AGWATER SOLUTIONS
Improved livelihoods for smallholder farmers

Small reservoirs and water storage for smallholder farming

The case for a new approach

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Background

Starting from the now widely recognized premise that agricultural water management (AWM) is a promising investment option to improve the livelihoods and food security of the rural poor, the entry point of the Agricultural Water Management Solutions (AgWater Solutions) Project has been to understand the opportunities and constraints to adoption of AWM best practices by smallholders in different settings, in order to identify what concrete measures can be taken to overcome them.
The ambitions of the AgWater Solutions Project are to provide practical answers to the following key questions:

- To what extent can farmers improve their food production with locally-available water management technologies and inputs?
- What impacts do these methods have on natural resources and environmental goods and services and the livelihoods of people relying on them?
- Where and how should donors, policymakers and lending agencies invest in order to sustainably and cost-effectively achieve the greatest livelihood benefits for smallholders out of improved AWM?

Offering farmers across Africa and India solutions to better manage water is at the heart of this project.

Drawing largely from the project's research findings, the present report focuses on water storage for agriculture, with special emphasis on small reservoirs as an important, promising AWM investment options highlighted by the project.

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The report is based in large part on the findings of the research by Jean-Philippe Venot, Charlotte de Fraiture, and Nti Acheampong (Venot *et al*., 2011). Contributions from Jean-Philippe Venot, Guido Santini, George Sikuleka, Ben Nyamadi, Oumar Seydina Traoré, Laurent Campaoré, Mahamadou Tiemtoré, Saa Dittoh, Girma Medhin, Hune Nega, Charlotte de Fraiture and Livia Peiser are gratefully acknowledged.

Introduction

Scope of this report

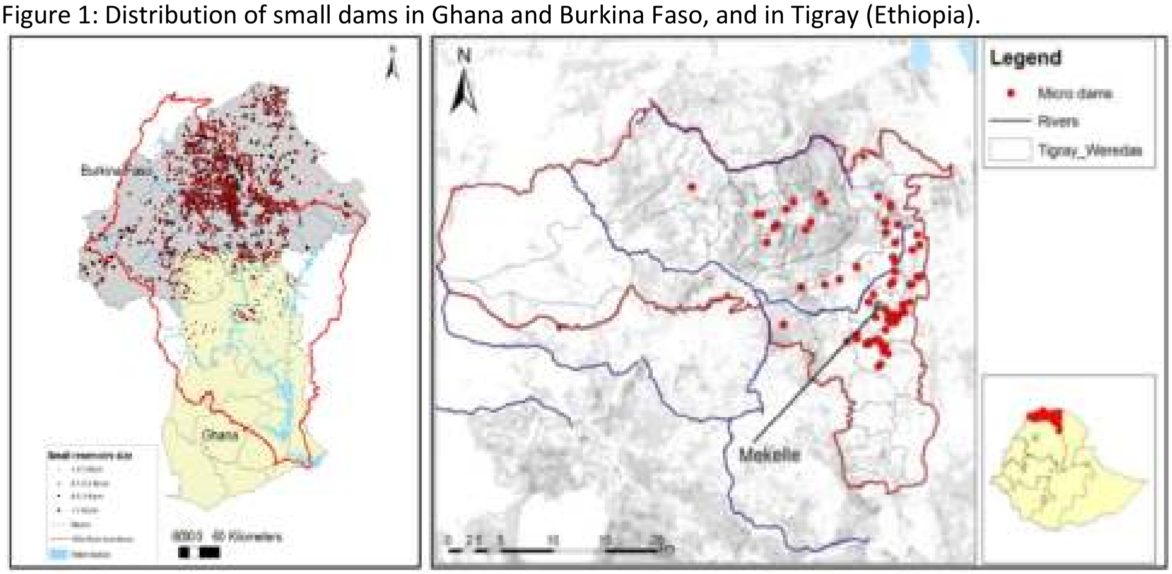
Small dams, reservoirs and water storage structures have long attracted the attention of those in charge of rural development and can be found all around the world where they are known under multiple names: tanks or johads in South Asia (India, Sri Lanka), açudes in Brazil, *petits barrages*, small reservoirs or micro-dams in sub-Saharan Africa, lacs collinaires in North Africa, pequeñas presas in Mexico and South America etc. Defining what 'makes' a small reservoir is not simple, as the criteria used to define them (size, stored volume, embankment height, type of infrastructure, modes of management, planning approaches, number of users served, irrigated area, etc.) vary widely from one place to another.

