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Report on Critical Biophysical and Socioeconomic Conditions for WH Adaptation

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Critical biophysical and socioeconomic conditions for WH adaptation
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1. Introduction

Outscaling of *suitable* water harvesting (WH) technologies has not *automatically* led to wide scale adoption. An agricultural technology working well in one place is not a guarantee for it to do well in another. Moreover, if conditions change over time, the technology might no longer produce the desired results. Programmes promoting *'success stories'* have to deal with this. The question of adaptation then arises: the technology has proven its usefulness but how can we ensure it will reliably perform also in other situations? What are the adjustments to be made? To what length should we go to boost adoption rates and prevent dis-adoption after the programme has gone?

The issue is discussed in this report in relation to the promotion of water harvesting (WH) technologies for rainfed agriculture in Africa. It reviews the critical conditions for widespread adoption and the consequential adaptation needs.

The WAHARA project[1] studied sixteen water harvesting (WH) technologies in Burkina Faso, Ethiopia, Tunisia and Zambia (Table 1). A description of the study sites and their WH potentials is given in WAHARA reports 3, 4, 10, 24, 25 and 26 (Ouessar, Sghaier, Zaied, & Abdeladhim, 2015; Ouessar, Hessel, Sghaier, & Ritsema, 2013; Ouessar, Hessel, Kirkby, Sghaier, & Ritsema, 2013; Kaushali & Fleskens, 2015; Arbi, Sghaier, & Ouessar, 2015; Nega & Woldearegay, 2015 respectively).

Putting the potential of these technologies in a larger perspective, this report evaluates the results from the four study sites in addition to information from other experiences to assess the flexibility of WH technologies to perform under different circumstances. It looks at both biophysical and socio-economic aspects of adaptation and concludes on the technologies' scope of application.

Table 1. Water harvesting technologies evaluated at the four WAHARA study sites

Burkina Faso	***Ethiopia***	***Tunisia***	***Zambia***
Zaï in combination with compost manure and micro-dosing	Series of hillside cisterns with bench terraces	Jessour	Ox-drawn Magoye ripper
Stone lines	Percolation/sediment storage ponds with hand dug wells	Gabion check dam	Ox-drawn strip tillage
Magoye ripper	Check dams	Tabia	Ox-drawn zero tillage with the GART planter
	Soil improvement methods: mulch, compost, EM (Effective Micro-organisms)	Cistern	
		Recharge well	
		Zaï	

2. Adaptation

Adapt to stay resilient

Adaptation is the innovative process of adjusting to changed or changing circumstances.

Circumstances may alter over time. For instance, farmers may be experiencing more variable rainfall over the years or an increase in droughts. Or, they observe that land degradation is causing their yields to decline. These external changes will *push* them at some stage to adjust the way they farm, in order to stay afloat. There are also *pull* factors reshaping the agricultural playing field such as new

[1] http://wahara.eu/

marketing opportunities and the introduction of improved crop varieties or mechanisation options that entice farmers to adapt their farming system so they will benefit from them.

Besides changes in time, also different locations and applications alter the circumstances, requiring doing the same things differently. For instance, when introducing a successful technology from somewhere else or for a different purpose, one cannot expect it to perform in the new situation just by copy and paste; some adaptation will be unavoidable.

In response to such changes, farmers will try and secure their livelihood. They pull through by merely staying afloat. Or, perhaps more ambitiously, they manage to make the farm more productive (increase its buoyancy through growth). Working within their means, they seek to strengthen their resilience as they prepare for or respond to calamities, exploit opportunities, make an existing technology work better, apply an existing technology for a different or an additional purpose or introduce a foreign technology and make it work.

Adapting should be worth it

Adapting doesn't come easily. People change their behaviour only if and when they really have to. Game changing decisions concerning one's livelihood need strong incentives. Farmers deliberately weigh their options before deciding to change. Scarcity of resources makes them risk averse; reducing if not preventing risks is always one of the highest priorities. Being poor toughens that attitude. According to Reij & Water-Bayer (2001), innovation finds fertile ground when farmers find themselves with no other options left, if their backs are against the wall.

Assuming that the possibility to change (a technology, a working method) is there, farmers go for it, according to the CIMMYT Economics Program (CIMMYT, 1988), but only if convinced that it will give them an acceptable marginal rate of return. Fifty percent if the new technology is for instance a simple adjustment of something farmers already know. The minimum acceptable rate of return increases if the technology requires farmers to learn new things. Recommending a technology with a rate above 100% seems generally safe. In other words; for every extra euro invested in the adaptation, a farmer wants that euro back plus an additional 50-100 cents, as a minimum. For cycles longer than 4-5 months or to compensate for learning periods, a proportionally higher profitability rate would be required.

3. WH adaptation

Adaptation in the context of this report is meant to be the innovative process of farmers making novel water harvesting concepts work for them, or making existing ones work better or respond better to changing working conditions. The report focuses at the conditions that make available WH technologies adaptable for changing situations, hence provide scope for WH outscaling.

A good adaptability of WH technologies is critical for their outscaling potential and robustness to function under altering working conditions. WH adaptation should help productivity increases in African rainfed agriculture to come about quickly enough and make them last long enough. The subject is significant in the light of WH's obvious usefulness; a strategy for farmers to build resilience under various situations of increasing water scarcity.

Underused potential

Water availability for farming is fundamentally changing in Africa under the pressures of climate change, progressive degradation of natural resources, population growth, urbanisation, economic development and perpetuating poverty. This mix of forces is cause for disaster as well as creating opportunities for agricultural progress. In any case, it demands -among other things- adequate technological responses that prove their value quickly. WH systems linked to technologies that make more productive use of the water would make sense for an abundant -and increasing- number of farmers. The list of proven, often ages-old WH technologies is long and there is a vast and enduring amount of knowledge and experience about a broad range of useful applications (e.g. Ackermann, Schöning, Wegner, & Wetzer, 2012; Critchley & Siegert, 1991; Dale, 2010; Glotzbach, et al., 2011; Inocencio, Sally, & Merrey, 2003; International Rainwater Harvesting Symposium 2015, 2015; Liniger & Critchley, 2007; Prinz & Singh, 2000; Reij & Steeds, 2003; Rockström, Hatibu, Oweis, & Wani, 2007; Steenbergen, Tuinhof, & Knoop, 2011; Thomas, 1997; Wani, Rockström, & Oweis, 2009).

However, the number of people actually applying WH is a lot less than one would expect, bearing in mind the extensive evidence of its applicability. In sub-Sahara Africa the adoption of sustainable land management (SLM) practices, which includes WH, is still alarmingly low (Liniger, Studer, Hauert, & Gurtner, 2011; Sietz & Van Dijk, 2015). In-situ WH technologies are the most widely practised and straightforward in terms of know-how, capital and organisation, however not securing enough water in case of extreme drought (Falkenmark, Fox, Persson, & Rockström, 2001). WH solutions that are suited to buffer large quantities of water accessibly for later agricultural use such as during serious droughts need larger scale ex-situ civil engineering works involving higher investments and being more complex.

The interest to promote WH is growing among African governments and donors and they have many examples to learn from, including a vast WH expertise from India and China as well (Falkenmark, Fox, Persson, & Rockström, 2001).

Adaptation capacity

Recognizing that water harvesting for rainfed agriculture works where it is used, it is still a question how *replicable* the technologies are. This goes beyond their strict technical designs; the *adaptation capacities* of the (intended) users of the technologies largely determine the technologies' replicability. It requires flexible WH designs but also flexible working environments.

In fact, adapting WH technologies may be complex, as illustrated by these common situations:

- WH adaptation is not easy if specific WH solutions were developed to match specific situations (Glotzbach, et al., 2011). For instance, the expectations to expand a traditional technology to neighbouring locations probably should be modest if the tradition didn't spread already. While doing a magnificent job, such a WH technology may look convincingly efficient in its simplicity and consequently easily promotable. However, some of them have been fine-tuned over time to suit unique local conditions or were needed as a way out under different socio-economic conditions, so in fact may not be easily replicable. Nonetheless, the WH principles applied in these specific WH solutions are universal, so important lessons can be learnt from them. In case of an ancient WH concept, modern technologies and construction methods may be exploited
- A WH technology is a necessary but not a sufficient solution. More often than not, a WH technology solves only part of the problem so requires additional measures. Often one or more WH technologies are integrated to be (more) meaningful. Spate irrigation systems such as jessour and tabia for example need to be accompanied by measures that facilitate productive use of the diverted water, such as in-situ WH technologies. For labour-intensive terracing to be worthwhile, securing water to mitigate dry periods may be required, e.g. by placing (and filling up) cisterns, as well as soil health enhancing measures such as mulching and fertilizing. Similarly, ox-drawn strip and zero-tillage are uneconomical if not accompanied by adequate weed control measures and the use of manure or fertilizer. Another example is the situation whereby a variety of WH technologies need to be

combined at different strategic places in a watershed to achieve one desired WH result, e.g. to raise the groundwater table in the valley sufficiently for crop production to thrive

- In rainfed smallholder farming in Africa, adoption of a technology is driven by a broad mix of complex and unpredictable factors and depends largely on the conditions at micro level (field, farm, household, local community). This aspect may be the biggest stumble block for the outscaling of essentially sound WH technologies. Sietz & Van Dijk (2015) emphasize that the adoption of soil and water conservation is substantially influenced by small-scale differences in bio-physical and market conditions. Fundamental to the problem are the many pressures that come with poverty; they cause farmers taking decisions that sometimes look haphazard and even counterproductive. Despite the farming households being remarkably innovative under the circumstances, having to work in harsh natural and social conditions with extremely few assets and little information and services substantially downgrades their freedom to choose and constantly forces them to look for stopgaps for immediate basic needs. It is cause for a perpetuation of insufficient production results, which keeps many trapped in poverty

Largely as a result of the previous point, farmers adopt a technology quite differently from each other as well as over time. Sietz & Van Dijk (2015) point to the highly dynamic nature of adoption. Seldom, the farmers can simply be grouped into adopters and non-adopters. Rather than *fully* adopting, a farming household may decide that it is better for them to adopt the new technology only *partly* (i.e. part of the technology or only on part of the farm), or to adopt *in steps.* Or, adoption is *delayed*. Perhaps at some stage farmers (partly) *dis-adopt*, some of whom thereafter may decide to (partly) *re-adopt*. WH technologies that were designed with this in mind may be easier to accept.

Complementing to the general knowledge about which WH technologies do well in principle, more detailed biophysical and socio-economic information is needed about how precisely to adapt a particular WH technology for it to actually work sustainably in a specific situation. It should include facts about the *economics* of the WH technology, both in monetary and non-monetary terms. This information is still rudimentary (Liniger, Studer, Hauert, & Gurtner, 2011; Giger, Liniger, Sauter, & Schwilch, 2015). The Addis Ababa Declaration *Unlocking the Potential of Rainwater* (International Rainwater Harvesting Symposium 2015, 2015) called on scientists to develop methods for quality control and replicability of rainwater harvesting products. Sietz & Van Dijk (2015) miss the necessary attention for the great diversity of local farming situations in soil and water conservation adoption studies. So, a bigger effort in adaptive and localised research will be required, and which encompasses the integration of indigenous and location-specific knowledge, benefit-cost analyses and natural resource management.

