. It also focuses on hygiene and water use at home, such as hygiene of the jerry can, the necessary reaction time of the cleaning product before drinking and appropriate storage. Following the training, each beneficiary is visited at least twice to ensure operation and management skills are being applied effectively. This results in better understanding of the operation and management of the RWH systems and hygiene practices, which leads to more tailor-made advice to future users of RWH systems. Training has proven to ensure effective and durable operation and management of RWH systems.

RAIN, Caritas Kaolack and CREPA Senegal are currently promoting RWH to the National Government as an effective option for water supply in specific regions of Senegal for integration into water policies and plans, as well as to recognize rainwater as an option for safe and sufficient water supply. RAIN is in the process of setting up a Rainwater Harvesting Capacity Centre (RHCC) in Senegal to work specifically on advocacy in addition to coordinating implementation and knowledge sharing at national level.

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Multiple aspects of rainwater

Nepal

Nepal is rich in water resources however access to water is not always ensured. Particularly rural communities living in mountainous regions tend to suffer from water scarcity due to the difficult terrain. Women and children invest many hours per day in fetching water, mainly from natural springs located downhill, which tend to recede more downwards during the dry period. Next to their domestic water needs, small-scale agriculture, kitchen gardening and livestock are other water consuming activities, which mostly depend on water availability during the rainy season. These activities are suffering from the lack of winter rains over the past couple of years in Nepal.

Another factor controlling livelihood standards in rural Nepal is the use of fuel wood for cooking and heating, which leads to serious health problems due to the air pollution in houses. The demand for fuel wood and the reduced water resources have both led to a decrease of forest areas in Nepal. Next to this, the collection of fire wood is another time consuming activity, again mainly for women and children.

Figure 1. Rainwater harvesting tanks in Bubeyrakhe, Nepal

For many areas in Nepal, especially in upper hill areas, rainwater harvesting is the only feasible option for having sufficient water supply, since piped water supply is extremely expensive in this type of terrain. Many NGOs in Nepal have become aware of the potential for rainwater harvesting and, although there was some initial hesitation to use rainwater as drinking water, projects have been implemented on a large scale. Roof water harvesting is most common in Nepal.

BSP-Nepal, an NGO, in collaboration with SNV- Netherlands Development Organization, initiated and implemented biogas plants at the household level by using animal dung and human faeces to produce biogas. This programme effectively improved health standards and reduced deforestation, since wood was no longer used for cooking. Significant time was saved for women who no longer had to collect firewood (not to mention the burden of carrying firewood to their house in this mountainous terrain). The biogas programme has led to the successful implementation of more than 205,000 biogas plants in 75 districts and the training of more than 60 construction companies in constructing biogas plants and rainwater harvesting systems. The success of the programme was commercializing the implementation of biogas plants, through cooperating with private construction companies in Nepal and setting up an attractive financial model. This model consists of 30% Government subsidy, 60% user's loan through Micro-Finance Institutes and 10% direct user contribution in cash and kind.

Owner of a 14 m³ rainwater harvesting tank and a 6 m³ biogas tank in Sarangkot, Palpa district, Nepal

When BSP-Nepal addressed my household for taking part in a project with biogas and rainwater harvesting, I immediately saw their potential. Since BSP-Nepal could only assist in financing a 6.5 m³ tank, my family financed the remaining money to have a larger 14 m³ tank. The water is used to operate the biogas tank and my wife can now cook on a gas stove! I have also made this greenhouse for tomatoes, which we use for our own consumption and also sell at the nearby market. I am now saving money to have another rainwater harvesting tank, so that I can expand my production and increase the family income.

Figure 2. Owner of a rainwater harvesting tank and a biogas tank in Sarangkot, Palpa district, Nepal

However, to operate the biogas plant, water is needed, which is scarce or hard to procure in mountainous areas. Currently, BSP-Nepal is combining biogas plants with rainwater harvesting tanks in areas where other sources of water are not feasible, making water available for biogas production, drinking (and other small domestic uses) and irrigation. The construction companies receive intensive training on the implementation of rainwater harvesting tanks (mostly 6.5 to 10 m³ tanks) and their work is regularly monitored and evaluated. In order to make rainwater harvesting a more financially-attractive solution for the poor rural populations, BSP-Nepal is currently looking into micro-finance options for rainwater harvesting as well.

