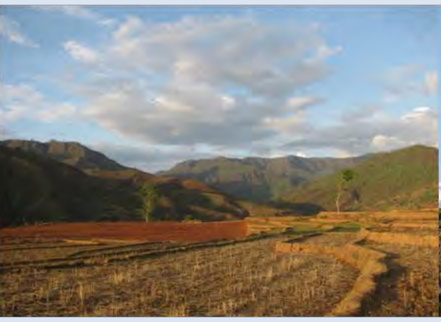



Potential for water buffering

A landscape based approach

3R approach with an example application for North Kenya

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Content

1 Introduction: an innovative view on intervention selection

1.1 Background

Buffering water in the periods when it is available can be a very beneficial solution to provide water in the periods when it is normally scarce, thus increasing the resilience to droughts. In arid and semi-arid lands water is scarce during a long period of the year, the short peaks of rainfall and long dry periods can cause substantial shortages in the water supply. In rural areas the total amount of precipitation is nonetheless often more than enough to fulfill the demand, when this water is stored. The interventions to increase the water storage can be referred to as 3R interventions (see box). These kind of interventions are already implemented in the various regions and they are generally well known to the implementing organizations, the donors, and the communities.

The selection of the interventions may however not be straightforward. The experience is that it can be difficult to assess the full scope of possible interventions that would be suitable within one area. Generally, the selection of the specific kind of intervention is based on community preferences, local knowledge of the implementing partner, or governmental advice. It is important to empower these organizations involved in water structure development with an easily applicable method to optimize the intervention selection.

In this publication we show how the selection of interventions can be approached in an innovative way based on the characteristics of the natural landscape. It shows that interventions which are not directly taken into account based on the previous experience, may be suitable in an area. The lessons learned in different areas may thus be exported to other areas. For this an area based approach is developed, which indicates at which locations what kind of interventions are suitable.

This approach can form a sound basis for an area integrated water supply strategy. It shows practical categories of which kind of interventions have a high potential within different parts of the country. It thus provides a framework which can inspire to consider different options, where good examples from physically comparable regions may be applied to other areas.

The results of this study can be beneficial to (1) policy makers and coordinating bodies: to evaluate and advice on planning of implementing organization, (2) Funding organizations: to indicate different options to provide funding for, and to provide an example of a feasibility phase which could be beneficial as a part of project calls and (3) Implementing organizations: an indication of the options to consider in an area in Northern Kenya when applying for funding, and an example of a feasibility phase to evaluate the options before determining the interventions which will be implemented.

1.2 Project & Methodology

This publication is part of the Kenya Arid Lands Disaster Risk Reduction – WASH Program (KALDRR), which is a project of the Millennium Water Alliance and Aqua for All which is executed in cooperation with the local implementing partners Food for the Hungry, Care, Worlds Vision and CRS. The project focuses on Northern Kenya, and for each of the implementing partners a focus area was examined in more detail, fieldworks were carried out in the following areas:

- Marsabit for Food for the Hungry
- Moyale for Care
- Turkana for World Vision
- Wajir for CRS.

The current approach combines the available information and expert knowledge. Generally available data is used to determine the different potential zones. This is supplemented and verified with the information obtained from the fieldworks in the four target areas spread over Northern Kenya. In this manner the results of the more detailed researched areas are scaled up to full focus area of the overall KALDRR program.

1.3 Reader's guide

This synthesis report provides an overview of the approach to determine different zones in the area, with each specific characteristics and interventions that are suitable for the regions, and its application for Northern Kenya. Chapter 2 shows the newly developed potential map based on the variations in the landscape in Northern Kenya. In chapter 3 the interventions are introduced with their requirements for the landscape, thus showing in which zones they are applicable. In Annex 1 some interventions examples and recommendations from the examined target areas are included to provide inspirational examples which may be extended towards other areas. In chapter 4 the characteristics of the zones and their potential for the application of water storage techniques is further detailed. Finally, chapter 5 gives the conclusions, and the directions for the use of this document. For more details on the physical analysis behind the results presented in this document, and the references, we refer to the background document "General physical landscape analysis" by Acacia Water, 2013.

Box 1 Recharge, Retention, Reuse (3R)

In this study the approach of 'Recharging, Retaining and Reusing water' (3R) to increase the amount of useful water has been followed. The central idea in the 3R approach is to store water when it is plentiful and to make it available for the dry periods – and also to extend the chain of uses. 3R interventions use buffers like shallow aquifers, the soil profile, open water or tanks to store water. The ultimate aim is to create secure water buffers, which can fulfill the water demand for the various different uses in the area. This translates into an increased resilience during drought periods, higher productivity and increased access to drinking water.

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

Retention
Retention means that water is stored to make it available in the dry periods. It creates wet buffers, so that it is easier to retrieve the water. Retention can also help to extend the chain of water uses. Additionally, retention may raise the groundwater table and may affect soil moisture and soil chemistry, which can have a large impact on agricultural productivity.

Reuse
Reuse comprises different elements. The simplest form is the use of the water in the dry period which was stored in the wet period. It can be further extended when the water is kept in active circulation. This can be achieved with the management of water quality, to make sure that water can move from one use to another, even as the water quality changes in the chain of uses. Further, reuse can be enhanced by reducing non beneficial evaporation to the atmosphere, and by capturing air moisture, such as dew, where possible.

2 Possible 3R interventions

The focus of the 3R approach is on increasing storage and availability of water (see box 1). 3R interventions and techniques are already broadly used. Figure 1 provides an overview of different often well-known types of 3R interventions that exist. Many of these have the potential to be implemented in more places besides the regions where they are currently applied, creating the opportunity to increase the water storage, and thus creating resilience against dry periods.

Four main categories of interventions can be distinguished:

- Storage in groundwater (either for domestic, livestock or agricultural water supply)
- Storage in soil moisture in the unsaturated zone (generally for agricultural purposes)
- Storage in closed tanks and cisterns (generally for domestic use)
- Storage in open reservoirs (usually for agricultural or livestock supply)

Each type of buffer has its own strength and weakness. The time that water is retained and stored differs between the systems. Where small tanks and soil moisture will help to bridge for example a dry season, large surface storage and particularly groundwater storage can help to bridge even an unusual dry year or series thereof. Usually different types of storage complement each other in water buffering at landscape and basin level.

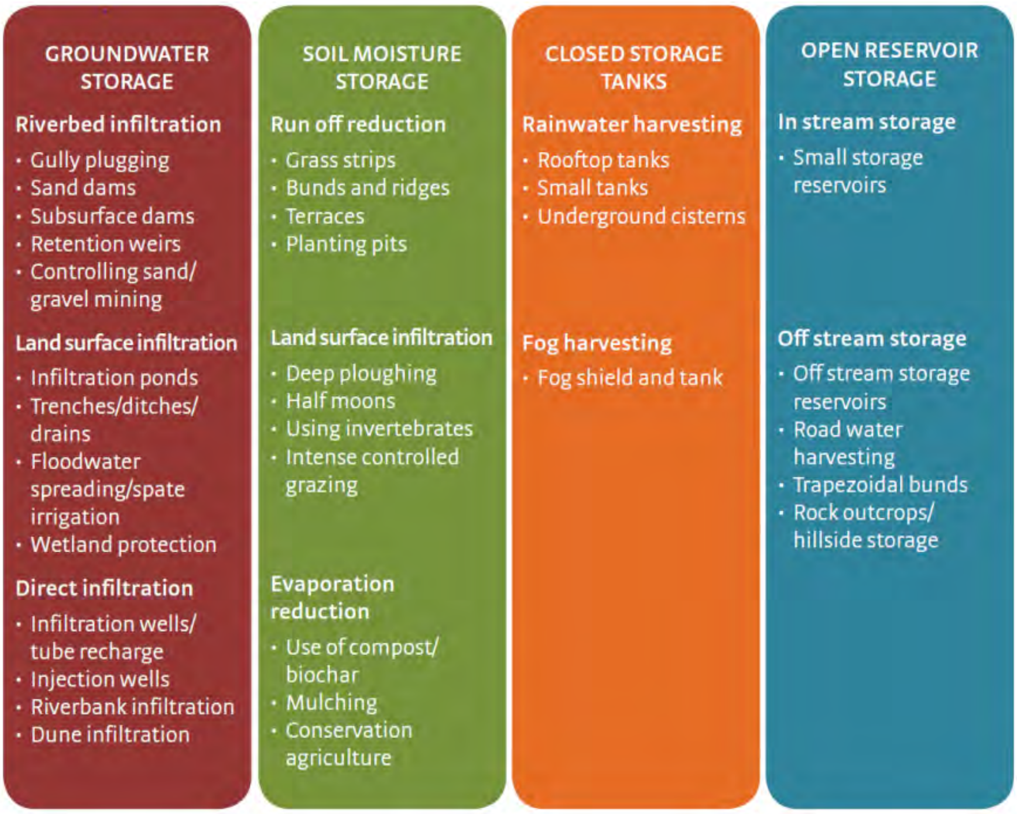


Figure 1 Overview of 3R techniques (replicated from Tuinhof et al., 2013)