Meanwhile, based on the currently available knowledge and means, practical action should be directed towards the intended WH users aimed at strengthening their adaptation capacity. Critical are to:

- Educate farmers and their service providers (and this should include information sharing among and with them) about the technical and organisational details and implications of WH technologies that have proven their value already
- Facilitate these stakeholders in all necessary ways to strengthen their position as professionals in agricultural supply chains in which they can make a decent income.

Figure 1 and Table 2 illustrate this last point and the fact that as any other technology, WH is not a silver bullet. For investing in WH to be meaningful a minimum of other critical conditions for productive farming should be met through the ownership of good quality farming assets and access to reliable services. So, WH is a tool or a service among other necessary tools and services that together form a hopefully effective, rewarding, sustainable and climate smart farming system.

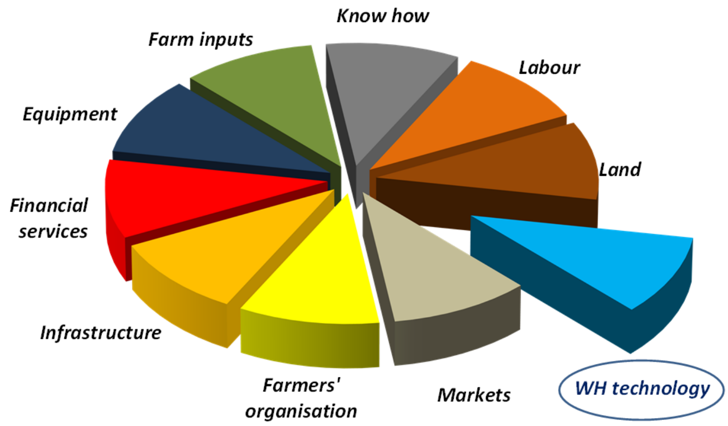


Figure 1. What farmers need

Table 2. Some major issues concerning farmers' access to key production assets

Assets	Issues in key words
Land	Secure land tenure, shortage of farm land, sustainable land management, soil health
Labour	Shortage of labour in peak periods, drudgery of female farmers in particular, access to farm power and mechanisation
Knowhow	Training and extension services, up-to-date information, farmer-to-farmer learning, field demonstrations, farming for business skills
Farm inputs	Availability of agro-dealers, farmers' access to seed, fertilizer, lime, herbicides and pesticides, Knowhow about inputs, quality seed
Equipment	Access to and knowhow of appropriate farm tools and equipment and maintenance services, reliability of equipment
Financial services	Financial literacy, access to loans, insurance, banking services
Infrastructure	Feeder roads, rural electrification, radio, mobile telephone, internet, conducive legal framework and law enforcement
Farmers' organisation	Smallholder representation and lobbying, agri-business groups, bulking centres, group governance and business management skills
Markets	Market facilities and services, marketing information, transport, access to formal markets, marketing skills
WH technology	Improved ground water levels, access to water for irrigation and livestock, water quality, protection against flooding, affordable and locally manageable WH facilities

Part of a holistic adoption process

The easier it is for farmers to adjust a WH technology to their needs and preferences, the quicker they will accept it and the more widespread and sustainable it will add value in areas where it matters most. Useful features of a technology from a farmer's point of view, and important in the light of effective WH adaptation, are for example:

- The technology is labour friendly; not prohibitive in additional labour requirement during peak periods of labour demand, not adding unacceptable drudgery, considerate for both genders' specific responsibilities in and off the farm
- The benefits, e.g. increased crop yields, are considerable, but also instant and consistent
- The farmers have ownership of the technology (individually, as a group or as a community)
- The technology is easy to apply and can be managed and maintained preferably at individual, i.e. farm level, or otherwise in small groups within a community

- The technology is replicable and flexible, i.e. it can be used widely on the farm, such as on different fields and possibly even for different applications
- The material requirements are accessible and affordable
- The farmers are well-informed and provided with technical guidance
- The technology integrates well with existing or other newly introduced practices, and enhances overall impact
- The technology comes with incentives (e.g. a programme not only helps a farmers' group to build a dam but also facilitates access to vegetable markets) or has multiple benefits (e.g. the water held by the dam can irrigate vegetables that are easily marketed, but also be used for drinking water for livestock, and for washing.
- The technology has the community's blessing, e.g. if:
    - Many other farmers can apply it too (thanks to the technology's replicability)
    - The community benefits as a whole (e.g. introduction of the technology is likely to enhance a community's overall development or has important spin-offs, such as more equitable access to water, sustainable use and possibly better quality of the water, creation of new job and market opportunities)
    - The people are quickly familiar with the technology, if it is for instance based on indigenous knowledge and not interfering prohibitively with local customs, hence reducing fear of the unknown and making sense quickly of how to do things
    - Habits can be changed and conflicts be prevented or mitigated (e.g. communal grazing can be changed into controlled grazing or cut and carry feeding systems).

So, there are individual farmer's preferences as well as communal ones, both kinds of which a farmer will have to consider. Male and female farmers will view the above points differently. Hence it is important to look for solutions that promote *gender equity*.

Recent strategies emphasize the need for a more holistic approach, including consideration for market, policy and institutional incentives for farmers and a more integrated natural resource management (Shiferaw, Okello, & Reddy, 2009) as well as a better *appreciation* of indigenous solutions (Critchley, Reij, & Willcocks, 1994). Shiferaw, Okello, & Reddy (2009) emphasised the importance of a menu of options developed with the farmers rather than a one-size-fits-all solution, due to the fact that these technologies mostly are site and even farm specific. They observed the need for innovation-based farmer participation as an iterative process for adaptation and outscaling of soil and water conservation technologies. Text box 1 highlights an example from Zimbabwe by Mukute (2015).

In an attempt to give direction to policy implementers, Reij & Steeds (2003) provided some pointers for success of investing in dryland agriculture (i.e. in semi-arid and sub-humid areas), both from an individual farmer's and a rural community's perspective. Noting that most of the pointers were actually not specific to drylands, they recommended:

1. Invest in simple on-farm water harvesting techniques in drylands as they tend to produce *immediate* benefits
2. Ensure that public investment supports private investment in water harvesting
3. Invest in agricultural research, which makes use of local knowledge as well, as it pays for the innovations needed to cope with continuously changing production conditions and market opportunities
4. Integrate the farmers' capability to innovate in agricultural and natural resource management programmes
5. Enable farmers to freely respond to market opportunities
6. Invest in rural roads (and connectivity in general) to reduce transaction costs and facilitate access to markets

7. Facilitate local communities and land users in sustainable management of the farm land and other natural resources
8. Strengthen diverse rural livelihoods (beyond just farming)
9. Promote rewarding saving and effective credit systems (but only in *buoyant* markets).

Basically, an evidence-based and market-oriented approach is advocated for that mobilizes local knowledge and ownership as well as straightforward on-farm technologies. The pointers provide valuable guidelines for strategizing WH adaptation.

Scope of application

In-depth knowledge about the local water issues and its causes and conditions, complemented with information about what a particular WH technology potentially can do, give insight in the WH technology's adaptability and scope of application:

- It provides information if and how well the technology will work under different conditions, i.e. in other locations, for other applications and under changing conditions over time
- It shows what to change (and what not) and helps to understand how this should be done. Changes may be needed in the technology's design, in the working environment, or in both.
- It assists in comparing the technology with others on suitability for a particular situation and the potential scale of adoption.

Equipped with such knowledge, all those involved in planning and implementing of WH at different levels of intervention and for different scales of WH (farmers, civil society organisations, extension personnel, researchers, authorities, national governments, rural/agricultural development agencies and other public and private support services), should be able to deal with adaptation issues efficiently and effectively:

- During (pre-)selection of WH options, to compare them and remain with one or more that are highly likely to

Text box 1. Example of gradually expanding farmer-driven WH adaptation (Source: Mukute, 2015)

In 1976 former employee Bouwas Mawara and his wife Nyengeterai, a shopkeeper, returned to their farm in Zvishavane, a semi-arid area in Zimbabwe. The farm consisted of a low-input garden watered from a manual well, fields that couldn't feed them year-round and some cattle that were too weak to plow. When soon the well ran dry, they began experimenting with WH. They started experimenting by digging a few trenches dead level along the contour to trap and store run-off. It was a fundamental diversion from the practice promoted by the government of contour ridges laid out under a slight slope to drain run-off away from the field.

By 1986, the couple had transformed all contour ridges on the farm into 85-320 meter long zero degree contours. Over the years they also widened and deepened the trenches (to 2 meter wide and 2 meter deep) so they could capture more water. Other adaptations were the construction of small cross dams in the trenches to retain water as in ponds, the introduction of fish in these ponds, which is less labour intensive than crops, as well as the installation of locally made clay pipes between the contours to transfer water to where it is needed.

In so doing, they managed to turn around the subsistence farm into a thriving system of two crops per year, fruit trees, and a herd of 70 cattle. They introduced relay cropping allowing harvesting two or three times per year from the same plot. They started to produce fodder for livestock and used the manure and crop wastes to fertilize the fields. Maize production increased from 1 ton/ha to 5 ton/ha.

The family became food and nutrition secure and started to have surplus production for income even during Zimbabwe's worst drought of 1992. They invested some of it in the cattle, a decent house and education of the children. The women on the farm were empowered as they could diversify into cash crops of their choice (groundnut and finger millet), of which the sale and income remained under their control and allowed them to invest in even higher value commodities such as chicken, goats and cattle.

The increased water levels benefited the whole community as neighbours in need came to collect water and some of the harvested water is released in streams and has also recharged the ground water.

*Bouwas and Nyengeterai have been actively sharing their innovating WH experiences and stimulated other innovators. With some of them they set up the Hupenyu Ivhu (*Life is Soil*) Farmer Innovators' Group in 1989. Adapting WH to different ecological conditions and producing for a market were key elements. Women were active WH adopters. The group, which at its peak had 550 members in three districts, is still functioning despite the harsh economic and social problems of late.*

provide an acceptable solution

- In a feasibility assessment, to resolve whether a WH technology can be made suitable for a given situation or by how much its performance could be enhanced
- When planning how to apply an in principle feasible WH technology, to assess what would need to be adapted and how to go about it to make it actually perform as envisaged
- During implementation of the chosen WH system, to validate the plan and fine tune or overhaul it based on the feedback.