The Swiss INGO Helvetas is implementing rainwater harvesting systems in three regions of Nepal. Their projects depict the combination of sanitation with water supply through rainwater harvesting. People with access to improved sanitation are still limited, especially in rural areas of Nepal. To address this, Helvetas combined the water supply projects with sanitation.

To come towards a more integrated approach of water resources management, Helvetas Nepal has developed a so-called Water Resources Management Programme (WARM-P), which is based on 30 years of experiences in water and sanitation, to address source conflict, water supply and its multiple uses and management at the village level. Due to the fact that existing water sources are often over-exploited and not well-managed within and between communities, Helvetas felt the need to facilitate communities to organise and prepare water resources management plans for multiple uses of water at the village level. Hence, WARM-P not only supports communities in water supply and sanitation, but also in preparing and implementing a Water Use Master Plan (WUMP) by the communities. The WUMP is a tool in guiding an integrated plan, and mapping all available

Ganga Chand

Owner of a 6.5 m^3 rainwater harvesting tank in Bubeyrakhe, Dailek district, Nepal

First I had to walk many times a day up and down the hill to fetch water from the spring with a large can. Now I only need to just go outside of my house and fetch the amount I need from my own tank. I am very proud and happy. My husband is now working as a paid mason in a rainwater harvesting project of Helvetas Nepal in a nearby village, since he was trained in constructing rainwater tanks during the construction of tanks in our village. The rainwater harvesting tanks have changed a lot for me and my family.

Figure 3. Owner of a rainwater harvesting tank in Bubeyrakhe, Dailek district, Nepal (photo: RAIN)

and potential water resources in an area. The WUMP has a strong social and technical component, based both on the needs and on the local circumstances of a village as well as the physical factors controlling available water resources for its maximum uses. Rainwater harvesting is one of the options for water supply in WUMP and WUMP can therefore be seen as a first step towards Integrated Water Resources Management at the village level.

The demand for rainwater harvesting systems is growing due to the successes achieved by NGOs all over the country. Since the beginning of 2009, the Nepalese Government has recognized rainwater as being an important source of water for domestic and productive use as well for groundwater recharge.

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RAIN Foundation - www.rainfoundation.org

Controlled drainage

The Netherlands

For a long time drainage has been seen as the removal of excess water to enhance crop growth. A more recent definition sees it more broadly as buffer management for multiple functions: 'Drainage is the processes of removing excess surface water and managing shallow water tables – by retaining and removing water – and of managing water quality to achieve an optimal mix of economic and social benefits while safeguarding key ecological functions' (World Bank, 2004).

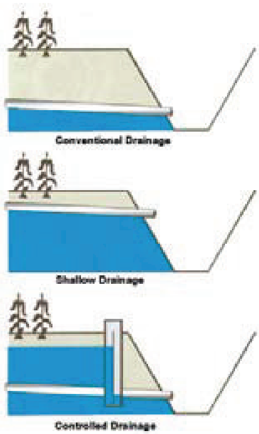

Figure 1. Various piped drainage systems

With this perspective drainage can serve a large number of functions: better public health, lesser damage to roads and other infrastructure, improved living conditions (less damage to houses, richer ecology, and agriculture). The benefits of drainage – if done well – can be large.

Central to the concept of integrated drainage management is controlled drainage. In conventional drainage water tables are set at a certain depth, but in controlled drainage they fluctuate – depending on the requirements of the standing crop or the different functions. Controlled drainage – in use in countries as varied as Bangladesh, China, Czech Republic, Egypt and the Netherlands – makes it possible to do precision buffer management.