Additionally, for successful implementation the 3R interventions have to fit with the intended use of the water and within the characteristics of the landscape. To locate the areas where different 3R interventions can be applied, a landscape analysis is therefore required. For example, storage of groundwater can be very beneficial, but it can only be applied where the ground is sufficient porous and where the water is not lost to too large depths. As an alternative, when the infiltration capacity is low, open water storage might be a feasible option. The application of the different options is thus dictated by the geo-hydrological characteristics of the landscape.

The 3R analysis focuses on this physical landscape analysis, in order to provide advice about the best manner to store water in the wet period, and make it available for use in the dry periods. This also includes an advice on the kind of locations where interventions should be placed to accumulate sufficient water to recharge the reservoirs.

In the KALDRR project the focus was on a landscape analysis of the options for water buffering for water supply, like domestic and livestock water. Therefore, the analysis is focused on open reservoir and groundwater storage (see figure 1), rather than soil moisture storage (which is generally for agricultural purposes). Closed storage tanks can mostly be applied independent of the landscape. Below an overview of the requirements for these kind of interventions is given, which determine which intervention is applicable at which location.

A. Pans and valley dams; in-stream or off-stream storage
- Water to fill to pan: from overland / road run-off, a rock catchment, or a stream (requires a sufficient large catchment upstream), or (diverted) water from a river
- Clayish sediments to line the pan. In case this is not present: artificial lining should be applied

B. Sanddams
- Water to fill the sanddam: from the stream in which the sanddam is implemented
- Coarse/sandy sediments supply in the stream to fill the aquifer behind the sand dam
- An impermeable layer at which the sanddam can be based (e.g. basement rocks or clayish layer)
- Stable, impervious river banks
- Select a location with limited width of the river to limit the extend of the dam
- Gradual slope in the river to create a relative large aquifer behind the dam

C. Subsurface dams
- Water to fill the subsurface dam: from the stream in which the subsurface dam is implemented
- Coarse/sandy sediments already present in the riverbed
- An impermeable layer at which the subsurface dam can be based (e.g. basement rocks or clayish layer)
- Stable river banks/ a steady river course
- Gradual slope in the river to create a relative large aquifer behind the dam

D. Shallow, freatic groundwater: well and riverbank infiltration
- Potential for shallow groundwater: relative shallow impermeable layer below a shallow aquifer, or high groundwater tables of the deep groundwater
- Accumulation of water (CTI-index)
- Infiltration of water into the shallow aquifer (may be reinforced by the wells, or in combination with E or F)
- Limited lateral loss (can be reinforced by B or C)

E. (Flood)water spreading and spate irrigation
- Water to spread over a larger area, from streams or rivers
- No downstream use of the spread water (this technique may use much water, part of which evaporates)
- Flat areas over which the water can be spread
- Potential for shallow groundwater (see D)
- Combine with A or D to retrieve the water; or

- Use these techniques to increase the local soil moisture for grazing areas or agriculture

F. Gully plugging, retention weirs, and other run-off reduction/infiltration options

- Locations with large run-off, e.g. steep locations, or locations with flow accumulation like in streams
- The soil should allow infiltration (otherwise see A)
- Should be combined with D or G to subtract the infiltrated water; or
- Springs should be present downstream to harvest the infiltration water; or
- Use these techniques not to harvest the water but to reduce erosion, downstream peakflow, or to increase the local (soil) moisture

G. Closed tanks

- Water to fill to tank: from rooftops, overland / road run-off, a rock catchment, a stream, or (diverted) water from a river

H. Deeper, confined aquifer groundwater: wells / boreholes

This is related to the deep groundwater system, while the zones are based on the shallow system.

- Sufficient (fossil) water in the deep aquifer to sustainably subtrackt; or
- Sufficient natural recharge; or
- Water to infiltrate: e.g. from a pond or pan
- Negligible groundwater flow in the aquifer
- Infiltration options to the aquifer

Figure 2 Sanddam near Nakabosan, Turkana

3 Variations in Northern Kenya & Zones with different potential

3.1 Variations indicated by various sources

In the Northern Kenyan areas where this project focuses on, substantial differences in the landscape are found. Most areas are dry with limited amounts of vegetation like scrubs, while some locations are more lush and green. The variations also extend to the possibilities to apply different 3R techniques. We combined various sources of information to characterize the area (figure 3), and evaluated it in a number of field visits at different locations in the area. Based on this we made a map which indicates the potential for the interventions in different zones (Figure 4).

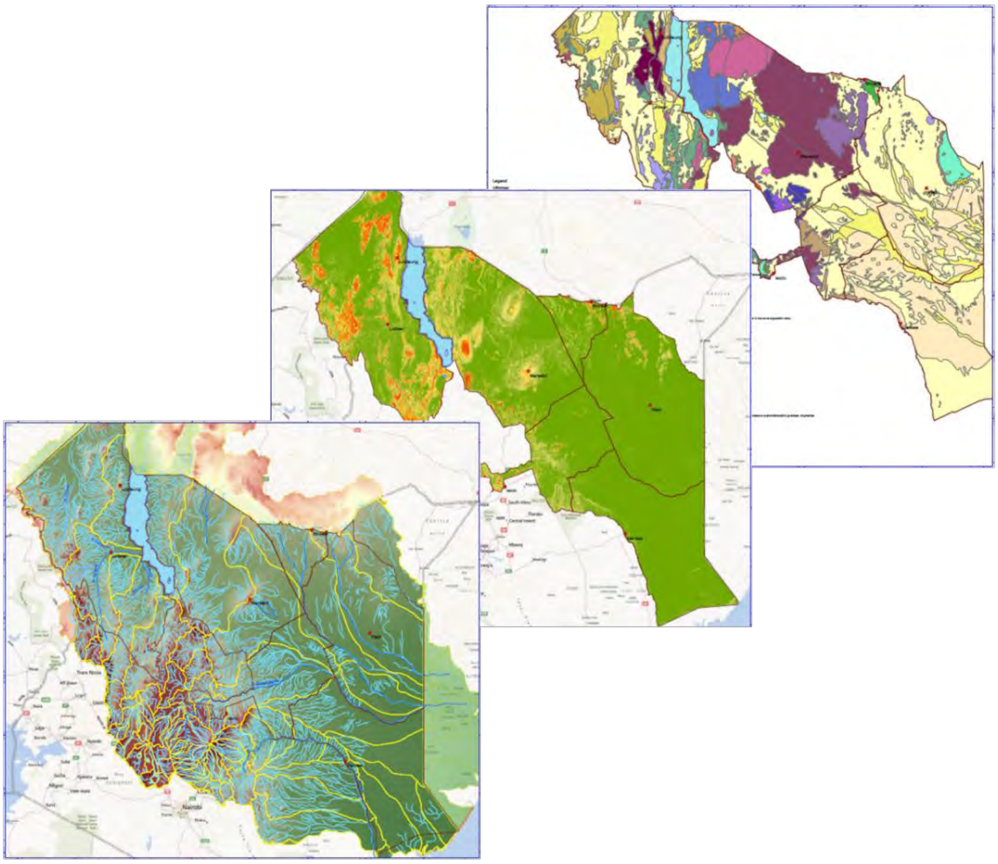


Figure 3 Various sources of information like the geology, the elevation and the flow accumulation were combined to characterize the zones with various water storage potential in the landscape (indicated in the next figure)

3.2 Division into different zones

The target area is divided in different zones, each of which has its own characteristics, and its own potential for the implementation of 3R interventions. A division is made based on the geological and morphological features that have an impact on the potential for recharge and retention. Important factors in this are:

(1) The distinction between mountainous and flat to gentle sloping areas. In mountains on the one hand the run-off velocity is generally high, and deep gullies may be found. The erosion can be more severe in mountains than in flat areas, and may provides more sediment in the rivers. Further, the slopes of mountains may be used as natural edges for the creation of a water reservoir. In flat to gentle sloping areas on the other hand, interventions that cover a larger area may be easier to realize. For example a dam in a gently descending river can create a long stretched reservoir, and floodwater spreading may be beneficial to increase the infiltration and the soil moisture over a larger area.