The following outlines a variety of reasons for WH adaptation in rainfed agriculture and different ways to do it:

1. Use WH for adapting to changing conditions over time:
    - To become more resilient against new threats, e.g. introduce WH to adapt to more unpredictable rainfall. Critchley & Siegert (1991) observed that sometimes a design needs to be modified to incorporate safety measures, such as cut-off drains, to avoid damage in years of excessive rainfall
    - To exploit new opportunities, e.g. increased demand for agricultural produce justifies investing in WH

2. Adapt a proven WH technology from somewhere else, e.g.:
    - In Tunisia, farmers who moved from the mountains brought their knowledge about the jessour and adapted this floodwater irrigation concept for use in the less steep foothills where they had settled. The adapted version, dubbed tabia, has additional lateral bunds and sometimes a flood diversion (Mekdaschi Studer & Liniger, 2013)
    - Farmers in Burkina Faso aimed to mechanise the successful zaï system which is based on manual labour, so quite drudging. In demonstrations facilitated by WAHARA, they observed that the ox-drawn Magoye ripper from Zambia could provide the answer. However, it needed to be adapted to fit on their type of tool frame and made suitable for pulling by donkeys or a horse

3. Adapt a WH technology for a different application, e.g. for:
    - *A different purpose*. E.g. zaï adapted from its common use in crop production to producing trees (zaï forestier); whereas on cropped land, the zaï planting pits are only 20 cm in diameter and 15 cm deep, for reforestation they need to be 100 cm wide and 50-70 cm deep. Another adaptation would be the use of pickaxes and steel bars to dig the pits as zaï forestier is recommended to rehabilitate severely eroded laterite soils, which are often very hard (Sawadogo, Yazew, Chomba, & Ouessar, 2013) and where hoes, commonly used for digging zaï on annually cropped fields, wouldn't do
    - *An additional application*. E.g. adapting the design of an irrigation pond to make of the water accessible also for livestock. The reason to make the pond more versatile can be for instance to make it more productive or to create a wider acceptance for introducing the pond in the community

4. Adapt a WH technology to work (better) under local conditions or to facilitate its uptake by local farmers, e.g.:
    - Prevent a too narrow inter-space between contour bunds on land where farmers have mechanisation and need to manoeuvre with oxen (Dale, 2010)
    - In the tabia system, adapt the length of a diversion dyke so the natural water collection area effectively becomes bigger, and possibly construct flood water

diversion dykes to capture water from nearby flood streams if they do occur (Mekdaschi Studer & Liniger, 2013)

  - Consider increasing the height and/or number of check dams in a gully, depending on the local water needs, the amount of water in-flow (i.e. more water available to retain), the gully profile (i.e. a deeper gully enabling a higher maximum water level behind the retaining wall, and a longer gully allowing for more dams) and down-stream water needs (i.e. enough water remaining available for requirements further down and possibly reduced siltation and improved water quality)
  - On slopes that require controlled drainage of excess water after heavy showers, lay out bunds (Dale, 2010) or permanent tied ridges (Elwell, 1993) under a slight gradient (about 1%) rather than along a dead level contour
  - In semi-arid southern Zimbabwe, farmers experiencing increasing drought problems decided to maximise water harvesting in their fields by laying out dead level contour ridges rather than respecting a 1% gradient as used to be promoted by the government (Mukute, 2015 – see Text box 1).
  - In Ethiopia it was observed that when stone bunds were introduced as a land and water conservation measure, land users made them bigger as they preferred larger stone walls capable to withstand pressures from livestock and other farming activities (Dale, 2010)

5. Combine WH technologies for added impact, such as:
  - The WH technologies studied under WAHARA in Ethiopia, each of which have their role in a different part of the drainage basin; when used in combination the overall WH impact improves more than can be achieved with all of the technologies acting separately
  - Mulching is a useful WH and soil management technology but may be not effective enough unless practiced with one or more other techniques such as terracing, ridging, conservation tillage and half moons
  - Apply zaï, trash lines or ridges in combination with stone bunds to maximise their joint impact and minimise damage to these WH structures by occasional downpours
  - Alternate soil bunds with fanya juu, which are more costly and laborious to make, for faster terrace formation and to adapt better to varying slopes (soil bunds being more suitable on steeper parts of the slope and fanya juu on more gentle parts). Fanya juu terraces (with ditch below the bank) are also better able to keep out cattle (Dale, 2010)

6. Make the local conditions conducive for WH development, e.g.:
  - Strengthening agro-input supply, creating access to finance, mechanisation and markets for small-scale farmers, and securing land tenure, are good agricultural strategies in general, creating an environment that motivates people to invest in more productive farming technologies, including WH technologies
  - A process of sensitization and information exchange will help to get the number of farmers required for a feasible rolling out of a WH technology before a choice of technology and an approach can be decided upon with the intended beneficiaries
  - For the introduction of promising but novel macro-level WH technologies affecting the community, sensitise the public about their usefulness and help them overcome their initial reluctance through consultation, information and transparent and responsive planning
  - Adaptation of policies, development plans and budgets and local organisational structures, such as policy support and regulation introduced to strengthen equal share of WH benefits in the community (e.g. water use rights)

- Training of people in the community to participate in the construction works
- Improve marketing facilities for farmers such as helping them to build and run commodity bulking centres, strengthening their marketing skills and facilitating their affiliation to representative producer groups, so that WH investments can be profitable
- Facilitate the farmers' access to credit for procuring productive farm inputs such as fertilizer and hybrid seed of high value crops, so to make the use of often laborious in-situ WH interventions more viable

7. Adapt a different technology to function for a WH purpose, e.g.:
    - The Magoye ripper was originally designed in Zambia as an improved seeding concept alternative to planting behind a plough. As farmers observed that it also improved water conservation in the field, it was later used to promote conservation agriculture and water harvesting on sloping land, and subsequently the implement's design was adapted with a focus on better water infiltration

8. Introduce a different technology to work in tandem with a WH technology to improve overall impact, e.g.:
    - Complement WH with a more productive farming approach, involving more intensive use of farm inputs (hybrid seed, cover crops, manure, compost, lime, inorganic fertilizers and pesticides) and more valuable crop types, irrigation and mechanisation, as they should help making the increased available water more productive. For instance, Hurni, et al. (2015) estimated for Ethiopia potential crop production increases over a 30-year period for combinations of two land and water conservation scenarios (keep as is and extended to all crop land above 8% slope) and two fertilizer application scenarios (maintain as is or extend to all crop land); see Table 3. It shows that extending the land and water management structures alone would prevent a 5% decrease of crop production over time, whereas extending fertilizing alone would be responsible for a 3% increase (so a 8% difference). However, there is a bonus for combining the two extension scenarios; not a difference in production of 5+8=13% but a bit more; 15%.

Table 3. Estimated crop production increases for Ethiopia after 30 years for different scenarios (Hurni, et al., 2015)

	Maintain fertilizing on currently fertilized crop land	*Extend fertilizing to all crop land*
Maintain current distribution of land and water conservation structures	-5%	+3%
Extend land and water conservation structures to all crop land steeper than 8%	0	+10%

9. A WH technology causes (planned) improvements of the landscape that enable more productive uses of the land, e.g.:
    - Terracing can be seen as a further development beyond simply demarcating fields by bunds; the fields themselves are treated. The levelling of their original slope will prevent run-off to gather speed, increase infiltration and on (steep) hill sides it will create a larger surface to cultivate. This process was observed in Ethiopia to occur 'automatically' with stone and stabilised soil bunds well taken care of; they silted up in a number of years and effectively turned into bench terraces. The resulting more gentle slopes allowed for crop cultivation where otherwise this would be too risky (Dale, 2010)

- Also in Ethiopia, the results from the WAHARA study site demonstrated that the strategic combined use of different WH interventions at different places in the watershed resulted in a significant strengthening of several eco-system services; e.g. increased vegetation and wild life diversity, reduced erosion, and more and easier accessible water for household use and agriculture and possibly reduced occurrence or intensity of flooding (Woldearegay, et al., 2015b).

4. Adaptation experience from the WAHARA study sites

Some experience on adaptation of WH technologies was reported from the study sites. In addition to locally known technologies, the use of the Magoye ripper from Zambia was tested in Burkina Faso and the Zaï technology from Burkina Faso in Tunisia as well as.

Selection criteria for WH technologies

The technologies (listed in table 1) were selected in local stakeholders' meetings from a range of WH technologies that are described in WAHARA report 16 (Sawadogo, Yazew, Chomba, & Ouessar, 2013). They were chosen based on their current or expected importance for the area following agreed criteria and priorities. The procedures of this participatory selection approach are explained in WAHARA report 17 (Sawadogo, Hessel, & Ouessar, 2013) and the results presented in report 18 (Sawadogo et al., 2013) as well as specifically for Tunisia also in WAHARA report 14 (Arbi, Ouessar, & Sghaier, 2013) and for Ethiopia in MU WAHARA team (2013) and WAHARA report 15 (WAHARA Research Team of Mekelle University, 2013). The stakeholders agreed on the criteria and their relative importance (Table 4). For Zambia, no ranking was reported (apart from the decision that only in-situ WH technologies could be selected for project budgetary reasons).

Table 4. WH technology evaluation criteria as agreed by the stakeholders at each study site
(Source: Kaushali & Fleskens, 2015)

Criteria rank	Burkina Faso	Ethiopia	Tunisia[a]	Tunisia[b]	Zambia
1	Improve yield	Improve productivity	Conserving water & soil	Increasing crop yields	*Not clear*
2	Increase biodiversity	Protect against erosion, increase arable land and reclaim plantation	Conserving biodiversity	Increasing farm income	
3	Give income	Adaptable and socially acceptable	Groundwater recharge	Construction and maintenance costs	
4	Crop diversification	Profitable	Increasing crop yields		
5	Improve water availability	Beneficial to females and youth	Increasing farm income		
6		Adaptable to different ecological conditions	Unemployment reduction		

[a] Based on environmental, economic and social criteria; [b] Economic criteria only

Improved crop yields were higher ranked than improved income, which may reflect a priority for food security rather than monetary income. Remarkably, together with improved crop yields, environmental criteria (biodiversity, reduced soil erosion) appear among the top priorities. Possibly this recognizes the stakeholders' awareness of their great dependency on natural resources.

Results from the study sites

The following information from the study sites was reported in WAHARA reports 28-30 (Woldearegay, et al., 2015a, Ouessar, Sghaier, Zaied, & Abdeladhim, 2015, Woldearegay, et al., 2015b):

Burkina Faso

- The adapted Magoye ripper from Zambia is a solution to the request by farmers to mechanise the popular zaï system, which is based on manual labour
- Use of soil fertility improving measures (compost and micro-dosing of fertilizer) made zaï more effective
- The combination of the use of improved seed varieties, soil management and supplementary irrigation from run-off water collected in dug ponds (banka) proved most gainful
- Access to seed of the right crop types and varieties is important (as demonstrated by the improved cowpea varieties tests in combination with zaï and appreciated by the women involved).

Ethiopia

- Pulling together the resources of different organisations (logistics, finances, expertise) enabled to realize the costly and involving WH works. The same cooperation is likely to facilitate further outscaling of WH. It also facilitates the uptake of research results as development organisations like to work and learn from researchers. However, there is still lack of knowledge how best to link research and development. The stakeholder workshops for information sharing and selecting WH technologies played a useful role in this regard; researchers not only could mobilize the all-important participation of the locals, but also received extremely relevant knowledge from them
- The design specifications of bench terraces, check dams and percolation ponds were adapted based on feedback from the field
- A combination of WH technologies (trenches, bench terraces, check-dams, afforestation) is most effective to harvest water in an entire watershed
- WH technologies other than bench terraces can be important to make the costly terraces profitable. While bench terraces reduce run-off, so help recharge the ground water, the generally dry conditions require a suitable alternative water source
- Bench terraces are a way to create new agricultural land in places where this is scarce, and is important for employment of notably the youth. However, the costs involved for constructing the terraces requires them to become productive. Hence the need for productive farm inputs and high-value crops grown intensively (fruit trees and vegetables allowing for multi-level cultivation) as well as a guaranteed water supply. Although the terraces reduce run-off and are instrumental in ground water recharge, the cropping system required supplement moisture, which was realised with water tanks (cisterns)
- Check dams reduce gully erosion, enhance groundwater recharge, store sediments and buffer moisture and enhance water availability at landscape level. In this way they are important for creating multiples ecosystem services and opening up different agricultural, employment and investment opportunities for communities, so are in themselves an important adaptation to people's livelihoods in their own right
- Ground water recharge through gabion check dams rendered shallow wells productive and made digging new ones worthwhile
- Supporting farmers to improve and maintain a productive soil health was proven important and requiring more attention. Organic ways of soil health improvement (mulching and dosing of effective micro-organisms and the use of vermiculite).