Techniques used

Historically, in the Netherlands, the exclusive aim of drainage has been the rapid drainage of soils and surface water. This facilitates timely seedbed preparation and planting by tractors and heavy farm equipment to minimize yield reductions that result when roots are submerged in an entirely saturated zone devoid of oxygen (anaerobiosis).
These 'conventional drainage' practices (figure 1) enable farmers to quickly remove surpluses of rainfall from plots into ditches, canals and rivers; but they also lead to water surpluses downstream in periods of high rainfall and to shortage and droughts in periods of less rainfall.

In recent years new 'controlled drainage' systems have been introduced by drainers and are becoming increasingly popular with farmers. Together with a drainer, a farmer developed a system of collector drains and pipes (the 'Van Iersel pipe') with which farmers can regulate the water table per drained plot. The enhanced control over the water table enables farmers to drain up to necessary depths during sowing and harvesting time, but retain water during drier periods. Preliminary results of field application with farmers in the southern provinces of the Netherlands show that the controlled drainage method reduced peak discharges and enabled better dispersion of groundwater under plots (more uniform groundwater table). Moreover the collector drains replace ditches this allows farmers to join plots by filling the ditches thereby increasing the cropping area and reducing labour time, i.e. driving back and forth on small plots.

Impact

To install this novel drainage system, field drains are lain deeper and at a higher frequency (spacing of 6 m - 8 m), and under the groundwater level. These then end up in a collector drain (a tube with a larger diameter than the drains) which then connects to a big pipe or well (figure 2). The groundwater level in the drains can then be manipulated by heightening or lowering the exit tube in the collector pipe.

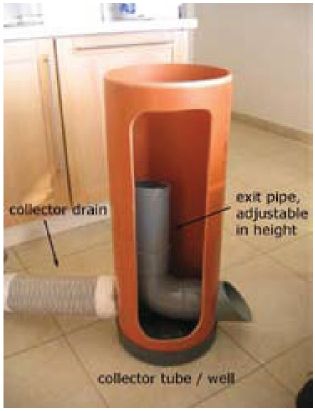

Figure 2. Collector tube well

By having drains placed deeper as well as at a higher frequency, groundwater levels are more uniform and allow for quicker dispersion of high intensity rains. This means that a higher average groundwater level can be maintained, but that peak groundwater levels are more likely to be avoided, allowing farmers better cropping in the erratic moderate sea climate in the Netherlands (sowing/ harvesting as well as circumventing anaerobiosis).

Furthermore, by maintaining a uniform groundwater table, less contact is made with the phosphorous saturated cropping layer. This reduces the amount of phosphorus that ends up in the drains. At the same time, due to the prolonged path of water through the soil to the drains submerged under the groundwater table, an increased denitrification can take place, reducing the amount of nitrogen ending up in the drains. The latter phenomena however requires further research and results in the Netherlands.

In certain states in the US on the other hand, controlled drainage has been recognized as a best management practice to reduce the transport and delivery of nitrogen and phosphorus to sensitive surface waters.

Agricultural drainage – experiences from Czech Republic

Being located in a moderate climate zone, the **Czech Republic** does not need drainage as a corrective measure after irrigation. However first drainage systems were constructed in clay–loamy soils in sugar-beet growing regions, where high rainfall or snowmelt caused waterlogging. Further drainage of agricultural mineral soils took place on a large scale over almost the whole of the twentieth century, targeting particularly those areas prone to waterlogging (covering quarter of the country's agricultural land). In the 1970s a start was made at using tile drainage for two-way soil water control; drainage, irrigation and/or water retention. Several systems of two-way control were built in the middle Labe lowland and in South Moravia. The *controlled drainage* on the last-mentioned site is still partially operational. (Adapted from Z. Kulhavý et al, 2007).