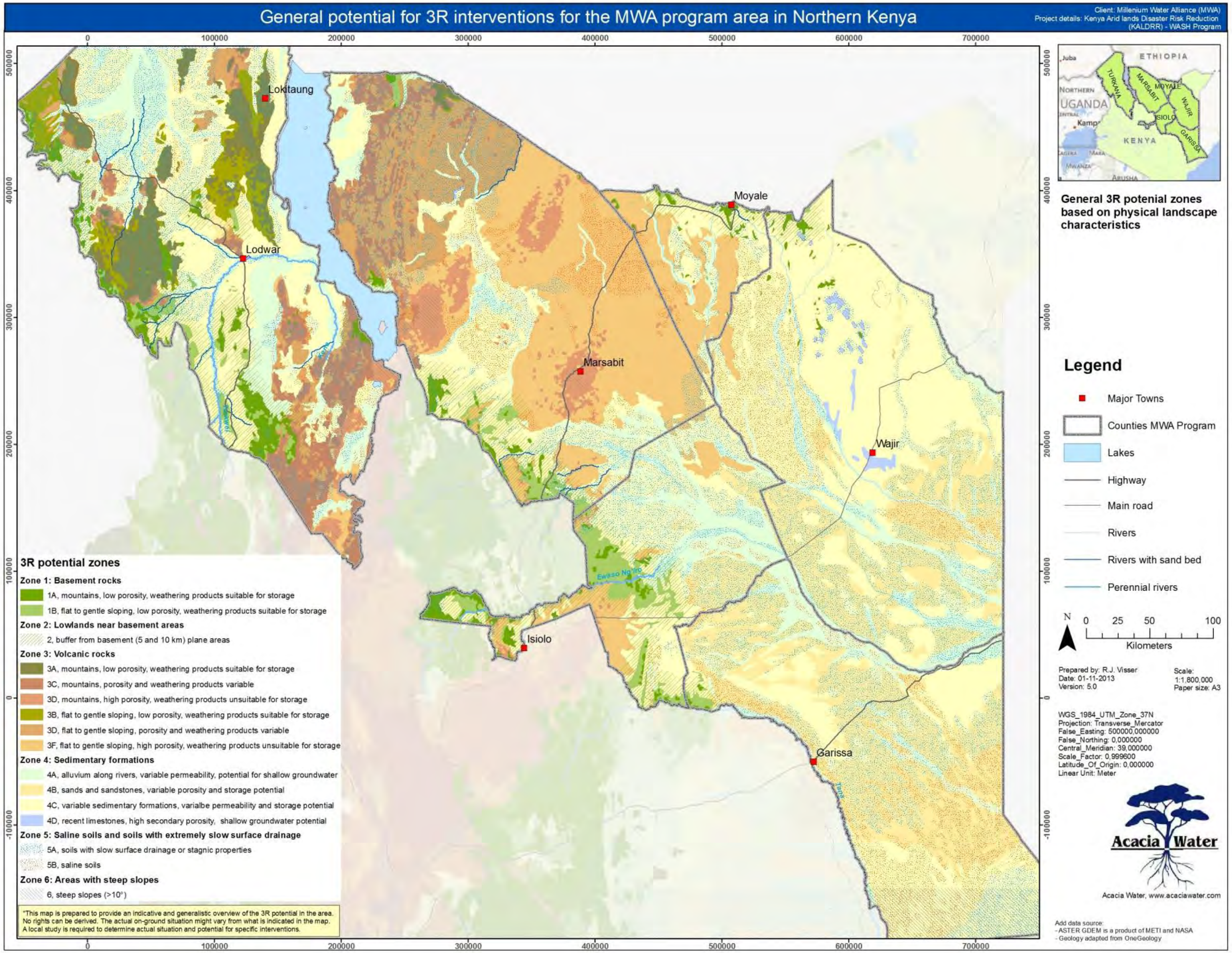
(2) The porosity or permeability of the subsoil. The porosity of the rocks or the vertical permeability of the soil determines how fast water infiltrates to deeper layers. When the porosity is low, the infiltration is limited, and the subsoil can serve as a good base for a reservoir to retain the water. Contrary, with a high porosity or permeability, water may be lost from a reservoir to deeper groundwater. When the purpose is to recharge the groundwater this may be desirable. When the purpose is to store water in the reservoir, a sealing may be required, which can consist of natural deposition or siltation, local available clay, or plastic or concrete (see also Annex B).

(3) The weathering products and sediments. Locations with sandy sediments may provide the opportunity to create sanddams, and -when a sandy riverbed is already present- subsurface dams. When the sediment consists of clayish material, it can provide the opportunity to reduce the infiltration losses of reservoirs. It may also increase the soil moisture potential, e.g. when combined with floodwater spreading. Since the sediment load is determined by the weathering products from the rocks and the soils, the 3R potential depends on whether the weathering products in the vicinity or upstream are suitable for storage (sandy products) or not (clayish products).

The zones are grouped in six categories, and several subcategories. The first category (zone 1) contains basement rocks, these rocks have generally a low porosity and weathering products suited for storage. The second category (zone 2) are the lowlands that receive the weathering products through the larger rivers from the basement rocks in zone 1, but do not consist of basement rock themselves. Zone 3 exists of the volcanic rocks, which have variable porosity and weathering products, therefore this category is subdivided in a number of subzones (zone 3A - F). Zone 4 covers the sedimentary formations which are generally flat to gentle sloping. Zone 5 provides an overlay for saline soils and soils with extremely slow surface drainage. Finally zone 6 indicates the mountainous areas with steep slopes. The appearance of the zones in Northern Kenya is indicated in figure 4.

Figure 4 (next page) Zones with different potential for water storage. The techniques that are feasable within each zone are indicated in table 1. This same map is included at a larger format in Annex C.

Tabel 1 (2nd next page) Indication of the kind of interventions that may be feasible within each of the zones indicated in figure 2. The marks in this table denote: x. possible; x. high potential; X. very high potential; (x). limited potential; ?. uncertain. The superscripts denote: 1. possibly sealing required; 2. combined with 3B, 3D, 3F, 4C, 4D, if impermeable layer is present. The indicated feasibility serves as inspiration and must always be checked with the local circumstances.


General potential for 3R interventions for the MWA program area in Northern Kenya
Client: Millenium Water Alliance (MWA)
Project details: Kenya Arid lands Disaster Risk Reduction (KALDRR) - WASH Program
Lokitaung
Lodwar
Moyale
Marsabit
Wajir
Isiolo
Garissa
Ewaso Ng'iro
Tana
ETHIOPIA
UGANDA
KENYA
TURKANA
MARSABIT
MOYALE
WAJIR
ISIOLO
GARISSA
General 3R potenial zones based on physical landscape characteristics
Legend
Major Towns
Counties MWA Program
Lakes
Highway
Main road
Rivers
Rivers with sand bed
Perennial rivers
0 25 50 100
Kilometers
Prepared by: R.J. Visser
Date: 01-11-2013
Version: 5.0
Scale: 1:1,800,000
Paper size: A3
WGS_1984_UTM_Zone_37N
Projection: Transverse_Mercator
False_Easting: 500000,000000
False_Northing: 0,000000
Central_Meridian: 39,000000
Scale_Factor: 0,999600
Latitude_Of_Origin: 0,000000
Linear Unit: Meter
Acacia Water
Acacia Water, www.acaciawater.com
Add data source:
- ASTER GDEM is a product of METI and NASA
- Geology adapted from OneGeology
3R potential zones
Zone 1: Basement rocks
1A, mountains, low porosity, weathering products suitable for storage
1B, flat to gentle sloping, low porosity, weathering products suitable for storage
Zone 2: Lowlands near basement areas
2, buffer from basement (5 and 10 km) plane areas
Zone 3: Volcanic rocks
3A, mountains, low porosity, weathering products suitable for storage
3C, mountains, porosity and weathering products variable
3D, mountains, high porosity, weathering products unsuitable for storage
3B, flat to gentle sloping, low porosity, weathering products suitable for storage
3D, flat to gentle sloping, porosity and weathering products variable
3F, flat to gentle sloping, high porosity, weathering products unsuitable for storage
Zone 4: Sedimentary formations
4A, alluvium along rivers, variable permeability, potential for shallow groundwater
4B, sands and sandstones, variable porosity and storage potential
4C, variable sedimentary formations, varialbe permeability and storage potential
4D, recent limestones, high secondary porosity, shallow groundwater potential
Zone 5: Saline soils and soils with extremely slow surface drainage
5A, soils with slow surface drainage or stagnic properties
5B, saline soils
Zone 6: Areas with steep slopes
6, steep slopes (>10°)
"This map is prepared to provide an indicative and generalistic overview of the 3R potential in the area. No rights can be derived. The actual on-ground situation might vary from what is indicated in the map. A local study is required to determine actual situation and potential for specific interventions.