Tunisia

- Jessour and tabia are not sufficient during prolonged drought; supplementary irrigation is advised then
- Zaï are a useful addition within jessour and tabia for the establishment of trees
- Groundwater recharge wells tend to silt up, so there is need to install siltation traps

- There is a risk of industrial and agricultural pollution of groundwater through the open connection with the surface through the recharge wells. This potential situation must be monitored and prevented wherever necessary.

Zambia

- Similar to the zaï in Burkina Faso, also in Zambia it is important to solve labour requirement issues experienced with the manually conservation farming system. All tested oxen-based systems tested under WAHARA are an effective answer to that, provided there is an efficient weeds control system in place
- Farmers would welcome dams (e.g. for irrigation and livestock production).

Overall, *combinations* of WH technologies proved to be important in different ways:

- Different WH technologies in different places in the watershed to complement each other and optimise water harvesting (as demonstrated in Ethiopia)
- A high variety of useful mixes of in-situ rainwater harvesting measures, micro-catchment systems and/or macro-catchment systems
- WH in combination with land management (e.g. create land on steep slopes by bench terraces and gully rehabilitation by gabion check dams)
- WH and irrigation, either irrigation to complement WH (e.g. supplementary irrigation under extreme dry conditions) or WH opening the opportunity to irrigate (e.g. check dam ponds)
- Soil improvement measures are important to make soil a better water bank (a WH technology in its own right) as well as to make other WH technologies if combined (more) worthwhile through improved productivity
- WH technologies strategically placed near agricultural land, so only if combined making sense
- WH technologies embedded in a more market-oriented production system, not only to complement other productive farming resources but also this farming approach often being a necessity for the WH technology to be worthwhile (farming for business making WH feasible).

Furthermore, in a choice experiment, the productivity and risk reduction as perceived by the stakeholders were compared. Results are presented in WAHARA report 24 (Kaushali & Fleskens, 2015). The authors concluded that *risk reduction* seemed to be more prominent at the more arid sites of Ethiopia and Tunisia, and mostly so in Tunisia, whereas at the two other sites (Burkina Faso and Zambia), which are in more sub-humid environments, *yield increase* was higher valued.

Quick Scan and PESERA/DESMICE

WAHARA report 19 (Kirkby & Irvine, 2013) presents a simple at-a-point *Quick Scan* tool developed in Excel for assessing the WH potential for a specific site. It computes the rainfall deficits in a given location (spatial resolution about 15 km^2) based on physical conditions such as rainfall, evapotranspiration and slope and it produces the consequently preferred cropped area ratio (CAR; ratio of water harvesting area to cropped area). The tool forecasts crop yields and risks of water deficits for different CARs over a period of 50 years for variable climate change scenarios. Hence, it gives hints for possibly suitable WH approaches.

The Quick Scan tool was developed to make calculations for any specific location in Africa (and elsewhere on earth) with publicly available climate and other data, which can be complemented with local information. Using a laptop, WH potential can be assessed on-the-spot anywhere in the field. While with QuickScan different potential WH technologies (or rather different required CARs) can be compared between locations across the continent, the tool does not have an option to map these out for larger areas.

The specific usefulness of QuickScan for WH *adaptation*, between places and over time, is limited to getting some insight in the possible need to consider adjusting WH plans or existing technologies so to meet the required CAR in a particular spot.

Further, WAHARA report 23 (Fleskens, Irvine, & Kirkby, 2015) introduces an integrated *PESERA/DESMICE* model capable of simulating hydrological and economic impacts, including food and water security, of WH from field to regional scale. The model was developed to assess the impact of the WH technologies using the experimental data from the study sites. Results give insight in the scope of application of the technologies beyond the study sites.

Adaptability of WH technologies

The research teams at the study sites provided information about the adaptability and scope of application of each of the tested WH technologies by responding to the following questions:

A. What are the critical conditions that make the technology effective? The conditions can refer to aspects of the technology itself or of the environment in which the technology is supposed to work. The relative importance (priorities) of the conditions and the way they interact may need to be considered as well.
B. How easy is out-scaling or optimising the use of the technology so it will work in other situations:
    1. Which aspects of the technology or the working environment can or must be adjusted and how?
    2. What are the realistic margins within which this can be done?
    3. What are the major implications? These can be recommended options or non-negotiables consequences, including additional adaptations of the system and/or suggestions not directly related to the technology itself.
C. What is the potential impact/scope of the technologies?

The results of this exercise are presented in Table 5 for Burkina Faso and Tunisia.

Table 5. Adaptability of some WH technologies

Burkina Faso

Zaï	A. Critical conditions		B. Adaptability (1) What to adapt and how?	B. Adaptability (2) Margins	B. Adaptability (3) Implications
Natural environmental aspects	Rainfall	Amount: 500-750 mm (annual) length of season: 90-120 days	Size of the holes, mechanization, improve of the quality of organic manure	Rainfall: 500-800 mm Rain day number:45 days	If rainfall >800 mm zaï is not necessary
	Other climatic conditions				
	Land	Slope of water collection area: 0,5-1%		Slope: 0,5-1% Cropped surface: > 2 ha Soil depth: > 0.5 m	
Socio-economic aspects	Population	Density =80-100 persons/km2 , annual population growth: - 2,1%, rural migration rate: 5%	Re investment of gold mining income for equipment in agriculture and livestock	Electricity, roads to improve trade and transformation	Support of credit through government and banks

	Economic development	Development of irrigated crops like horticulture, building little dams	Development of crop distribution through markets	Best organization of natural resource management	Development of artisans and other sectors
	Policy	Increase investment of soil and water conservation technologies	Adapted rural policy to the needs of population		Policy of rural credit for smallholders
	Land	Land management by farmers, pastoralists	Adapted national rules to local situation (law for land)	Local community arrangements (possibly based on traditions) may do as long as trusted by individual farmer	Best integration between agriculture and livestock in the same area
	WH cost-benefit	High benefit for using WH	Reduce the need of labour by mechanization	Adapting the lay-out or the choice of materials to reduce investment or running costs	Risk of failure if no support of credit
	WH effectiveness for farmer	Yield improve, rehabilitation of degraded land, tree regeneration	Improve the income and food security in the same year	Increase livestock breeding	
	Farming skills and attitude	Scarcity of labour due to other activities	Training and technical backstopping of farmers		
	Farmers' organisation	Best organization for trade and fertilizer availability	Best organization for equipment		
	Farmers' services	Supply of suitable planting materials and inputs			
C. Potential impact	Geographical applicability		Technology can be applied to other regions of Burkina (central part and east) about 100,000 ha		
	Number of people affected		Number of people benefiting from 400,000 to 1,000,000		
	Impact on food security		Secure food availability 2 to 3 times compared to no users		
	Impact on economic growth		Increased crop yield, reduced risk of production failure, diversification of income sources		
	Impact on climate change adaptation		More people more resilient through reduced risk and increased productivity as evidenced by the above three impacts		

Stone bunds	**A. Critical conditions**		**B. Adaptability**		
			(1) What to adapt and how?	**(2) Margins**	**(3) Implications**
Natural environmental aspects	Rainfall	Amount: 500-800 mm (annual) length of season: 100-120 days	Distance between the lines depend on the slope and the importance of erosion	Rainfall: 500-800 mm Rain day number:45 days	If rainfall >800 mm stone bunds are used to control erosion and conserve the organic manure
	Other climatic conditions				
	Land	Slope of water collection area: >1% space: surface cropped land/water collection area >		Slope: 0,5-1% Cropped surface: > 2 ha Soil depth: 0,40 to 0,8 m	

		1/3 (the "catchment ratio")			
Socio-economic aspects	Population	Density =65-80 persons/km2 , annual population growth: - 2,1%, rural migration rate: 5%	Diversification of crops (cereals, leguminous etc.)	Electricity, roads to improve trade and transformation	Support of credit through government and banks
	Economic development	Development of irrigated crops like horticulture, building little dams	Development of crop distribution through markets	Best organization of natural resource management	Development of artisans and other sectors
	Policy	Increase investment of soil and water conservation technologies	Adapted rural policy to the needs of population		Policy of rural credit for smallholders
	Land	Land management by farmers, pastoralists	Adapted national rules to local situation (law for land)	Local community arrangements (possibly based on traditions) may do as long as trusted by individual farmer	Best integration between agriculture and livestock in the same area
	WH cost-benefit	High benefit for using WH	Reduce the need of labour by mechanization	Adapting the lay-out or the choice of materials to reduce investment or running costs	Risk of failure if no support of credit
	WH effectiveness for farmer	Rehabilitation of degraded land, re-greening	Improve the income and food security in the same year	Increase livestock breeding	
	Farming skills and attitude	Scarcity of labour due to other activities	Training and technical backstopping of farmers		
	Farmers' organisation	Best organization for trade and fertilizer availability	Best organization for equipment		
	Farmers' services	Supply of suitable planting materials and inputs			
C. Potential impact	Geographical applicability		Technology can be applied to other regions of Burkina (central part and east) about 170,000 ha		
	Number of people affected		Number of people benefiting from 1000,000 to 1,500,000		
	Impact on food security		Secure food availability, improve of 50% of food security		
	Impact on economic growth		increased crop yield, reduced risk of production failure, diversification of income sources		
	Impact on climate change adaptation		More people more resilient through reduced risk and increased productivity as evidenced by the above three impacts		

Bouli	**A. Critical conditions**		**B. Adaptability**		
			(1) What to adapt and how?	**(2) Margins**	**(3) Implications**
Natural environmental aspects	Rainfall	Amount: 400-700 mm per season	The size of the bouli depend on physical situation, number of ha to use and the importance of run off and slope	Rainfall> 400 mm	allow cropping of storage area
	Other climatic conditions				
	Land	To be installed in clay soils with		To be installed in runoff water courses	

		protection of tree			
Socio-economic aspects	Population	200 households			
	Economic development	Use with crop having a big value in the area (horticulture, maize)	Roads, market, equipment		
	Policy	Supportive for water resources mobilization / crop production			
	Land	Community land	Land management for the benefit of all groups	Local community arrangements (possibly based on traditions) may do as long as trusted by individual farmer	
	WH cost-benefit	Investment to be accrued by the government		Adapting the lay-out or the choice of materials to reduce investment or running costs	Reducing investment costs would cause reduced productivity, higher risks and/or need for more frequent maintenance
	WH effectiveness for farmer	Give income, food security, fight against hunger	The sustainability of bouli depend on the maintenance and the protection		
	Farming skills and attitude	Need labour	Number of active person for garden crops		
	Farmers' organisation	Existence of a good organization			
	Farmers' services	Good distribution of products			
C. Potential impact	Geographical applicability		All part of the north-western region and others parts with same conditions		
	Number of people affected		Number of benefitting 50,000 in the northwest		
	Impact on food security		Reduced incidences of crop failure		
	Impact on economic growth		Number of small animals increase when using bouli		
	Impact on climate change adaptation		More people more resilient through reduced risk and increased productivity as evidenced by the above three impacts		