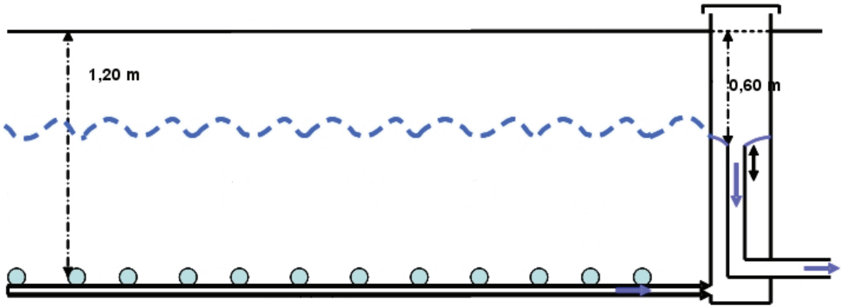

Figure 3. Controlled drainage: deep drain, collector drain and height adjustable pipe in well

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Conjunctive use of groundwater and surface water in large-scale irrigation

Morocco

In many large-scale irrigation systems there is now 'a conjunctive reality' where a large – and sometimes even the main – portion of the water at the farm gate comes from groundwater and not from direct surface supplies. There is a high density of wells in the surface irrigation systems, largely fed by seepage water, which is subsequently used and reused – an example of extending the water chain.

Description

In conjunctive systems water is used from surface supplies and from groundwater management. In many of India's mega-irrigation systems the larger part of the water comes from such shallow wells (Shah, 2009). The same is the case for Pakistan (Van Steenbergen, 2007). A telling example of how the intense use of the groundwater buffer made it possible to live comfortably through a period can be seen in the drought in Pakistan in the period 1999–2003. During this period the outflow from the main reservoirs dipped by 20%. However, contrary to what one might expect, there was no reduction in agricultural production but a modest increase. The explanation is the more intense use of groundwater – in the Punjab Province increasing from 42% to over 50% of farm supplies. In the Sindh Province many new wells were developed and, as a result, a huge waterlogged area disappeared. Whereas this area stood at 2.2 million ha, it was reduced to less than 0.5 million ha after three years of drought. The conjunctive use of surface and groundwater in large-scale irrigation systems not only made it possible to survive the drought, but also set the scene for a far more productive resource management system. Intriguingly climate variation triggered better resource use and higher productivity.

The Tadla system in Morocco is another example of a conjunctive irrigation system. The Tadla irrigation scheme is located 200 km south-east of Casablanca in Morocco. It covers an irrigated area of about 100,000 ha and is managed by the regional agricultural development authority of the Tadla (ORMVAT). Annually, between 323 (2001/02) and 1003 million m^3 (1991/92) of surface water is diverted to the scheme. The Tadla irrigation scheme is an important producer of agricultural commodities at a national scale, including milk and meat.
Groundwater use in Tadla took off after 1980, when cropping patterns were liberalized. Earlier crop choices, input supply and marketing were controlled by the state irrigation agencies and cropping was homogeneous. Under the new regime farmers were allowed to choose their own crops. The irrigation supplies by the ORMVA irrigation agencies were more demand driven yet at times of drought many restrictions were enforced.
It was however the access to groundwater that made it possible to have a diversified system also

Figure 1. Using groundwater and surface water for irrigation purposes in Morocco

able to shift to higher value farming systems and introduce new horticular crops. Another prime example is the upsurge in dairy farming based on the cultivation of alfalfa, which has the highest water productivity of all.
Intriguingly, as water productivity increased, the area under cultivation also expanded. Surface water resources in Tadla decreased under reduced rainfall, particularly in the period 1980–1992. The quality of surface irrigation was also under pressure: the capacity of reservoirs was reduced under the impact of sedimentation, canal networks were getting old and inefficient irrigation techniques lead to important loss of water resources.

Techniques used

Irrigated agriculture in the Tadla plains is now characterized by a conjunctive use environment. Farmers increasingly use groundwater resources in addition to available surface water resources. There are between 8,000 and 10,000 wells in the surface irrigation areas, with a well having a typical discharge of 15 l/s. In the zone outside the irrigated perimeter there are also more than 4,500 pumping locations, of which more than 1,300 wells pump from the Eocene aquifer (Hammani, 2007). Pumping levels vary widely between years due to the large variations in rainfall, but are estimated in the order of 140 Mm^3 – or 15% to 50% of total farm gate water delivery. All this signifies the importance of the groundwater buffer both for increased production and for drought mitigation. There are some drawbacks with respect to the conjunctive system. Firstly, there is concern that groundwater use may have exceeded sustainable supply. Water used to be pumped from shallow depth consisting mainly of accumulated leakage from the surface irrigation system, but now increasingly the deeper Eocene aquifer is tapped. Secondly, there are equity issues. There is a bias in ownership: particularly larger farmers have a well of their own, and other farmers access additional water by buying it from well owners or from unsanctioned surface irrigation supplies. Thirdly, groundwater governance is altogether missing. Quite typically groundwater pumping is only possible with official authorization, but almost all farmers install their well without a permit. Current unenforced regulation creates a vacuum and a blind spot in policy implementation.