3R potential zones

Zone 1: Basement rocks

- 1A, mountains, low porosity, weathering products suitable for storage
- 1B, flat to gentle sloping, low porosity, weathering products suitable for storage

Zone 2: Lowlands near basement areas

- 2, buffer from basement (5 and 10 km) plane areas

Zone 3: Volcanic rocks

- 3A, mountains, low porosity, weathering products suitable for storage
- 3C, mountains, porosity and weathering products variable
- 3D, mountains, high porosity, weathering products unsuitable for storage
- 3B, flat to gentle sloping, low porosity, weathering products suitable for storage
- 3D, flat to gentle sloping, porosity and weathering products variable
- 3F, flat to gentle sloping, high porosity, weathering products unsuitable for storage

Zone 4: Sedimentary formations

- 4A, alluvium along rivers, variable permeability, potential for shallow groundwater
- 4B, sands and sandstones, variable porosity and storage potential
- 4C, variable sedimentary formations, varialbe permeability and storage potential
- 4D, recent limestones, high secondary porosity, shallow groundwater potential

Zone 5: Saline soils and soils with extremely slow surface drainage

- 5A, soils with slow surface drainage or stagnic properties
- 5B, saline soils

Zone 6: Areas with steep slopes

- 6, steep slopes (>10°)

	A Pans and valleydams	B Sanddams	C Subsurface dams	D Shallow, freatic groundwater: wells and riverbank infiltration	E (Flood)water spreading and spate irrigation	F Gully plugging, checkdams, and other run-off reduction /infiltration options	H Closed tanks	G Deeper, confined aquifer groundwater: wells / boreholes
Zone 1A	x^1	**X**	x	**x**		x	x	(x)
Zone 1B	x^1	**x**	**X**	**x**	x	?	x	(x)
Zone 2		x^2	**x^2**					
Zone 3A	x^1	**x**	x	x		x	x	(x)
Zone 3B	x^1	x	**x**	x	x		x	(x)
Zone 3C	x^1	?	?	?		x	x	x
Zone 3D	x^1	?	?	?	?		x	x
Zone 3E	x			x		x	x	x
Zone 3F	x			(x)		x	x	x
Zone 4A	x			**x**	**x**		x	x
Zone 4B	x^1	(x)	(x)	?	x	?	x	x
Zone 4C	x		?	(x)	x	?	x	x
Zone 4D	x			**X**		?	x	x
Zone 5A	**x**					x		
Zone 5B	**x**			?		?		
Zone 6		(x)				**X**		

Tabel 1 Indication of the kind of interventions that may be feasible within each of the zones indicated in figure 4. The marks in this table denote: x. possible; x. high potential; X. very high potential; (x). limited potential; ?. uncertain. The superscripts denote: 1. possibly sealing required; 2. combined with 3B, 3D, 3F, 4C, 4D, if impermeable layer is present. The indicated feasibility serves as inspiration and must always be checked with the local circumstances.

4 Description of the different zones

3R interventions with potential within Zone 1

Zone 1A Mountainous basement areas

Very high potential for sanddams, high potential for the use of shallow groundwater, potential for pans, subsurface dams, run-off reduction measures and closed tanks. An extra sealing for the pans may be required.

Zone 1B Flat to gentile sloping basement areas

Very high potential for subsurface dams, high potential for sanddams and the use of shallow groundwater, potential for pans, floodwater spreading, and closed tanks. Uncertain potential for run-off reduction measures. An extra sealing for the pans may be required.

4.1 Zone 1 - Basement rocks

Zone 1A & B

Zone 1 consists of areas with basement rocks, like granite and gneiss. The weathered material originating from these rocks has a high sand content and shows a good potential for water storage. Generally basement rocks have a low permeability, except at the locations of large cracks. They thus form a solid, impervious base for dams and mostly prevent infiltration to large depths, thus creating shallow groundwater potential.

In mountainous areas the sandy weathering material is transported downslope along streams. When the slope of the terrain is between 1 and 10º (zone 1A) sand may easily accumulate in stream beds behind sand dams. In this slope range the impervious basement rocks are usually close to the surface providing a good base for the dams. When the slope of the terrain is below 1º (zone 1B) the production of sandy weathered material may be limited. Nonetheless, in these relatively flat areas local deviations in the general slope may be just enough for the accumulation of coarse sand in stream beds, thus still creating scope for sanddams or subsurface dams.

Figure 1 Left panel: River near Kamatonyi, Marsabit (zone 1B). Right panel: Rivers with sandbed in basement areas in Laisamis, Marsabi, zone 1A (left), and zone 1B (right). On the upper right a basalt plateau can be oserved (zone 2B/3E)

4.2 Zone 2 - Downstream of basement rocks

> **3R interventions with potential within Zone 2**
> ***Zone 2 Buffer zone from basement rock***
> High potential for subsurface dams, and potential for sanddams. Both when combined with zone 3B, 3D, 3F, 4C, 4D, if a impermeable layer is present. (should be combined with the layer below the hatch; where a potential is indicated with one of the crosses for zone 2, it replaces the potential in the underlying zone)

Zone 2A&B - Buffer zone downstream of the basement rocks of zone 1

This zone consists of areas that are within reach of intermediate to large rivers carrying sand from the upstream and adjoining basement rocks. After a heavy rainfall event, the larger rivers may carry sand over large distances and deposit the sediments several kilometres downstream, beyond the area where the basement rocks appear. The sandy deposits are expected to show good potential for water buffering along the rivers in zone 2.

We have chosen a buffer zone of 5 km (zone 2A) and 10 km (zone 2B) around Zone 1 , indicated on the map with a hatch over the non-mountainous zones. This is generally in line with the field and satellite observations, but locally the sand rivers can extend far beyond this buffer. It should therefore be seen as an indication, and the extend should be confirmed for each location individually.

The feasibility of sanddam or subsurface dams depends on the characteristics of the soil and rocks in the zones underlying the rivers of zone 2. A shallow impermeable layer is required, which may be the found in zone 3B, 3D, 3F, 4C and 4D, but due to the inhomogeneous nature of the rocks or sediments in these zones this always has to be checked locally. When a vertical resistance is missing the water will infiltrate to greater depths and may be difficult or even impossible to retrieve. The hatched buffer zone should therefore always be regarded in combination with the underlying zone.

Whether the construction of an in-stream solution in sedimentary areas is possible depends also on the stability of the river banks. With instable banks a river may change its course unexpectedly. Broadly zone 2A may have more potential for sanddams than zone 2B, because of the more pronounced riverbeds near the bedrock of zone 1. Subsurface dams have potential in both zone 2A and 2B.

Figure 2 Riverbed with sandbed near Nakabosan, and a shallow well in the riverbed at Kalemngorok, Turkana

4.3 Zone 3 – Volcanic rocks

Zone 3 consists of all types of volcanic rocks. A distinction is made between mountainous areas and flat areas, and volcanic rocks with clayey and sandy weathering products.