This paper considers all 'off farm' water storage, mostly above but occasionally underground, of a volume inferior to 1 million m^3, the uses of which include but are not necessarily limited to agricultural production (for crops, livestock, fish), and with a special focus on small dams or reservoirs (SRs).

Although they clearly offer a "solution" to some water-related problems currently faced by the rural populations, SRs are complex entities with far-reaching implications; they are certainly not a panacea that can apply everywhere indistinctively. To be correctly implemented, SRs require a number of favourable factors and a carefully crafted approach. Besides, even where the conditions for success are met, they may not be the most cost-effective alternative. Eventually, as any other "tool", their impact will eventually depend on how they are used and maintained.

While not necessarily limited to a specific region, this report is based mostly on the results of research conducted in countries of sub-Saharan Africa (Venot *et al.* 2011), and it is likely that it is therefore more relevant to the sub-Saharan African region than to other regions of the world (Figure 1).

Figure 1: Distribution of small dams in Ghana and Burkina Faso, and in Tigray (Ethiopia).



Source: Venot et al, 2011.

Aims of this report

The aim of this report is therefore to:

- Highlight the important role of small water storage structures for food security and smallholders livelihoods improvement;
- Encourage governments and their partners to actively support storage as part of their rural poverty alleviation strategies;
- Underscore the "do's and don'ts" in the process of selecting agricultural water storage options;
- Propose a set of principles, approaches and measures for the planning, design, construction, and management of small storage structures in light of gathered experience and of the research conducted under the project.

For whom is this report written?

This report is written primarily for governments, donors (ODAs, NGOs, private foundations…) and investors wishing to stimulate the productivity of smallholder's agriculture through the promotion of water storage infrastructure, and all those in charge of their design, construction, operation and management.

Sources of information

A large number of case studies and interviews have been carried out in the framework of the AgWater Solutions Project, especially in Burkina Faso, Ghana, Ethiopia and Zambia. A literature review has also been conducted, the main references of which are mentioned at the end of this report.

Why is storage important for smallholder farming?

The need to secure water supply for farming

Currently, dramatic changes are threatening the water security of many rural populations in developing countries, particularly with regard to agricultural water. The prominent driving forces for increasing pressures are:

Exogenous:

- Climate change and variability (water is the defining link between climate and agriculture);
- International influences: trade agreements, markets demand and supplies.

Endogenous:

- Human/livestock densities increase while the land carrying capacity decreases (as a result of land degradation);
- Rising and competing uses (especially urban water);
- Widespread expectations for livelihood improvements.

Water storage is like an insurance mechanism for the smallholder. It acts as a buffer against the variability of the rainfall regimes and therefore increases the resilience of the farmers against: (i) dry spells during the rainy season, as well as (ii) rainfed-crop failure, in as much as it allows farmers to secure at least one dry season crop that can either be consumed or sold.

Today, smallholder farmers feel increasing vulnerability to water shortages; consequently, the demand for water storage is rising. The more unreliable the natural supply becomes, the greater the need for water storage. With stored water accessible, farmers feel less vulnerable to climatic fluctuations, and thus are encouraged to invest more in agricultural inputs and equipment to improve their farming productivity.

The demand for water storage is rising

In sub-Saharan Africa (SSA), which is the primary geographical focus of this study, numerous SRs were constructed in the 1950s and early 1960s, primarily for livestock watering and soil and water conservation purposes. The focus shifted through the mid-1980sto drought proofing, largely promoted by the World Bank and other Development Agencies in response to severe droughts in the 1970s, and later, in the 1990s to irrigation development.