The conjunctive reality of Tadla represents many large-scale irrigation systems. The use of the groundwater buffer underneath the surface irrigation systems has ended drainage problems and has facilitated a move to higher value agriculture. It has helped overcome dry periods, dry spells as well as shortcomings in the irrigation infrastructure.

Although conjunctive use is commonplace, conjunctive *management* is not. There is much to gain by improvements in dovetailing surface irrigation supplies and buffer management, for example:

- In planning new surface irrigation systems, the condition of the aquifer underneath should be taken into account. Buffer characteristics have a large impact on the scope and ease of reuse of seepage water and hence the overall efficiency of the system and ability to deal with droughts;
- In general the high efficiency, productivity and resilience of conjunctive systems should be appreciated. Sometimes water is diverted from well-functioning conjunctive systems to new areas – where the scope for reuse is less and, as a result, the irrigation supplies are used only once and then effectively lost;
- In large irrigation systems, surface water distribution should be dovetailed with groundwater use. In parts of the command area where there is intense use, surface water irrigation duties could be increased to maintain the ideal balance between recharge and reuse of shallow groundwater. In other areas where the scope for conjunctive use is less – for instance in areas with saline groundwater – irrigation duties could be decreased;
- In areas with saline groundwater it may make sense to curtail surface supplies and invest in drainage for another reason. Avoiding oversupplies of surface irrigation water (as is currently the case in some systems) will create more storage space in the upper layers. This will allow for the formation of a sweet/ brackish water lens, fed by seepage and rainfall, which could then serve as a source of drinking water. Though far from perfect, such sources are much better than using highly-polluted surface irrigation water, as is now the reality in several such systems;
- Special measures can be considered to increase the recharge of the groundwater buffer in large-scale irrigation systems. High monsoon flows in the river can be partly routed through irrigation and drainage canals so as to replenish the groundwater buffer;
- In conjunctive management more attention is required for water quality. The intense and repeated use of water will affect the water quality and care should be taken that salinity and pollution loads remain limited.

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Making the most of road infrastructure for recharge, retention and reuse

Kenya, China, Brazil

Figure 1. A murram pit, Kenya (Source: Nissen-Petersen, E, 2006)

Introduction

Roads and railroads and their embankments are major landscape elements which strongly effect water storage and retention – planned or unplanned. There is substantial investment in road development and rehabilitation: often it is the single largest expenditure item in public budgets. Increasingly infrastructure is also targeted by private investment. Connecting buffer management with road development makes it possible to achieve groundwater recharge at scale and adapt large areas to the effects of climate change.

During heavy rains the second nature of many roads becomes apparent: they intercept surface runoff and generate streams on their relatively compact surfaces. The location of the road in relation to contour lines, the height of the embankment, the longitudinal and lateral slope of the road, the surface material and the underdrainage are all important factors in determining how water is retained and generated around road infrastructure. Whereas this can cause damage to roads and gullies in adjacent fields, adequate road drainage can be a valuable source of water that can be applied to land directly or made available for infiltration. The following examples outline how the effective use of road drainage can be used for storage and recharge:

Figure 2. Charco dam (Source: Nissen-Petersen, E, 2006)

Description

In Kenya borrow pits are excavated during road construction. The *murram* (figure 1), or laterite soil, found at the bottom of such pits is usually impermeable and in demand for paving dirt roads. The murram pits can also be used as storage ponds. A channel from the road to the pit can be dug preferably at a 3% incline to avoid scour. Critical sections of the pit can be plastered by a mix of clay and lime to prevent too much seepage. Another important measure is the creation of a spillway paved with stones to prevent any collapse of the pit due to water pressure. The correct height can be calculated by gradually heightening the spillway. Using borrow pits for storage is cost effective since all that remains to be done is to dig the channel to the pond.