Zone 3A & B – Volcanic rocks with low permeability and sandy weathering products

The hydrological characteristics of the volcanic rocks within this zone (quartz rich rocks like rhyolite or dacite) are comparable with those of the basement rocks of zone 1. These rock also form generally an impervious base, except at locations with large cracks. Additionally, the weathering product of these volcanic rock is coarse to sandy. This can thus be a source for sand rivers with a water buffering potential. The sediments in the rivers originating in volcanic areas area usually greyish in colour, while the sand in the basement rock areas is more light yellow to brown. These zones thus have a comparable potential as zone 1, with good potential for in-stream interventions, and potential for shallow groundwater.

Zone 3C & D – Volcanic rocks, permeability and weathering products variable

In zone 3B an 3C the signature of the volcanic rocks is less pronounced than in the zones 3A-B and 3E-F. The weathering products can be either sandy or clayey, and the permeability of the rocks within this zone is not well known either. The characteristics of this zone are therefore in between those of 3A-B and those of 3E-F. Local research is required to specify the characteristics of this zone further.

Zone 3E & F – Volcanic rocks, high permeability, clayey weathering products

The volcanic rocks in this zone are generally rather porous and have a high permeability. Therefore, water can here often infiltrate to larger depths and shallow groundwater is not expected to be common in this zone. Locally however, these volcanic formation can contain harder rocks with low permeability. Such locations may be recognized by changes in the relief, and are mainly expected in the mountains (zone 3E) and at the edges of the plateaus (zone 3F). Here springs can be found, and some shallow groundwater potential.

The rocks in this zone produce clayey weathering products. The streams contain little or no sand and may have steep and deep valleys like is observed on Mount Marsabit. These weathering products are unsuitable for aquifer creation behind a sand or subsurface dam. When impermeable layers of clay or harder rock can be determined, the plateaus where there is supply of sandy materials in the rivers (i.e. zone 3F combined with zone 2A/B) may have a potential for sanddams or subsurface dams.

The clayey components in the weathering products do provide the opportunity to create ponds in which the infiltration loss is strongly reduced due to siltation. Therefore, small or large valley dams (in the mountains, zone 3E) or water pans with earthen dams (on the plateaus, zone 3F) can be constructed to store surface water. Silt traps are vital to avoid silting up of the reservoir.

3R interventions with potential within Zone 3

Zone 3A&B low permeability, sandy products

High potential for sanddams (3A) or subsurface dams (3B) and potential for sanddams, subsurface dams, pans, the use of shallow groundwater, floodwater spreading, run-off reduction measures and closed tanks. An extra sealing for the pans may be required.

Zone 3E&F high permeability, clayey products

Potential for pans, shallow groundwater (limited in 3F), run-off reduction, and closed tanks. Uncertain potential for run-off reduction measures. Local materials are expected to be suitable for sealing of the pans.


Figure 3 Left panel: Stream on the slopes of Mount Marsabit (zone 3E). Right panel: Volcanic plateau with basalt outcrops, Marsabit County (zone 3F)

Box 2 Examples of identified 3R interventions

Potential for new sand- and subsurface dams in Zone 1

In the Marsabit target area (see Annex A for the local 3R potential map) basement rocks are found in the southern part of the area, these areas are mostly relative flat to gentle sloping (zone 1A). Many of the rivers in the southern part of the target area have potential for riverbed storage, especially the western part, where the Kamatonyi and Lontolio villages are located (Annex A). For the construction of sand dams a number of success factors exist. These include a sediment load in the river that consist of sand which will create an aquifer with sufficient porosity to store enough water, hard rock or clayish layers on which the sand dam can be constructed, and relative narrow locations in the rivers (e.g. 5-20m width) so that the required dam does not become too large. These requirements are all met at several locations in zone 1A in the target area. At the visited locations the sand was estimated to have a storage capacity of between 25 and 30%. Based on these analysis a new sanddam will be constructed at Kamatonyi Village, where currently no existing (improved) water source is present.

Potential for pans and valley dams in Zone 3E

The northern part of the target area contains the slopes of Mount Marsabit, which consist of volcanic rocks with high porosity (trachytes, basalts and pyroclastics), with weathering products that are mostly unsuitable for storage, in mountainous areas (zone 3E). Various water pans are found at the slopes. Some pans are mainly used for domestic supply, while most pans are mainly for livestock (see Annex A, example 3a and 3b). Water pans at the slopes mostly collect runoff water from gullies or small streams. When the pans are sited well, natural lining may be sufficient. When dams are located at smart places in the landscape, large reservoirs can be created with relative small interventions. An example of a landscape feature, which with a limited investment can be used to create a large reservoir is located 6 km south of Kamboe (see Annex A, example 4a). Here a volcanic crater was observed through remote sensing and visited during the field assessment. This crater has a seasonal stream flowing through a narrow valley on the south-eastern side, with a catchment of about 6 km^2. A small valley dam, of about 30 m wide and 8 m high at this location, could store an estimated volume of 2,000,000 m^3, while an embankment with an height of 10 m could store over 5,000,000 m^3. Next to storing surface water, a reservoir may also recharge groundwater and increase the yield of boreholes and springs lower in the catchment if water infiltrates from the reservoir.

4.4 Zone 4 – Sedimentary formations

The sedimentary rocks can be separated in different categories, which are mainly distinctive in their permeability.

Zone 4A Sediments: Alluvium along rivers

The alluvium along rivers generally consists of different layers which are deposited by the river. This can contain sandy and clayey layers. The advantage of these sediments is that the vertical resistance of the clay layers is generally moderately high, this preventing a quick loss of water to larger depths. Additionally, due to the sand layering, the horizontal resistance can be small, providing good opportunities for riverbank infiltration. The characteristics of these sediments, and their occurrence along rivers provide opportunities for shallow groundwater, which can be enhanced for example by floodwater spreading.

Zone 4B & 4C Various sedimentary formations & sandstone formations

The sedimentary areas exist of different types of lithological and geological formations, with different kind of soils. These have various infiltration rates, and permeability towards the deeper layers. Also the soil properties vary from sandy to clayey. At some locations the shallow groundwater was observed to be substantial (e.g. Turkana), but this was not everywhere the case, depending on the permeability of the rocks and the soils. A specific distinction was made for sandstone. This produces sandy weathering products, and may therefore provide potential for sanddams or subsurface dams, if rivers are pronounced. Further research on this zone (which was not abundant in the target areas) is recommended. In these generally relative flat areas foodwater spreading can be well applicable, increasing the area of the green areas found to surround the streams.

Zone 4D Recent limestone formations

A separate zone in formulated for the recent limestone formations. These were observed to have a high potential for shallow groundwater, for example in the Wajir region. These areas consist of limestone, which has good storage properties, with layers of less permeable rocks. At locations water with good quality is already available, which can be subtracted with wells, while at other locations increased aquifer infiltration should be applied to store water of good within these formations.

Figure 4 Picture taken from the mountain near Nakabosan, looking towards the Turkwel River, Turkana (zone 4c)

3R interventions with potential within Zone 4

Zone 4A Alluvial sediments

High potential for shallow groundwater and floodwater spreading, potential for pans and closed tanks.

Zone 4B Sandstone formations

Potential for pans, floodwater spreading and closed tanks. Limited potential for sanddams and subsurface dams, unknown potential for shallow groundwater and run-off reduction. An extra sealing for the pans may be required.

Zone 4C Various sedimentary formations

Potential for pans, floodwater spreading and closed tanks. Uncertain potential for shallow groundwater and uncertain potential for subsurface dams and run-off reduction.

Zone 4D Various sedimentary formations

Very high potential for shallow groundwater, potential for pans and closed tanks, uncertain potential for run-off reduction.

Figure 5 The edge of different zones is clearly visible in the field with in the left panel the Kaisut dessert (zone 4C) and in the right panel the adjacent floodplain (zone 4A).

4.5 Zone 5 – Soils with high salinity and slow surface drainage

In zone 5 two soils types with distinct characteristics are indicated, because they can affect the 3R potential. The first are soils with a slow surface drainage (zone 5A). These soils are characterized as soils with extremely slow surface drainage of the terrain: water ponds at the surface and large parts of the terrain are waterlogged more continuous periods of more than 30 days (www.isric.org). This is confirmed in the field, especially in the Wajir target area, where soils were found with a low infiltration rate. Also planosoils are expected to have a low infiltration rate as an eluvial horizon with stagnic soil properties is present in this soil. These soils are also included on zone 5A. This zone is particularly interesting to develop pans, since the water lingers at the surface, and often natural ponds are already found in these zones, which can be developed further. Due to the slow infiltration rate, the options for shallow groundwater potential, and the run-off reduction with the purpose of infiltration, may be limited.