Magoye ripper	A. Critical conditions		B. Adaptability		
			(1) What to adapt and how?	(2) Margins	(3) Implications
Natural environmental aspects	Rainfall	Amount: 500-800 mm (annual) length of season: 100-120 days	Depth of the furrow may depend on the type of soil and the animal (cow, donkey, horse)	Rainfall: 500-800 mm rain day number:35-40 days	If rainfall >800 mm the Magoye ripper is not recommended, ploughing is better
	Other climatic conditions				
	Land	Slope of water collection area: >1%		Slope: 0,5-1% Cropped surface: > 2 ha Soil depth: 0,40 to 0,8 m	
Socio-economic aspects	Population	Density =70-90 persons/km2 , annual population	Diversification of crops (cereals, leguminous etc.)	Electricity, roads to improve trade and transformation	Support of credit through government and banks

		growth: - 2,1%, rural migration rate: 5%			
	Economic development	Development of irrigated crops like horticulture, building little dams	Development of crop distribution through markets	Best organization of natural resource management	Development of artisans and other sectors
	Policy	Increase investment of soil and water conservation technologies	Adapted rural policy to the needs of population		Policy of rural credit for smallholders
	Land	Land management by farmers, pastoralists	Adapted national rules to local situation (law for land)	Local community arrangements (possibly based on traditions) may do as long as trusted by individual farmer	Best integration between agriculture and livestock in the same area
	WH cost-benefit	High benefit for using WH for income	Reduce the need of labour by mechanization	Adapting the lay-out or the choice of materials to reduce investment or running costs	Risk of failure if no support of credit
	WH effectiveness for farmer	Rehabilitation of degraded land, re-greening	Improve the income and food security in the same year	Increase livestock breeding	
	Farming skills and attitude	Scarcity of labour due to other activities	Training and technical backstopping of farmers		
	Farmers' organisation	Best organization for trade and fertilizer availability	Best organization for equipment		
	Farmers' services	Supply of suitable planting materials and inputs			
C. Potential impact	Geographical applicability		Technology can be applied to other regions of Burkina (central part and east) about 100,000 ha		
	Number of people affected				
	Impact on food security		Improve of 80% of food security		
	Impact on economic growth				
	Impact on climate change adaptation		More people more resilient through reduced risk and increased productivity as evidenced by the above three impacts		

Banka	**A. Critical conditions**		**B. Adaptability**		
			(1) What to adapt and how?	**(2) Margins**	**(3) Implications**
Natural environmental aspects	Rainfall	Amount: 400-600 mm per season length of season: >90 days	The size and depth of the banka depends of the area to irrigate and the crop	Rainfall: 400-600 mm Rainy period:90 days	need to adapt crop types
	Other climatic conditions				
	Land	Individual land or maximum 2 neighbouring fields			
Socio-economic aspe…	Population	Density : 80 persons/km2			

	Economic development	Crop production locally a significant economic activity			
	Policy	Supportive for sustainable local crop production			
	Land	Soil fertility improvement, individual land			
	WH cost-benefit	Necessity of investment to have moto pump for irrigation	To have more benefit use intercropping maize/tomato		Reducing investment costs would cause reduced productivity, higher risks and/or need for more frequent maintenance
	WH effectiveness for farmer	Yield improve, income			
	Farming skills and attitude	Training and more labour	Need for awareness, training		
	Farmers' organisation	Best organization to have credit for inputs	Need for strengthening of group governance and management		
	Farmers' services	Supply of suitable planting materials and inputs			
C. Potential impact	Geographical applicability		Technology is experimental but interested more households in north-western part (100 000 ha) in the context of climate change		
	Number of people affected		Number of benefitting households (maximum 10 in the study site)		
	Impact on food security		The supplement irrigation with banka reduces incidences of crop failure and allow good yields		
	Impact on economic growth				
	Impact on climate change adaptation		More people more resilient through reduced risk and increased productivity as evidenced by the above three impacts		

Tunisia

Jessour	A. Critical conditions		B. Adaptability		
			(1) What to adapt and how?	(2) Margins	(3) Implications
Natural environmental aspects	Rainfall	Amount: 100-250 mm (annual) length of season: >60 days	Space: increase catchment ratio proportionally with less/more rain, more/less slope, less/more soil depth, by adjusting dyke length and/or by adjusting cropped area spillways: increase/decrease number with more/less rain intensity, more/less slope, and/or reinforce against erosion with more rain intensity, more slope	Rainfall: 100-500 mm Rainy period:30-60 days	If rainfall >500 mm other known technologies or water uses more feasible need to plan for different production level and/or costs need to adapt crop types in case of long droughts, supplemental irrigation is needed if cropped land >2 ha, need for mechanisation
	Other climatic conditions				
	Land	Slope of water collection area: > 5% space: surface cropped land/water collection area > 1/3 (the "catchment ratio")		Slope: 1-5% Cropped surface: > 0.2 ha Soil depth: > 0.5 m	

Socio-economic aspects	Population	Density <18 persons/km2 , annual population growth: - 0,68%, rural migration rate: 0,5%	Reducing rural migration: providing subsidies for design and implementation of traditional and innovative WH techniques, this will enable the youth to engage in agriculture as the ideas will make farming interesting.	Provision of group amenities such as drinking water, electricity, roads and telephones in rural areas	Need a rural development program and innovative natural resources management, that means engagement of government and decentralisation of decision making
	Economic development	Crop production locally a significant economic activity, olive oil and livestock are the major source of farm-income	Cope with markets access issues and problem of olive oil and meat processing: promote olive oil and meat value chain	Diversifying economic activities on secondary and tertiary economic sectors to alleviate pressure on natural resources	Need a capital flows to regions and sectors with more investment opportunities and higher value added
	Policy	Supportive for sustainable local crop production and natural resources conservation (soil and water conservation strategy)	Policy/enhancement of water and soil conservation strategy & rural development policies: based on previous impact assessment studies, several policies rules should be revised (common land, etc.)	Mutual learning on policies impact assessment together with policy makers, scientist and actors	Need involvement of local population and regional policy makers to come-up with more effective policies coherent with local conditions
	Land	Ownership: runoff catchment area, cropped land, dykes and spillways legally owned by individual farmer	Land use plan and long-term (and preferably inheritable) individual user rights to be established or reviewed by community or state farmers may own and use land as a group if well organized and all members benefit	Local community arrangements (possibly based on traditions) may do as long as trusted by individual farmer	Likely slower uptake and/or lower effectiveness
	WH cost-benefit	Minimum investment costs by use of local materials (soil), basic tools and existing slope labour (…. Person days for construction and …. Person days per year for maintenance) high value crops justifying costs	Ameliorate assessment approach; to incorporate social and environmental cost and benefit (ecosystem services etc.)	Adapting the lay-out or the choice of materials to reduce investment or running costs	Reducing investment costs would cause reduced productivity, higher risks and/or need for more frequent maintenance
	WH effectiveness for farmer	No or controlled grazing of crop land			
	Farming skills and attitude	When starting, farmer convinced of benefits and skilled to lay-out and construct the terraces, dykes and spill-ways; when using, farmers skilled to maintain the system and make economical use of it	Need for awareness, training and technical backstopping of farmers		Likely slower uptake and/or lower effectiveness

	Farmers' organisation	In case land is used by a group	Need for strengthening of group governance and management		
	Farmers' services	Supply of suitable planting materials and inputs			
C. Potential impact	Geographical applicability		Technology currently practised on 5,000 can be expanded to cover 20,000 ha in Tunisia		
	Number of people affected		Number of benefitting households increasing from 2,000 to 8,000		
	Impact on food security		Reduced incidences of crop failure: from 3 to 1 out of 5 years		
	Impact on economic growth		Increased crop yield, reduced risk of production failure, diversification of income sources, increased farm income (the net present value at 12 % discount rate) is 2,073 DT and the internal rate of return is 23 %)		
	Impact on climate change adaptation		More people more resilient through reduced risk and increased productivity as evidenced by the above three impacts		

Tabia	**A. Critical conditions**		**B. Adaptability**		
			(1) What to adapt and how?	**(2) Margins**	**(3) Implications**
Natural environmental aspects	Rainfall	Amount: 100-200 mm per season length of season: >60 days	Space: increase catchment ratio proportionally with less/more rain, more/less slope, less/more soil depth, by adjusting dyke length and/or by adjusting cropped area	Rainfall: 100-500 mm Rainy period:30-60 days	If rainfall >500 mm other known technologies or water uses more feasible
	Other climatic conditions				need to plan for different production level and/or costs
	Land	Slope of water collection area: > 5% space: surface cropped land/water collection area > 1/5 (the "catchment ratio")	spillways: increase/decrease number with more/less rain intensity, more/less slope, and/or reinforce against erosion with more rain intensity, more slope	Slope: 1-5% Cropped surface: > 0.2 ha Soil depth: > 0.5 m	need to adapt crop types in case of long droughts, supplemental irrigation is needed if cropped land >2 ha, need for mechanisation
Socio-economic aspects	Population	Density <18 persons/km2 , annual population growth: - 0,68%, rural migration rate: 0,5%	Reducing rural migration: providing subsidies for design and implementation of traditional and innovative WH techniques, this will enable the youth to engage in agriculture as the ideas will make farming interesting.	Provision of group amenities such as drinking water, electricity, roads and telephones in rural areas	Need a rural development program and innovative natural resources management, that means engagement of government and decentralisation of decision making
	Economic development	Crop production locally a significant economic activity, olive oil and livestock are the major source of farm-income	Cope with markets access issues and problem of olive oil and meat processing: promote olive oil and meat value chain	Diversifying economic activities on secondary and tertiary economic sectors to alleviate pressure on natural resources	Need a capital flows to regions and sectors with more investment opportunities and higher value added
	Policy	Supportive for sustainable local crop production and natural resources conservation (soil and water conservation strategy)	Policy/enhancement of water and soil conservation strategy & rural development policies: based on previous impact assessment studies, several policies rules should be revised (common land, etc.)	Mutual learning on policies impact assessment together with policy makers, scientist and actors	Need involvement of local population and regional policy makers to come-up with more effective policies coherent with local conditions
	Land	Ownership: cropped land, dykes and spillways legally	Land use plan and long-term (and preferably inheritable) individual user rights to be established or	Local community arrangements (possibly based on traditions) may do as	Likely slower uptake and/or lower effectiveness

		owned by individual farmer; water collection area secured for sustainable use by individual farmer	reviewed by community or state farmers may own and use land as a group if well organized and all members benefit	long as trusted by individual farmer	
	WH cost-benefit	Minimum investment costs by use of local materials (soil), basic tools and existing slope labour (…. Person days for construction and …. Person days per year for maintenance) high value crops justifying costs	Ameliorate assessment approaches; to incorporate social and environmental cost and benefit (ecosystem services etc.)	Adapting the lay-out or the choice of materials to reduce investment or running costs	Reducing investment costs would cause reduced productivity, higher risks and/or need for more frequent maintenance
	WH effectiveness for farmer	No or controlled grazing of crop land			
	Farming skills and attitude	When starting, farmer convinced of benefits and skilled to lay-out and construct the terraces, dykes and spill-ways; when using, farmers skilled to maintain the system and make economical use of it	Need for awareness, training and technical backstopping of farmers		Likely slower uptake and/or lower effectiveness
	Farmers' organisation	In case land is used by a group	Need for strengthening of group governance and management		
	Farmers' services	Supply of suitable planting materials and inputs			
C. Potential impact	Geographical applicability		Technology currently practised on 5,000 can be expanded to cover 20,000 ha in Tunisia		
	Number of people affected		Number of benefitting households increasing from 2,000 to 8,000		
	Impact on food security		Reduced incidences of crop failure: from 3 to 1 out of 5 years		
	Impact on economic growth		Increased crop yield, reduced risk of production failure, diversification of income sources, increased farm income ,		
	Impact on climate change adaptation		More people more resilient through reduced risk and increased productivity as evidenced by the above three impacts		