A more elaborate type of storage pond is the so-called *charco dam* (figure 2). The construction of the *charco dam* requires increased manual labor, but seepage and evaporation are reduced in this type of storage pond. Several designs are commonly used, yet the 'calabash' shape is preferred as it provides maximum storage for a minimum amount of work, and because internal and external pressures are evenly distributed. In sandy soil the calabash shape can be relatively easily lined with clay soils to prevent infiltration losses.

Figure 3. Irish bridge (Source: Nissen-Petersen, E, 2006)

In Datong Township in Sichuan Province, China, more than 50,000 miniature rainwater harvesting tanks were constructed over a period of 15 years, and over 300 ponds have been constructed to facilitate irrigation in dry periods. These cylindrical underground rainwater harvesting tanks are constructed with only a small opening above ground to save limited cropland. They are constructed along roads, trails and land boundaries, and use the drainage flows from these. The tanks typically have a volume of 30 m^3. They are 25 cm thick and made of limestone rocks, bricks and sand. These materials as well as their small opening prevent water loss after the water has entered the tank. The tanks have two pipes: a small one for irrigation and a bigger one to remove sediment within the tanks. Every 3 to 5 years the tanks are cleaned manually. Before the inlet a sediment trap is constructed. The increased storage has facilitated the cultivation of sugar cane, tobacco and mulberry, and the subsequent yields per hectare, as well as increased rural incomes.

In Brazil, 520 infiltration ponds have been built along highways by Autovia, under its 'Water Way' initiative. Autovia is a major private sector road operator in Brazil. The infiltration ponds collect road runoff and allow it to infiltrate and replenish the groundwater buffer. The average capacity of the ponds is 4000 m^3. The soil in the pond also functions as a filter and removes some of the pollutants. The Water Way initiative resulted in an increase of groundwater recharge from 25% to 31 %, the surface runoff has decreased from 65% to 57%, and the evaporation has increased from 10% to 12%.

Techniques used

In making use of road runoff, water quality is a paramount concern. In some areas the runoff from roads contains substantial quantities of motor oil and other pollutants. Recharging groundwater with this water would do more harm than good. In this case runoff is drained so as not to be in contact with the shallow groundwater. Also the sealant used in the surface of roads and parking lots requires attention, as it may contain coal tar that could be carcinogenic.

There are many other links between road planning and buffer management, such as designing underdrainage so as to maximize retention, using Irish bridges (figure 3) or low causeways as subsurface dams, and improving groundwater recharge from permeable surfaces (see overview).

Conclusion

In promoting better buffer management and climate change, adaptation size and impact are important. It is not about isolated useful measures, but the challenge is to improve storage capacity on a large geographical scale. This requires a strong link with regional planning processes, such as the construction and rehabilitation of major road infrastructure.