The second soil type specifically indicated are the soils with saline characteristics, like Solonetz and Solonchacks. The presence of these soils may affect the ground water quality. Therefore, they may limit the options for groundwater storage with good quality, and storage above ground may in these areas be preferred over groundwater storage. However, the effect of salinity varies greatly with the type of salts present, soil permeability, climatic conditions, and the kind of crops grown, therefore further research and local specification are recommended.

3R interventions with potential within Zone 5

Zone 5A soils with slow surface drainage

High potential for pans, and potential for run-off reduction (should be combined with the layer below the dots; where a potential is indicated with one of the crosses for zone 5A, it replaces the potential in the underlying zone).

Zone 5B saline soils

High potential for pans (better option that other in-soil interventions), and uncertain potential for shallow groundwater and run-off reduction/infiltration (should be combined with the layer below the dots; where a potential is indicated with one of the crosses for zone 5B, it replaces the potential in the underlying zone).

4.6 Zone 6 – Mountainous areas with slopes steeper than 10 degree

The areas with steeper slopes have at some points other potential than the rest of the mountain areas. The steep terrain may provide good options for valley dams, when the edges are steep, open water reservoirs with a good volume to surface ratio can be created, thus limiting the relative evaporation loss. However, when the slope of the streambed is very steep, the reservoir behind the dam will be relatively small, so good site selection is required. This also implies that the potential for sanddams with an appropriate volume is reduced compared to locations with less steep streambeds. At the steeper slopes erosion may be more pronounced, and interventions to reduce erosion like for example check dams or gully plugs may have a high potential. Reduction of the run-off velocity by contour bunds and terraces can be very feasible in these areas to increase the infiltration in these areas, and improve the possibilities for grazing areas and possible agriculture. In the 3R potential map the zones with slope steeper than 10° are indicate by a hatched area.

3R interventions with potential within Zone 6

Zone 6 steep slopes

Reduced potential for sanddams, extra potential for run-off reduction (should be combined with the layer below the hatch; the potential specifically indicated in zone 6 replace the potential in the underlying zone).

Figure 6 Stream on the slopes of mountains near Moyale Town

5 Conclusions and recommendation for use

Within Northern Kenya different zones with various characteristics have been found. Some areas are mountainous, while others are flat. Also the geology differs within the area, where basement rocks, sedimentary formations and volcanic formations can be found. The combination of the different characteristics determine which interventions may be suitable for the storage of water. Therefore, a methodology was developed in which generally available data were combined with the lessons from the fieldworks that were performed in the area. Based on this 5 different zones, most of which with subzones, were distinguished.

A map of the different zones is developed for Northern Kenya (figure 4). In the local reports for the four target areas (Acacia Water & IRC, 2013) a general overview of the interventions that can be considered in the different zones is given. This can serve as an inspiration for considering interventions outside the currently applied interventions within a region. For further inspiration in the boxes a number of examples from the visited target regions are included. These can serve as ideas which may also help to improve the interventions in other areas.

When examining a region, the map provided in this publication can serve as a guidance for the interventions to be considered. Nonetheless, it should be kept in mind that the provided maps are based on generally available data, which may be coarser than the fine heterogeneity in reality. Also within one zone variations can be expected, as is described in chapter 4. Not all interventions indicated as possibilities will therefore indeed be suited everywhere within the zones. The feasibility always needs to be checked with the specific local circumstances. The zonal maps can thus strengthen the area consideration and can be used as a practical starting point, but never to replace the area detailed local examination.

In the current approach much of the generally available data is used to determine the different potential zones. This is supplemented and verified with the information obtained from the fieldworks in four target areas spread over Northern Kenya. Hence, the current map is a state of the art product, which combines the available information and expert knowledge in an innovative way.

The approach can in future projects be exported towards other areas, and it can be further refined by adding extra analyzes and information. Therefore, recommended future research is the further analysis of satellite information, and field analysis of the zones which were currently not covered by the target areas.

Figure 10 Use of the 3R potential zonal map in the regional planning

The zonal maps are used as such a practical starting point in the local analysis for the KALDRR project in Northern Kenya. The landscape based approach strengthened here the results of the local surveys. In this project the 3R zonal map was applied in the following manners:

- As a guideline to think of alternative solutions. E.g.:
    - In the various regions it was noted that a centered water supply like new boreholes could cause problems such as a new concentration of people and overgrazing. The 3R approach provided decentralized alternative options for the water supply;
    - At some locations with saline water in the boreholes, subsurface and sanddam potential could be indicated to provide a water supply of better quality.
    - Floodwater spreading opportunities to extend the grazing areas were brought into vision in the Marsabit and Moyale target areas to reduce overgrazing.
- To support the identification the physically most efficient location for implementation. E.g.:
    - The implementation of pans was advised at locations with a good natural lining potential, because soil or rock types with a low permeability are present;
    - Proper locations for the sanddams and subsurface dams were selected in rivers with the correct type of sediment for water storage based on the appearance of basement (zone 1 & 2) or suitable other formations (zone 3A-D).
- To indicate specific locations with a high potential for 3R interventions. E.g.:
    - A sandriver containing natural barriers with a high potential for the application of sanddams was found in the Moyale target area. The communities in this area and the 3R potential were previously unknown to the implementing partner, and is now selected as one of the high potential pilot areas.
    - A preparatory study based on the zonal map, combined with for example satellite images, was shown to help to investigate remote areas, where the aid of organizations is currently less focused because of logistic difficulties.
- To indicate the upscaling potential of interventions and to extend local experiences to other areas. E.g.:
    - The well functioning pans found in the Moyale target area serve as inspiration for the improvement of existing and new pans in the rest of the areas;
    - Shallow groundwater storage, which was found along the seasonal rivers in the target areas may be applicable to more seasonal rivers in the Wajir and Moyale target area;
    - The identified potential for the application of subsurface dams in the Turkana target area can very suitably be extended over the edges of the investigated target area.

The zonal approach and the results for Northern Kenya presented in this document can, as illustrated by these examples, be beneficial for funding and implementing organizations. Additionally, the landscape based approach is recommended to be used by policy makers and coordinating bodies to evaluate and advice on planning. In the figure below the next steps of integration of the landscape based approach in planning are indicated. The information presented in this publication can be used as indication of the interventions that may be feasible within this area, and as an example of a feasibility phase that can help to target at the right solutions to increase the resilience to drought within a region.

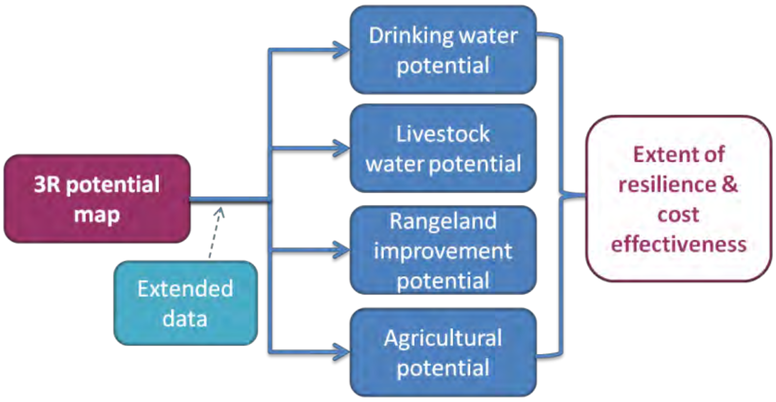


Figure 11 possible applications of the 3R potential map towards a landscape based, area integrated water resources planning and cost effective resilience.