Check dams	A. Critical conditions		B. Adaptability		
			(1) What to adapt and how?	(2) Margins	(3) Implications
Natural environmental aspects	Rainfall	Amount: 100-200 mm per season frequent runoff events (at least 3/year)	Spacing: increase/decrease with less/more runoff, adjusting dyke length spillways: increase/decrease number with more/less rain intensity, more/less slope, and/or reinforce against erosion with more rain	Rainfall> 100 mm	Silting up causes reduction in storage capacity and efficiency plan for other structures silt removal if possible allow cropping of storage area
	Other climatic conditions			Runoff events > 3events/year	
	Land	To be installed in		To be installed in	

		runoff water courses	intensity, more slope	runoff water courses	

Socio-economic aspects	Population	Na			
	Economic development	Crop production locally a significant economic activity			
	Policy	Supportive for water resources mobilization / crop production			
	Land	Public land presence of an aquifer to be recharged	Land use plan and long-term (and preferably inheritable) individual user rights to be established or reviewed by community or state farmers may own and use land as a group if well organized and all members benefit	Local community arrangements (possibly based on traditions) may do as long as trusted by individual farmer	Likely slower uptake and/or lower effectiveness
	WH cost-benefit	Investment to be accrued by the government		Adapting the lay-out or the choice of materials to reduce investment or running costs	Reducing investment costs would cause reduced productivity, higher risks and/or need for more frequent maintenance
	WH effectiveness for farmer				
	Farming skills and attitude				
	Farmers' organisation				
	Farmers' services				
C. Potential impact	Geographical applicability		This technology has been already practiced in the main (1st order) water courses (wadis) of the country but can be extended to other orders		
	Number of people affected		Number of benefitting households increasing from 2,000 to 8,000		
	Impact on food security		Reduced incidences of crop failure: from 3 to 1 out of 5 years		
	Impact on economic growth				
	Impact on climate change adaptation		More people more resilient through reduced risk and increased productivity as evidenced by the above three impacts		

Recharge well	**A. Critical conditions**		**B. Adaptability**		
			(1) What to adapt and how?	**(2) Margins**	**(3) Implications**
Natural environmental aspects	Rainfall	Amount: 100-200 mm per season frequent runoff events (at least 3/year)	Spacing: increase/decrease with less/more runoff, adjusting dyke length spillways: increase/decrease number with more/less rain intensity, more/less slope, and/or reinforce against erosion with more rain intensity, more slope	Rainfall> 100 mm	Silting up of the filter can cause reduction in efficiency plan for other structures silt removal (maintenance)
	Other climatic conditions			Runoff events > 3events/year	
	Land	To be installed in runoff water courses in combination with storage structures (check dams,		To be installed in runoff water courses in combination with storage structures (check dams, dams, lakes, etc.)	

		dams, lakes, etc.)			
Socio-economic aspects	Population				
	Economic development	Crop production locally a significant economic activity			
	Policy	Supportive for water resources mobilization / crop production			
	Land	Public land Presence of an aquifer to be recharged	Land use plan and long-term (and preferably inheritable) individual user rights to be established or reviewed by community or state Farmers may own and use land as a group if well organized and all members benefit	Local community arrangements (possibly based on traditions) may do as long as trusted by individual farmer	Likely slower uptake and/or lower effectiveness
	WH cost-benefit	Investment to be accrued by the government		Adapting the lay-out or the choice of materials to reduce investment or running costs	Reducing investment costs would cause reduced productivity, higher risks and/or need for more frequent maintenance
	WH effectiveness for farmer				
	Farming skills and attitude				
	Farmers' organisation				
	Farmers' services				
C. Potential impact	Geographical applicability	This technology has been practiced only in few sites (as experimentation) of the country but can be extended to all watersheds (either in dry or more humid regions).			
	Number of people affected	Number of benefitting households increasing from 2,000 to 8,000			
	Impact on food security	Reduced incidences of crop failure: from 3 to 1 out of 5 years			
	Impact on economic growth				
	Impact on climate change adaptation	More people more resilient through reduced risk and increased productivity as evidenced by the above three impacts			

Zaï	**A. Critical conditions**		**B. Adaptability**		
			(1) What to adapt and how?	**(2) Margins**	**(3) Implications**
Natural environmental aspects	Rainfall	Amount: 100-300 mm per season length of season: >60 days	Space: increase/decrease catchment ratio proportionally with less/more rain, less/more soil depth, by adjusting cropped area	Rainfall: 100-500 mm Rainy period:30-60 days	If rainfall >500 mm other known technologies or water uses more feasible need to plan for different production level and/or costs need to adapt crop types option to introduce conservation farming and/or modern inputs to optimise water use option to adapt grazing intensity
	Other climatic conditions				
	Land	Flat copping land - to be used in combination with jessour/tabias		Flat copping land - to be used in combination with jessour/tabias	

					if cropped land >2 ha, need for mechanisation
Socio-economic aspects	Population	Density <18 persons/km2			
	Economic development	Crop production locally a significant economic activity			
	Policy	Supportive for sustainable local crop production			
	Land	Ownership: cropped land, dykes and spillways legally owned by individual farmer; water collection area secured for sustainable use by individual farmer	Land use plan and long-term (and preferably inheritable) individual user rights to be established or reviewed by community or state Farmers may own and use land as a group if well organized and all members benefit	Local community arrangements (possibly based on traditions) may do as long as trusted by individual farmer	Likely slower uptake and/or lower effectiveness
	WH cost-benefit	Minimum investment costs by use of local materials (soil), basic tools and existing slope labour (…. Person days for construction and …. Person days per year for maintenance) high value crops justifying costs	Nothing	Adapting the lay-out or the choice of materials to reduce investment or running costs: not a realistic option	Reducing investment costs would cause reduced productivity, higher risks and/or need for more frequent maintenance
	WH effectiveness for farmer	No or controlled grazing of crop land			
	Farming skills and attitude	When starting, farmer convinced of benefits and skilled to lay-out and construct the terraces, dykes and spill-ways; when using, farmers skilled to maintain the system and make economical use of it	Need for awareness, training and technical backstopping of farmers		Likely slower uptake and/or lower effectiveness
	Farmers' organisation	In case land is used by a group	Need for strengthening of group governance and management		
	Farmers' services	Supply of suitable planting materials and inputs			
C. Potential impact	Geographical applicability		Technology currently practised on 5,000 can be expanded to cover 20,000 ha in Tunisia		
	Number of people affected		Number of benefitting households increasing from 2,000 to 8,000		
	Impact on food security		Reduced incidences of crop failure: from 3 to 1 out of 5 years		
	Impact on economic growth				
	Impact on climate change adaptation		More people more resilient through reduced risk and increased productivity as evidenced by the above three impacts		

5. Developing a framework of WH adaptation principles

Making a WH technology work, or work better than it already did, needs tweaking the working environment as well as the technology's design features. This process starts already with the selection and planning of a new or upgraded WH system and usually continues and fine-tunes during implementation. It involves getting an understanding of:

- The performance benchmarks of the WH technology; how should the technology work and what should it achieve?
- The conditions brought forward by the situation in which the WH technology has to work
- The extent of the technology's flexibility to suit these conditions
- The flexibility of the situation to make the technology suitable.

The conditions for the WH technology to work well relate to technical and economic feasibility, agricultural suitability and -certainly in the case of macro-level WH systems- on its social (shared values) and environmental (ecosystem services) merits as well. A good understanding of the facts allows for finding workable compromises under usually conflicting situations and informed decision taking. Besides flexible designs of the WH technology, plans and targets of the WH adaptation project that are not too rigid is important as well. According to Critchley & Siegert (1991), especially in the early stages of implementation it is unrealistic to plan for all contingencies, and arrogant to assume that the techniques and approaches planned from the outset cannot be improved and therefore, learning from experience, and from interaction with the people, is a much better approach. Hence, the importance of building a solid participatory monitoring and evaluation system as well as local consultations and an internal feedback system for timely steering of the process in the desired direction, in addition to gathering lessons learnt for policy and future interventions.

Generally, the less complex the WH environment, the easier it will be to adapt to it. The following comparisons illustrate this. However, for each the most preferable choice still depends on the actual situation.

- Individual farmer manageable (e.g. in-situ) technologies as opposed to others (e.g. ex-situ) that have to be coordinated by the local community or at national level
- WH technologies directly applicable in rainfed farming systems versus those that require irrigation facilities (i.e. additional investments)
- Secure private title to land as opposed to feudal or unregistered tenure or communal land use arrangements
- WH systems with a small social and/or ecological footprint rather than systems with competing human and wild life claims on the land and the water (including downstream trade-offs)
- Farming systems linked to developed and profitable value chains (so largely self-financing) versus subsistence farming (which are usually limited by financial illiteracy, dependency on grants and lack of services).

The lessons illustrated here are that when planning interventions, outscaling projects should look to exploit straightforward opportunities as much as they are actually available as well as -if possible- arrange to make the complicating conditions more conducive. At the same time, though, a large enough critical mass of actual and potential users/beneficiaries that can easily be brought together is important to justify investing in the development of a WH technology for a particular new situation. For instance, farmers cannot raise groundwater level on their own; this is only going to work if everyone joins in to treat the whole watershed. Moreover, highly urgent (e.g. humanitarian) situations may leave little choice. For example, in Tunisia, the rainfall is so little that simple (in-situ) WH would not harvest sufficient water. Hence, larger schemes are necessary, which are more complex.

Furthermore, adaptation may not in all cases be the best solution in the long run. For instance the combination of climate change, an increasing population pressure and a developing economy in which other sectors than agriculture are becoming much more significant, could make farming in certain areas no longer attainable in the foreseeable future. Early signs were observed at the WAHARA study site in Tunisia, and probably also in Ethiopia. If this is the case, continued investments in WH are critical to mitigate disasters and buy time, yet might prove to be *temporary* solutions only. Strategies need then to be developed for the future that can help prepare and offer the farmers an *alternative* livelihood, locally or elsewhere, rather than them having to hang on to farming.

Hence, in some situations WH might not provide the final solution, but it can help to bridge the period that is needed to find alternative livelihoods. In other situations though, WH can provide a lasting solution that allows farmers to maintain or improve their livelihoods even in the face of changing climate or increasing population.

In both situations, insight into the various conditions is needed and can be provided by answering the following questions:

- Which aspects facilitate the adaptation of a WH technology? These circumstantial aspects critical for the adaptation process to succeed could be called *indirect* adaptability criteria
- Which of these, if any, have to be adhered to no matter what? These could be called *non-negotiables*
- Which aspects can be adapted, and how, so to make the WH technology performing (better)? These then would be the *direct* adaptability criteria
- What do these adaptations accommodate for; how exactly would the adaptations make the technology more suitable?