Subsequently, the performances of these SRs came into question, particularly those built for irrigation purposes, with many SRs rarely meeting initial expectations. In some cases, the SRs performed below expectations because of unfinished SR infrastructure (e.g., in Burkina Faso). In other cases, the SRs became trapped in a downward spiral of low performance and infrastructure degradation. This, added to the general disaffection towards agriculture that pervaded development policies at the time, made new construction fall to a very low level. Rehabilitation needs – due mainly to deficient maintenance – rose sharply, and a shift towards more investments in the "software", i.e. the management of these reservoirs, imposed itself. This coincided with the sweeping era of Irrigation Management Transfers (IMT) for large-scale irrigation schemes in many countries and, although the situation was different for SRs – where the government irrigation agency usually intervened little after building the infrastructures - the consensus was that, in their case too, proper O&M could be solved through the formation of Water User Associations (WUAs). However, not much was done in practice: WUAs were formally installed but the capacity building effort required to make them functional often remained insufficient (Ghana and Burkina Faso are good examples of this state of affairs).

More recently, agriculture is slowly coming back on the development agenda and is increasingly recognized as the strategic engine of growth and poverty reduction that it historically has been –and still is for many countries. Donors and governments in developing countries are looking again for sound investments in the sector. The potential of irrigation in terms of improvements in land, labour and water productivity makes its promotion attractive for public actors as does the visibility of the associated infrastructures. Hence there is a renewed interest for the provision of irrigation facilities and a new mood for indicative irrigation and water storage planning.

The demand from farmers for SRs is likewise growing. As mentioned earlier, farmers themselves are increasingly suffering from water shortages for their livestock and crops (the irrigable land per capita as well as yields from rain-fed farming have decreased), and there is growing popular demand for improved access to water for rural livelihoods. SRs offer one of many possible solutions. Individual and on-farm SR solutions are generally preferred to collective options. This will likely increasingly be the case as the cohesion of local communities loosens.

From the supply side, SRs are now appealing to public investors (governments and the donor community) as they are perceived as a potentially good match between prescriptive ("top-down") and participatory ("bottom-up") planning. There is a willingness to invest and foster the transformation of the current scenario into a virtuous path towards improved performance and outcomes (figure 2).

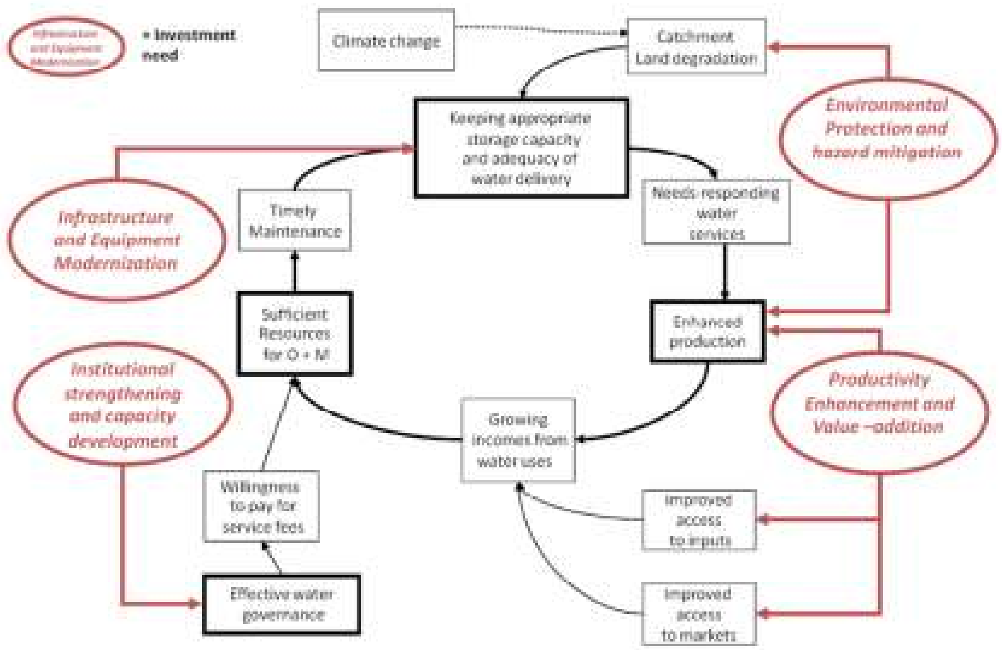


Figure 2: The virtuous cycle of performance enhancement and associated investment requirements