6 Annex A Local example of the 3R potential map

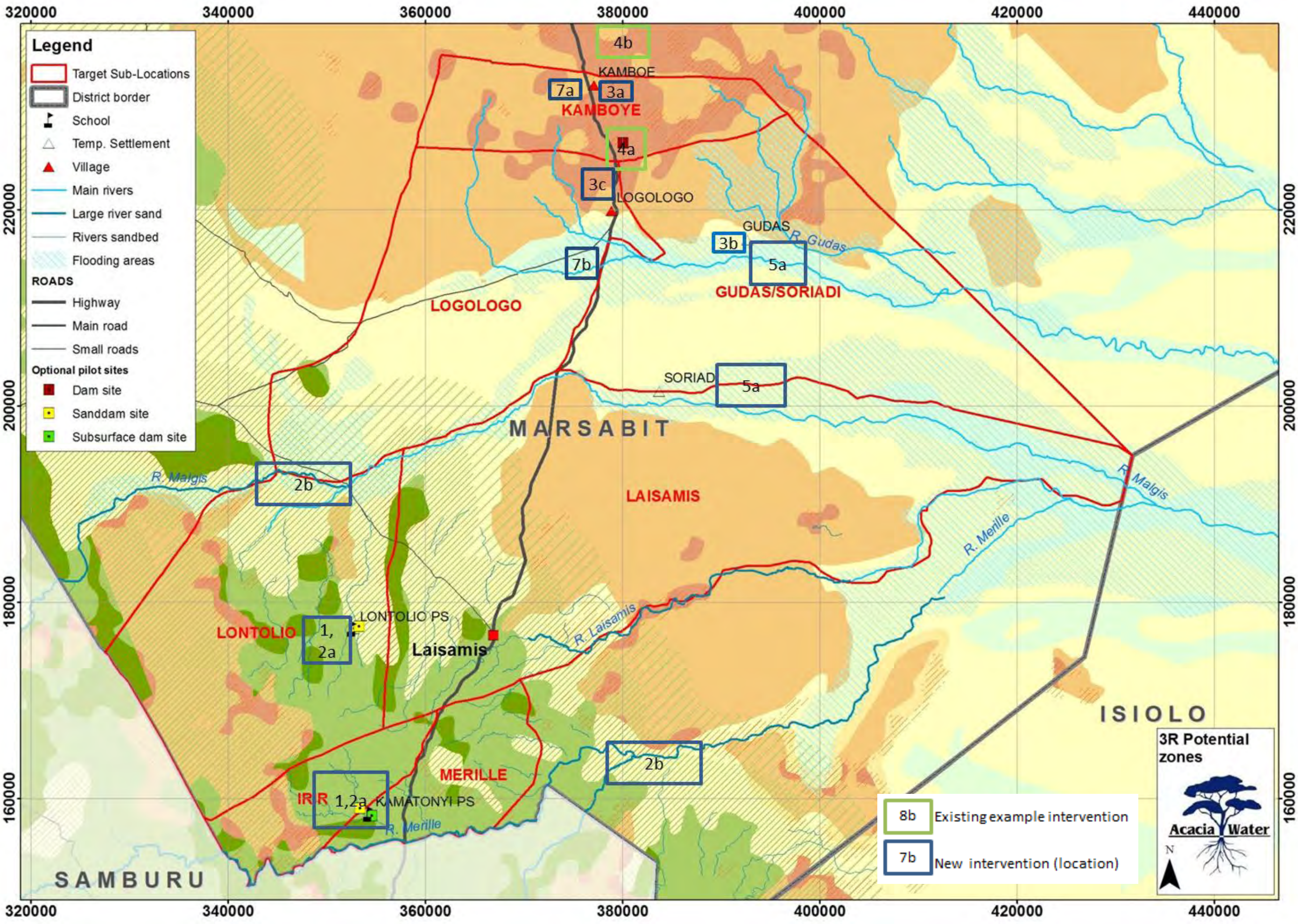


Figure A-1:3R potential zones in the Marsabit target area. The different colors denote the zones, the numbers the existing example interventions and examples of identified potential interventions.

3R Potential zones

Zone 1: Basement rocks

- 1A, mountains, low porosity, weathering products suitable for storage
- 1B, flat to gentle sloping, low porosity, weathering products suitable for storage

Zone 2: Lowlands near basement areas

- 2, buffer from basement (5 and 10 km) plane areas

Zone 3: Volcanic rocks

- 3A, mountains, low porosity, weathering products suitable for storage
- 3C, mountains, porosity and weathering products variable
- 3D, mountains, high porosity, weathering products unsuitable for storage
- 3B, flat to gentle sloping, low porosity, weathering products suitable for storage
- 3D, flat to gentle sloping, porosity and weathering products variable
- 3F, flat to gentle sloping, high porosity, weathering products unsuitable for storage

Zone 4: Sedimentary formations

- 4A, alluvium along rivers, variable permeability, potential for shallow groundwater
- 4B, sands and sandstones, variable porosity and storage potential
- 4C, variable sedimentary formations, varialbe permeability and storage potential

Zone 6: Areas with steep slopes

- 6, steep slopes (>10°)

Examples:

1. Rivers with sandbeds and shallow hardrock (Zone 1A)
2. Wide river bed with sandy sediments
   a. Underlain by hardrock and with rock barriers (zone 1A, 1B)
   b. In the sedimentary areas, within the buffer zone (zone 2)
3. Water pans preserved for specfic use
   a. Mainly for domestic use
   b. Mainly for livestock watering
   c. For road construction, in the future available for other uses
4. Open water storage opportunity's
   a. Volcanic craters
   b. Valley dams in pronounced valleys
5. Flooding areas
   a. River floodplains, with good grass
   b. Floodwater used for irrigation
6. Erosion reduction
   a. Gullies present on steep slopes
   b. Gullies eroding the road
7. Road water harvesting
   a. Water storage created by former road quarry
   b. Road causing floodwater spreading

7 Annex B Order of magnitude for storage capacity of 3R interventions

Each kind of intervention has its own typical storage capacity. In the table below an estimate of the order of magnitude of storage that is associated with different interventions in provided. This is order of magnitude is based on common storage capacities of interventions in the program area, but individual cases vary.

To estimate the amount of water that is available for water use, the losses from the storage also have to be taken into account. For example, pans can store relative large amounts of water (about 5,000-25,000m^3) however, the losses from pans are also substantial, about 5 mm/day is lost to evaporation during the dry period, which can add up to 1.5 m during a dry period of 10 months. Additionally, water is lost from leakage. When a good clay lining is available from the local material, the leakage can be limited. Nonetheless, still in that case the leakage loss can be in the order of 1 m/dry period or more. Therefore if pans are intended to be used for the full dry period an extra investment in proper lining (e.g. compacted lining, concrete or plastic lining) to reduce the water losses can be beneficial. Also the depth of the pan should be sufficient (>3-4 m), because otherwise most of the water will be lost to evaporation and possibly leakage. For the rest of the interventions we refer to the table below.

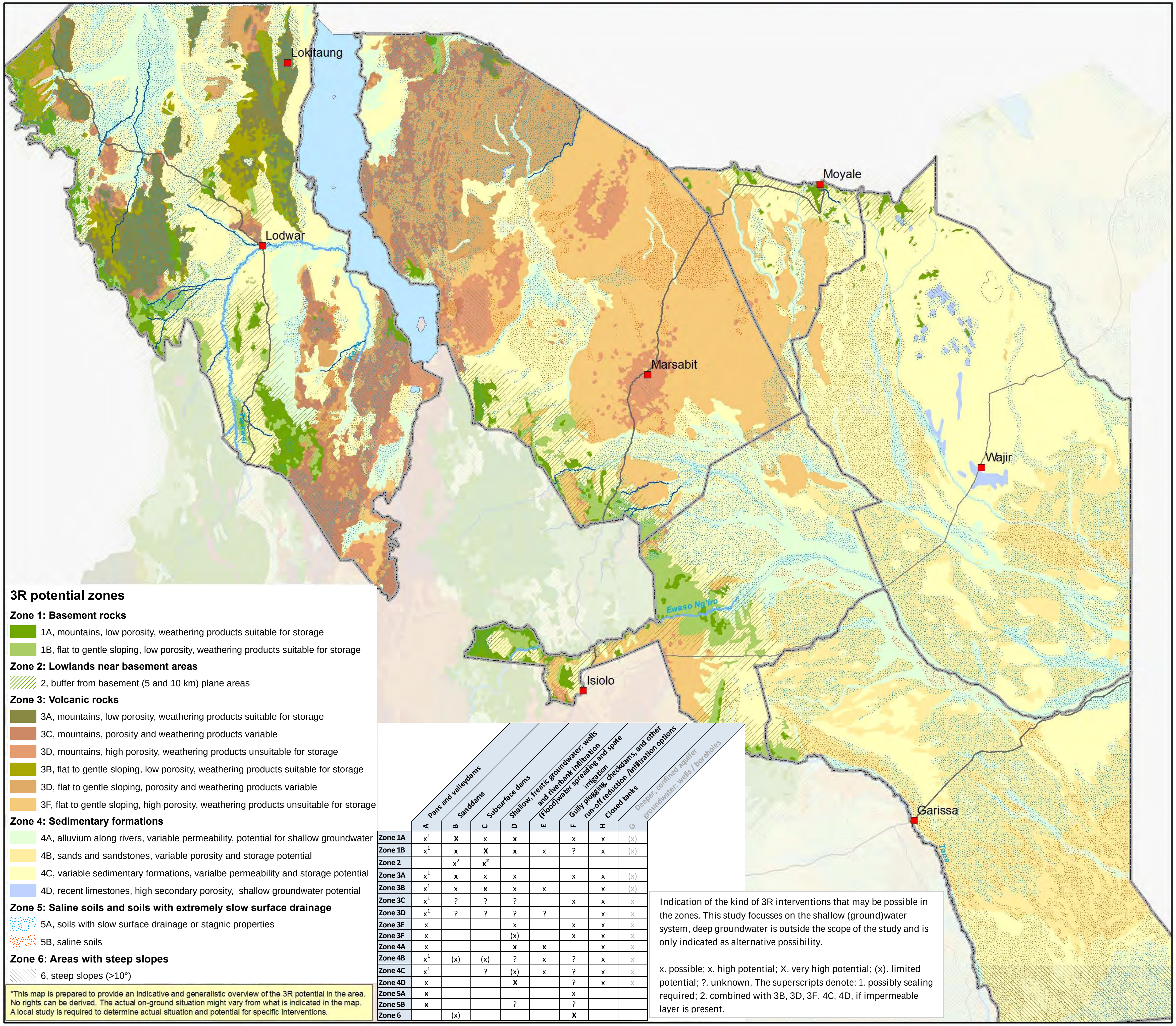
Table B-1: Global indication of the order of magnitude of the storage capacity and the losses associated with different interventions.