The answers can be grouped according to the major categories of conditions catering for the WH technology itself as well as the environment in which it has to work. In Table 6 six categories are considered:

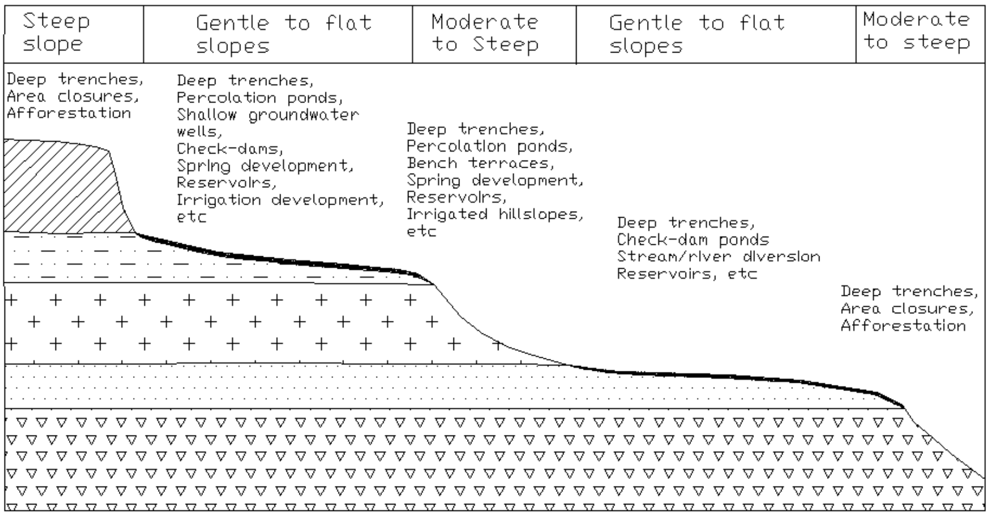
- Design of the WH technology
- Climate
- Land
- Natural environment (other than climate and land)
- Agricultural system
- Socio-economic situation.

While for clarity the conditions are separated into categories, it is understood that in fact they strongly interrelate with each other; the conditions of the agricultural system change if the socio-economic environment changes, for instance, and this may affect the WH technology design criteria.

The indirect adaptability facilitating aspects make adaptation possible or easier whereas otherwise this would be hard, risky or impossible. For example, it may be easier for farmers adapt their farming system to integrate a WH technology if they enjoy statutory land ownership than under a customary land use system. Or, adaptation of the WH technology would be meaningful, affordable or do-able only if certain criteria are met; e.g. a minimum amount of prevailing rain would be necessary to make the ratio between the water catchment area and the productive field financially feasible or socially acceptable, or the soil on a steep slope being too thin or fragile would not allow for terracing, or ready demand for certain agricultural commodities justifying the integration of an improved WH system in the farming system.

Any of the adaptability facilitating criteria that are non-negotiable should be indicated as well as their suitability margins or conflict preventing measures. For instance, a particular WH technology is suitable only within a certain range in slope steepness while others are more flexible in that regard (Figure 2), or investing in the WH technology is only worthwhile if fertilizer and/or seed for cash crops, or trucks to transport materials to construct the WH facilities are available. Also refer to Table 5, which for several WH technologies gives an adaptability margin for different critical conditions and the implications if these margins are not met.

Further, the adaptability facilitating criteria may indicate what could be adapted (if possible) as a result of opportunity or dictated by urgency. This then should be reflected by one or more direct adaptability criteria. For example, for a WH technology to be (more) effective it may be deemed necessary to change customary land use arrangements, e.g. introduce statutory title to land for individual farmers or limit/exclude communal grazing rights for particular fields. Or, increasingly erratic rainfall may force farming households to expand the rainwater catchment area of their spate irrigation systems, or scarcity of land in the valley and better uphill water harvesting opportunities makes a farmer decide to bring into production the steeper slopes in the mountains and gradually terrace them. Depending on the population density and land ownership arrangements there may or may not be enough space for such expansions. Or, a group of farmers decide to embark on a high value commodity to make investing in WH affordable and realise that they need to join hands and bulk the produce as a cooperative to enable access to a profitable market.



Symbol	▽▽▽▽▽	(dots)	+ + + +	(dashes)	(hatching)	(dark fill)
Rock/Soil type	Volcanic rockI	Volcanic rockII	Volcanic rockIII	Volcanic rockIV	Volcanic rock V	Soil (silt and clay)
Permeability	Moderate	Low to moderate	Moderate	Low to Moderate	High	Low to moderate

Figure 2. Suitability of WH technologies on slope is limited by local steepness and/or rock/soil type
(Source: Woldearegay, Kifle. Mekelle University. Ethiopia)

Updating Table 6 for a local situation and a selected WH technology will help to estimate not only what room for adaptation there is but also whether the changes are worthwhile, i.e. will make the newly adapted water harvesting technology producing enough of the intended benefits. The following six paragraphs describe how in this table the various categories of WH adaptation conditions should be understood.

Adaptability of the technical WH design
The more straightforward the WH technology concept (its principal as well as its structural design), the easier it will be to adjust the construction works to different situations. Simultaneously, it will be more likely that people accept and adapt to it so to make it work. Indicators are (1) simplicity and time to build, change, upgrade and expand it, (2) access to the necessary building skills, tools,

materials and infrastructure, (3) ease of managing, using and maintaining the WH technology, and (4) safety.

Major characteristics of highly adaptable technologies are:

- Existing and locally accessible know-how and resources are largely or entirely adequate
- Little learning required
- Lending itself for relatively small adjustments rather than needing a fundamental overhaul:
    - Easily scalable to suit different sizes as demanded by different conditions:
        - Tweaking dimensions, such as the length and height of a dyke or the depth of a pond
        - Repeating the same design more or less times for the desired result (modular design), e.g. making more ridges to expand the system on adjacent land and using more cisterns of a particular size for higher water storage requirements
    - Easily adjustable to different natural conditions, e.g.:
        - Lengthening the diversion dyke in a tabia system to capture more water from a catchment area for crop production, i.e. adjusting the ratio between catchment area and production area to:
        - Adjust to reduced rainfall as a result of climate change
            - Make the system suitable for another location
            - Make the system more productive (where water is the limiting factor or in combination with more farm inputs)
            - Adjusting the spacing between ridges according to the slope; closer on a steeper slope
        - Adjusting the cross slope of ridges in the field or of diversion dykes/channels:
            - Along the contour where there is no risk of overflowing (which would cause serious erosion damage) or where it is important to harvest all the water that can possibly be captured
            - Under a small slope (e.g. 1%) where such a risk exists, e.g. due to intense rainfall, so excess water can be drained safely
    - Simple alternatives can be introduced to get more or less the same result with acceptable trade-offs (if any), e.g. using soil instead of stones for making bunds, if stones are not easily available. A trade-off is that the soil bunds do not last as long, so need more frequent maintenance/rebuilding
    - One or more simple additions to the original design, e.g.:
        - Tabia was developed from the original jessour system by adding a couple of lateral bunds and optionally also a diversion dyke
        - Stabilizing soil bunds and earthen spillways with a stone lining
        - on steeper slopes (e.g. above 3 %) to reduce the gradient and better retain the water by additionally constructing terraces
    - Combining of different technologies, e.g.:
        - Stone bunds and zaï/tassa/basins (planting pits)
        - Bunds/ridges/furrows and basins together forming micro-catchments in which the bunds direct water to the basins
        - Combining micro-catchments with in-situ WHs, e.g. planting pits and/or bunds with mulching and/or manuring
- Multi-purpose benefits (e.g. the stored water will be available for a variety of uses) and/or benefits for many people, hence creating the necessary critical mass of local people supporting the adaptations. Such flexibility can be an asset as long as it doesn't require stifling compromises

- Mechanisation is an option, to obtain a similar effect but faster and/or with less labour, e.g. animal drawn ripping/furrowing instead of manual digging of planting pits, or to service more people.

Adaptation to climate

In a practical sense, climate cannot be adapted but has to be adapted to (unless sustained long-term mitigation on a global scale takes place). The expected volumes of rainwater that need to be dealt with by the WH technology at any given time are an important determinant not only to know if the technology would be suitable in principle, but also how to adapt the technology if it is. Climatic conditions can have an impact on the structural design of the WH system as well, such as covered water storage to reduce water loss through evaporation and protection against wind erosion due to sand storms (also determined by land conditions). In the context of water harvesting for rainfed agriculture, the key climatic indicators are (1) rainfall amount, (2) rainfall extremes and (3) variability (all three assessable through daily rainfall measurements), as well as the amount of water that is lost on a daily basis through (4) net evaporation[2]. Large differences in rainfall amount and variability between years as well as rainfall extremes (flooding, dry spells) within agricultural seasons are not conducive for the adaptability of any WH technology. High evaporation may cause the need for covering of water storage facilities, e.g. by roughening of the soil surface, mulching and/or cover cropping in places where water is supposed to infiltrate, and by covering of water storage tanks. With WAHARA's QuickScan tool the water saving impact of covering tanks to prevent evaporation can be estimated (Kirkby & Irvine, 2013).

Adaptation to and of the land

Together with the climatic conditions, the topography, vegetation, soil characteristics and the geology of the land determine the rainwater harvesting and conservation potential or requirement that the WH technology design has to take into account; how much and how quickly will the runoff be, how much water will infiltrate into the soil and how much will percolate and be stored in the aquifer. Indicators are: (1) the surface; average slope angle and features such as roughness and crusts, (2) vegetation types and density, (3) the soil; texture, structure, erodibility and depth, and (4) the rock bed; type and structure. The land features have a direct impact on the structural options and structural design of the WH system as well; e.g. for locally available building materials, suitable locations and dimensions of the constructions, making use of run-off on crusted soil or to concentrate water, distance to and types and volumes of temporary or permanent surface water. In most WH concepts adaptations to the land are made, ranging from small soil improvements such as through minimum tillage, fertilizer application or concentrating water via downhill ploughed land, and small in-situ soil surface changes such as through stone lines, zaï and half-moons, to larger in-situ land surface changes such as through bench terraces and percolation trenches and ex-situ changes in the landscape such as through jessour and check dams.

Natural environment (other than climate and land)

Basically any other ecosystems services, including through clean, reliable and abundant supply of water, natural vegetation and water bodies, wildlife and biodiversity. They can be secondary or unintended WH results from increased groundwater recharge, yet highly important for sustainability and down-stream benefits. Important are WH adaptations that protect these ecosystem services as much as needed to ensure sustainable livelihoods of the farming households (including the use of the natural environment around the cropped land by livestock and for harvesting various wild life

[2] Not evapotranspiration. Unlike net evaporation, which is locally a loss caused by climate, *transpiration* is productive use of water by plants and a gain if these are *wanted* plants (unless the objective is to maximize water storage for later use such as irrigation or livestock production, rather than for rainfed vegetation). Evaporation is determined by wind speed, air pressure and the differences in temperature and in humidity between the air and the drying surface, but can be directly measured on a daily basis.

products) and as much as possible to prevent conflicts arising from competing (human but also wildlife) claims on the natural resources.