ROAD INFRASTRUCTURE	RELATION TO 3-R BUFFER MANAGEMENT
Road embankments	The position of road embankments along contour lines and the height of the embankments can be made in such a way so as to retain surface runoff and sheet flow and cause it to infiltrate.
Road drainage	Road drainage can be an important source of water – supplied directly to the land, stored in surface ponds or recharged through infiltration ponds. However, the quality of the drainage water is important and there may be examples where polluted water is best removed through lined drains or evaporation ponds. The quality of the recharge water may also be treated by soil filtration or first-flush systems.
Road recharge in areas with saline groundwater	Similarly in areas with high saline groundwater tables, road drainage – including the surface runoff intercepted by road embankments - can add up to a substantial amount of water. In areas with high saline groundwater recharge, high embankment and lined drains may remove a large part of the runoff to avoid it adding to the high saline groundwater tables.
Road surfaces	Permeable instead of impervious surfaces will increase recharge to the groundwater buffer and will also prevent sharp peaked floods from large built-up areas. In recharge, however, water quality concerns are important. The road surface itself may contain for instance coal tar sealant with carcinogenic polycyclic aromatic hydrocarbons, known to cause cancer. Water quality also concerns contamination by motor oil and the like. Water quality can be partly improved by infiltration boxes. Fine soil layers below the pavements will prevent pollutants to reach the buffer. The permeable road need to be cleaned every four years (depending on the intensity of use) to prevent clogging, while the soil layer lasts for 50-100 years
Culverts and underpassages	The size of the underdrainage facilities determines the speed by which excess water is removed. This can be manipulated by limiting the size of culverts or providing them with a gate. In doing so, large areas can be compartmentalized in order to slow down and retain surface runoff, to cause it to infiltrate and to avoid stunted flood peaks from the larger area. Care is required, however, because undersized crossdrainage can also cause local flooding and waterlogging.
Irish bridges	Irish bridges (also called low causeways) are often constructed in ephemeral rivers. They can be used to increase upstream water levels in the riverbed and the adjacent land, effectively acting as subsurface dams. Care is required to only retain groundwater but not to entirely block the subsurface flow, as this will negatively impact downstream water levels.

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4. Conclusion

Climate change is unequivocal, and in many parts of the world it increasingly strikes a chord with people who experience its consequences. In the poorest parts of the world, climate change dangerously amplifies long-standing livelihood insecurity and is exacerbated by resource degradation – pollution, erosion, and unwise use.

3R can help further the development agenda by preventing undue suffering from wide climate swings or from water scarcity and degradation in general. 3R is about the local water buffer and its potential, through proper management, to improve the lives of the people who live near it.

The cases show that optimal use of water resources through recharge, retention and reuse provides options for coping with climate variability. 3R is even more relevant under conditions of climate change. Even without considering future climate conditions, an urgent need for more water security undoubtedly exists. Numerous simple measures can greatly improve the situation on the ground. They require relatively small investments, and provide immediate and long-term benefits. 3R applications are among the most cost-effective actions that improve access to water and increase the productivity of farmland and pastoral areas. Given climate change scenarios, they become even more useful and should increasingly be incorporated into planning, design and operational concepts, since they will create resilience against the vagaries of climate change.

Some of the examples go even further than no regret or resilience approaches. As demonstrated by the responses to droughts in Morocco, Namibia and Pakistan, in some cases, climate variability and climate change can even push us into better resource management.

To maximize benefits, the water buffer must be improved in large areas: basins, sub-basins, districts, and municipalities. Implementing 3R at the basin level will make a real and self-sustaining change. As part of IWRM, it has the potential to reach into the fields of land planning, sustainability of ecosystems, infrastructure design and regional development. It will encourage and strengthen the river basin organizations at the heart of water resources management, and further their successful cooperation with other stakeholders, including water users and communities. These benefits apply to arid and humid areas alike.

Despite their availability, techniques to strengthen sustainable water management are not always put to use (i.e. analytical techniques such as applied hydrogeology and a new generation of remote sensing that makes it possible to register rainfall, record soil moisture and construct water balances). Tailored and locally specific climate information is there, too, or can be derived from regional assessments. The assessment of costs and benefits for new 3R infrastructures can then be based on experience from existing 3R applications and coupled with forecasts about surface ocean temperature, precipitation and run-off.

The techniques to implement 3R exist, but their under use leaves a trail of missed opportunities. The case studies highlight the practicalities of recharge, retention, reuse and rainwater storage, and clearly demonstrate that 3R is not a distant dream. It can be taken up here and now, at regional to local levels.

We believe that a new approach to water resources management is necessary – one that is based on making optimum use of the water buffer, considering the local and basin-wide conditions, triggering individual and private investment, and integrating all options coherently for development. Balancing all natural and socio-economic functions will guarantee the highest degree of comfort and reassurance for developing nations all over the world.


Be buffered
Sometimes
you're standing
on a solution
without even
knowing it...
META META
Acacia Water
RAIN
BGR
co-operative programme on water and climate
UNESCO