	Intervention	Order of magnitude of the storage capacity	Losses
A	**Pans and valley dams**	About 5,000-25,000 m3 in the pans Volume of retention valley dams depends of the elevation. E.g. 2,000,000-5,000,000 m3 could be stored in the reservoir proposed in Marsabit. From this volume the waterloss by evaporation should be subtracted.	Evaporation loss is about 5 mm/day. For pans of 3m depth this is about 50% of the volume. Leakage adds another loss, therefore locations with a good natural clay lining should be selected or concrete or plastic lining should be applied.
B	**Sanddams**	About 100-5,000 m3, depends on the steepness of the riverbed behind the dam. Since sanddams are mostly applied in elevated areas the storage is limited by the slope of the bottom of the reservoir behind the dam.	The evaporation loss is rather small. Leakage depends on the permeability of the layer on which the sanddam is based, this can be small in e.g. basement areas. Nonetheless, the efficiency loss can be tens of percent's.
C	**Subsurface dams**	1,000-30,000 m3 depending on the steepness of the riverbed, the depth of the impermeable layer and the width of the riverbed. 30,000 m3 can be achieved in flat riverbeds with a gradient of the bottom of the riverbed of < 1 promille	The evaporation loss is rather small. Leakage depends on the permeability of the layer on which the subsurface dam is based. This can be larger in e.g. the sedimentary areas. Therefore, depending on location of application the efficiency of sanddams may be somewhat smaller than that of sanddams.
D	**Shallow, phreatic groundwater: wells and riverbank infiltration**	Location dependent, depends on the aquifer characteristics	-
E	**(Flood)water spreading and spate irrigation**	See D, additionally, this techniques are often applied to create grazing grounds or to irrigate agriculture, rather than storing water.	-
F	**Gully plugging, retention weirs, and other run-off reduction/infiltration options**	Depends on the possibilities to retrieve the water (e.g. springs). Additionally, this techniques are often applied for erosion reduction and to create grazing grounds or agriculture, rather than to store water.	-
H	**Closed tanks**	Generally 5-200 m3, also depends on the amount of water to fill a tank. With e.g. rooftop harvesting this can be the limiting factor (a roof of 30m2 provides with 300mm rain 9 m3 of water).	When the tanks are properly constructed, the losses will be minimal. When the tank is filled, not all water may be stored, because the first flush may be excluded to improve the quality.

8 Annex C Large 3R potential map

General potential for 3R interventions for the MWA program area in Northern Kenya

Client: Millenium Water Alliance (MWA)
Project details: Kenya Arid lands Disaster Risk Reduction (KALDRR) - WASH Program



3R potential zones

Zone 1: Basement rocks

- 1A, mountains, low porosity, weathering products suitable for storage
- 1B, flat to gentle sloping, low porosity, weathering products suitable for storage

Zone 2: Lowlands near basement areas

- 2, buffer from basement (5 and 10 km) plane areas

Zone 3: Volcanic rocks

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- 3D, mountains, high porosity, weathering products unsuitable for storage
- 3B, flat to gentle sloping, low porosity, weathering products suitable for storage
- 3D, flat to gentle sloping, porosity and weathering products variable
- 3F, flat to gentle sloping, high porosity, weathering products unsuitable for storage

Zone 4: Sedimentary formations

- 4A, alluvium along rivers, variable permeability, potential for shallow groundwater
- 4B, sands and sandstones, variable porosity and storage potential
- 4C, variable sedimentary formations, varialbe permeability and storage potential
- 4D, recent limestones, high secondary porosity, shallow groundwater potential

Zone 5: Saline soils and soils with extremely slow surface drainage

- 5A, soils with slow surface drainage or stagnic properties
- 5B, saline soils

Zone 6: Areas with steep slopes

- 6, steep slopes (>10°)

*This map is prepared to provide an indicative and generalistic overview of the 3R potential in the area. No rights can be derived. The actual on-ground situation might vary from what is indicated in the map. A local study is required to determine actual situation and potential for specific interventions.

	A: Pans and valleydams	B: Sanddams	C: Subsurface dams	D: Shallow, freatic groundwater: wells and riverbank infiltration	E: (Flood)water spreading and spate irrigation	F: Gully plugging, checkdams, and other run-off reduction /infiltration options	H: Closed tanks	G: Deeper, confined aquifer groundwater: wells / boreholes
Zone 1A	x^1	**X**	x	**x**		x	x	(x)
Zone 1B	x^1	**x**	**X**	**x**	x	?	x	(x)
Zone 2		x^2	**x^2**					
Zone 3A	x^1	**x**	x	x		x	x	(x)
Zone 3B	x^1	x	**x**	x	x		x	(x)
Zone 3C	x^1	?	?	?		x	x	x
Zone 3D	x^1	?	?	?	?		x	x
Zone 3E	x			x		x	x	x
Zone 3F	x			(x)		x	x	x
Zone 4A	x			**x**	**x**		x	x
Zone 4B	x^1	(x)	(x)	?	x	?	x	x
Zone 4C	x^1		?	(x)	x	?	x	x
Zone 4D	x			**X**		?	x	x
Zone 5A	**x**					x		
Zone 5B	**x**			?		?		
Zone 6		(x)				**X**		

Indication of the kind of 3R interventions that may be possible in the zones. This study focusses on the shallow (ground)water system, deep groundwater is outside the scope of the study and is only indicated as alternative possibility.

x. possible; x. high potential; X. very high potential; (x). limited potential; ?. unknown. The superscripts denote: 1. possibly sealing required; 2. combined with 3B, 3D, 3F, 4C, 4D, if impermeable layer is present.

General 3R potenial zones based on physical landscape characteristics

Legend

- Major Towns
- Counties MWA Program
- Lakes
- Highway
- Main road
- Rivers
- Rivers with sand bed
- Perennial rivers

N

0 25 50 100
Kilometers

Prepared by: R.J. Visser
Date: 01-11-2013
Version: 5.0

Scale: 1:1,800,000
Paper size: A3

WGS_1984_UTM_Zone_37N
Projection: Transverse_Mercator
False_Easting: 500000,000000
False_Northing: 0,000000
Central_Meridian: 39,000000
Scale_Factor: 0,999600
Latitude_Of_Origin: 0,000000
Linear Unit: Meter

Acacia Water, www.acaciawater.com

Add data source:
- ASTER GDEM is a product of METI and NASA
- Geology adapted from OneGeology

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