Agricultural system
Going beyond the land aspects and eco-systems affecting WH adaptability, the production systems on the farms give clues about the types of WH that may be suitable and how easy or how difficult it is to fit in a particular technology. Indicators are the size of the farm, the various farming enterprises and objectives as reflected by the types of crops (including trees) and livestock produced, the field sizes and shapes, the land use intensity such as mechanisation level and use of external inputs and land use customs such as communal grazing, the productivity levels and the extent of additional farm investments required to make WH feasible. Further, the various services available to farmers (refer to Figure 1) largely determine what is possible in terms WH adaptation.

Socio-economic situation
This category covers a wide range of financial and economic parameters of the direct beneficiaries, the farmers. Ways to minimize the risks and costs without jeopardizing the technical specifications and maximize the benefits are strategies to accommodate a WH technology and make it (more) suitable for new situation. Indicators are (1) clear and reasonable capital, operational costs and labour requirements at the various stages of implementation, a positive cost/benefit ratio and a quick debt servicing plan and (2) economic benefits (preferably multiple) that are quickly and clearly visible, address important needs and are significant and sustainable. Also refer to the section *Adapting should be worth it*. Besides financial and economic costs and benefits for the direct beneficiaries, there are communal ones as well that affect the adaptability of the WH technology. Technologies can have a higher adaptability if it comes with benefits for the community and no trade-offs that are prohibitive, e.g. an artificial storage structure offers the option for clean drinking water, which is costly but an urgent social and developmental need and possibly a necessary motivation for such an investment. It enhances acceptance and local cooperation, it increases social capital, number of potential beneficiaries, multiple water uses, build-up of social capital and economic benefits for the community (employment, income, knowledge and skills, status, innovation). Also refer to the section
Part of a holistic adoption process . Storage structures offer option for multiple uses. The more costly a WH investment is the more effective, market driven, multi-purpose and/or urgent it needs to be.

Table 6. Conditions for water harvesting adaptation

Aspects determining the adaptability of the WH technology			
Category	**Aspects facilitating WH technology adaptation**	**Aspects that can be changed**	**To accommodate for what**
Design of the WH technology	Already existing WH structures and available WH expertise (to build, use and maintain WH systems) Concept is suitable for a wide range of biophysical and socio-economic environments Simplicity of the design makes it easier to adjust; indicators of simplicity of the design: • All who need to understand it do understand • The design is not complicated more than necessary • It doesn't require a high level or high variety of skills • It requires (mainly) locally available skills, manpower, tools and materials • It can be made quickly • It is scalable; can be easily expanded and replicated (e.g. modular design) • It is easy to add new things or to integrate other technologies Reasonable financial costs make technical adjustments feasible; consider: Investments, variable and labour costs (including for maintenance), payback amount, payback time during construction/use/alterations	Particular specifications: • Dimensions • Choice of materials • Order of construction in time • Design alterations/choice of design options Know-how: • Understanding and skills of local stakeholders to implement WH	• Required WH capacity; the envisaged volumes of water can effectively be harvested, transported and stored • Application level; integration of complementary farming technologies (e.g. irrigation, mechanisation, modern farm inputs, high-value agricultural commodities), other water uses than farming, more and other beneficiaries • Other aims/benefits • Financial costs; capital investments, running costs at each phase of development of the WH technology (design, construction, use) • The limitations and opportunities of the working environment
Aspects determining the adaptability of the working environment			
Category	**Aspects facilitating WH technology adaptation**	**Aspects that can be changed**	**To accommodate for what**
Climate	Knowledge about the key climate conditions and their trends help establish: • Best overall design, including choice of alternative options • Design specifications	Climate cannot be changed (unless by long-term mitigation on a global scale, which is outside the scope of WH adaptation)	Not applicable
Land	Effective runoff from WH catchment area Knowledge about the key topographic, soil and geological conditions help establish: • Location • Best overall design, including choice of alternative options • Design specifications	Surface - slope (terracing), topography (afforestation, de-stumping and cleaning surface to become more suitable for desired farming systems) Soil - structure, organic matter content, coverage, nutrient content (reduced/zero tillage, mulching, conservation farming, integrated soil fertility management) Rock bed - unpractical to change	Create room for WH technology Make WH technology (more) effective and efficient by: Adjusting for run-off intensity Making land (more) suitable for rain water catchment Making land (more) accessible/suitable for farming Increasing infiltration rate and water holding capacity of the soil Increasing productivity of the soil

Table 6. Conditions for water harvesting adaptation (continued)

Aspects determining the adaptability of the working environment (continued)			
Category	**Aspects facilitating WH technology adaptation**	**Aspects that can be changed**	**To accommodate for what**
Natural environment (other than Climate and Land)	Ecosystem services: • Adequate amounts and quality of local building materials make WH construction and adaptation easier • Agricultural potential of the natural environment that justifies investing in WH and WH changes	Optimise maintenance, build resilience, and expand ecosystem service delivery: • Water reserved for natural vegetation and wildlife • Pollution; limit and control • Protect against (excessive) mining of the environment (i.e. extraction larger than natural regrowth) • Space reserved for natural vegetation and wildlife; size, location, quality, access Use of ecosystem services: • Knowledge; strengthen, document, use • New ecosystem services; introduce, exploit	• A broad natural sustainability base for the preferred WH system and changes • Better chances for successful and efficient implementation and maintenance of the WH system and changes
Agricultural system	Individual rather than communal farming practices can make integration of a WH technology into the farming system less complicated Productive farm assets and methods may help the WH technology to be financially or economically more feasible, hence justify certain adaptation efforts Synergies between different components of the agricultural system (e.g. livestock for manure, draft power for soil tillage)	Farming skills training, research, extension and information services Farm enterprise annual crops, trees, livestock, aquaculture, forestry Commodities crop type and variety, livestock/fish breeds Production units - fields number, shape, length and width, fencing Mechanisation level manual, animal draft power, motorised Irrigation have it - yes or no, adjust it - type, size	Productive farming assets make the WH technology (more) compatible and financially and economically feasible Match production unit size to water catchment capacity Adapt production unit shape to make the WH technology more effective/efficient
Socio-economic environment (other than Agricultural system)	Trade-offs, income, food and nutrition security, spin-offs in employment, skills, economic and social development, education, health, community strength and stability, cultural pride Necessary technical know-how and experience available for implementation, community organisation, financial management, use, maintenance	Acceptance Sensitization; information, testimonies, exposure, demonstration Participatory planning Use of local capacities; labour, skills, input supply, other services Alternative uses of the WH technology for other beneficiaries; introduce/add/improve Capacity building Skills at each phase (design, construction, use) for technical know-how, management, facilitation (community organisation, governance), use and maintenance Labour force, tools and equipment, building materials Enhancing overall benefits Productivity and sustainability of rainfed farming (introduce/reorient/improve) Statutory land tenure; introduce, reinforce Services for marketing, farm input supply, training, information, financing, risk reduction (insurance) Multiple uses for WH technologies; introduce/add, make more effective, efficient	A more flexible or diverse use of the WH system and larger community acceptance, participation and know-how will facilitate decision taking, increase local ownership and local participation, and improve the likelihood for a WH technology to be effective and sustainable Enhancing complementary services for greater farm productivity and income can help justify the additional costs of a WH technology

6. Conclusion: scope for WH adaptation

The devil is in the detail

The concept of WH, retaining runoff for productive use, is universal and simple. Making it work isn't necessarily too. It requires adjusting to conditions that cannot be changed while making smart adjustments among those that can be. However, the bio-physical and socio-economic conditions are numerous, interconnected, often conflicting, and they differ widely between locations, even at short distance, as well as over short and long spaces of time. At field level, the working conditions are usually highly variable, so more often than not *unique*. Moreover, the real adaptation challenge is not to make a WH technology *work* under new conditions but to make it *worthwhile*; the expected benefits must be realised with limited resources, without taking a lot of time and for enough people. It adds to the complexity of practical WH adaptation.

So, modifying a WH technology's design and/or its working conditions to produce an acceptable result within the accessible means can be an intricate balancing act. It explains why WH doesn't spread easily, with an abundance of clearly working examples around for such a long time. At the same time this underlines the importance of adaptation in WH outscaling projects; there can be no adoption without adaptation. It also implies that there is no *precise* WH adaptation working model for *general* use.

To realize the vast scope of WH in African rainfed agriculture, we need to use a general working approach and the capacity to fine-tune it on a case by case basis. The principle of such an approach should be to thoroughly understand and apply WH *principles* inspired by successes from elsewhere rather than trying to use these examples as *blueprints*. It entails an iterative process of observation and learning from what works, to comprehend the underlying conditions of the WH example and the target situation, as well as a pragmatic implementation capacity.

In such an approach, careful monitoring and evaluation of the results at any stage and feedback for the next step -or to improve the last- will be essential. It requires the capacity to integrate local knowledge with insights from elsewhere and an allowance for a not too long but long enough learning curve as well as the stakeholders' willingness to learn and their long-term commitment. More than many other technologies, WH affects the community, even if limited to individual farms. Family farming in Africa is very much embedded in and depending on strong communal customs and traditional rules. Introduction of WH can be drastic enough a change, hence run into obstacles raised by the community despite all good intentions. This has implications for the way WH is being introduced.

Guidelines for a practical WH adaptation approach are worked out in WAHARA WP5 deliverable 3.

Need for a WH adaptation database

The WOCAT database[3] contains *general* facts and figures of WH technologies. As discussed in this report, proper WH adaptation and effective outscaling of WH technologies depend on knowledge of *local details* in particular. WOCAT in its present form cannot cater for the localised data that an adaptation project has to deal with and without which it may easily fail. Therefore it would be helpful to add to the WOCAT database format the option to document the more detailed information of *actual adaptations*, big and small, that have been applied somewhere in the world with success. A lot of knowledge about this is available but scattered. Furthermore, WH innovations are taking place likely on a regular basis but in isolation so remain invisible to the

[3] https://www.wocat.net/en/knowledge-base.html

outside world. This load of detailed experience if brought together in an accessible way would be a great source of ideas and learning for WH adaptation elsewhere, be highly instructive on how to do things and helpful in preventing people needing to reinvent the wheel. Hence, there should be an interactive facility to ask for information that may not yet be in the database but that others could answer on-line (and whose answers then become part of the database). All aspects pertaining to the relevant social drivers of success (e.g. gender equality, youth involvement, agri-business development, community organisation, trade-offs and policy support), the economics of the WH technology, farming conditions and services, natural resource management as well as data on climate, land and other natural conditions and the technical WH design should be made room for. To set up the required database structure and enable and promote its practical use will require a special effort. Possibly, this could be a WOCAT project.

Strengthen and use local innovative capacity and farmer services

A WH adaptation project must demonstrate direct economic sense locally (if not instant rewards then at least immediately an outlook for these in the not too distant future). Critical for sustained economic success are policy support, local ownership, local skills and inputs, access to adequate finance, profitable markets, private sector involvement and availability of services as well as professional farmers who can make the WH investments profitable.

To farm successfully, one must be an innovator, certainly when to survive under straining conditions, so always with the pressure to stay productive. Farmers' innovations are testimonies of success, even if they are small changes making use of local opportunities such as local materials and natural features (costing little money) and preferably are simple too (costing little time and effort). An adaptation strategy should bank on such farmers for their creative capacity to innovate and solve problems and see opportunities. However, they cannot do it without having ownership of productive resources and access to a range of farmer services.

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