Storage serves a variety of uses

Although often designed for a single purpose, small reservoirs generally serve a combination of several possible uses (Table 1). This state of affairs supports the rationale for designing SRs with multiple uses in mind, from the very beginning of the planning process, based on intensive consultations with potential users from all segments of the populations and stakeholders as a whole. Ex-ante consideration of the various uses will generally induce the selection of desirable, compatible technical and organisational options.

For some uses, the environmental or physiographic context will be a strong determinant of the feasibility of the approach. For instance, in somewhat hilly terrain, such as parts of Ethiopia, Tanzania and parts of western SSA, iDE's rich experience in Nepal with multiple use reservoirs combining domestic and irrigation water could serve as a model –where there are no significant health and quality issues. In other cases, such as in parts of West Africa, there is a preference to partially separate domestic water supplies by building small wells around SRs.

In rather flat terrain, like in most of the Western African Sahel, typical users will include livestock, irrigation and fish production. Surface water for domestic use may be added but because of the generally low quality of SR water, water treatment is more easily done and managed at the household level (home water-filtering devices). As this option requires substantial training, domestic water needs may be better addressed locally through recharge of shallow aquifers such as groundwater dams or sand dams, as well as nearby wells.

Table 1: Multiple uses of Small Reservoirs

Use	Nature of use	Contribution	Remark
Drinking	Consumptive	Health (livelihood)	*Water treatment needed, preferably at household level*
Livestock	Consumptive	Cash, health (nutrition), power and plant nutrients	*Access to water by cattle may turn into a major source of conflicts with irrigators, particularly in the dry season. In addition, cattle are a frequent source of pollution.*
Crops	Consumptive	Cash and health (nutrition)	*Where there is market access, high value - added crops may be preferred over staple crops. In any case, crop diversification is welcome.*
Fisheries	Non consumptive	Cash and health (nutrition)	*Fish culture may be better managed in ponds fed by the reservoir but requires significant inputs in addition to water.*
Thatching Grass	Consumptive	Cash and shelter	
Brick-making	Consumptive	Cash and shelter	*Siltation*
Recreation	Non consumptive	Health	*Health hazards associated with surface water (disease vectors, parasites…)*
Cottage industry	Consumptive	Cash	

Water storage is a source of diversification

Storage opens possibilities for new economic activities where water is a production factor. As far as agricultural production is concerned, reliable access to irrigation water from storage opens a great potential for crop diversification. Paradoxically this stands all the more true when irrigation water is limited in volume and duration: where irrigation water is relatively abundant, the usual tendency may be to use it for rice, whereas less water-demanding crops with higher value -such as vegetables – are more attractive in many respects. For instance, vegetable production (with fast-growing crops) is the only relatively easy option to take advantage of irrigation water that is available for no more than 3 months of the dry season, as happens with many SRs in semi-arid SSA. However, these profitable crops are also quite labour and management–intensive, usually perishable and often pose commercialization challenges. Yet, even when their output is mainly dedicated to self-consumption and their direct effect on income is limited, vegetable growing can allow a much welcome diversification of the family diet, with positive impact on health and productivity.

In short, water storage does allow diversification of economic activities but this diversification will not necessarily happen spontaneously and requires significant capacity-building (especially technical training of users as well as improved access to other inputs such as good-quality seeds) in order to materialize.

Climate change will increase rainfall variability

The reality of human-induced rapid climate changes is not any more challenged. Although the consequences widely vary with the local parameters and are still hard to predict, there is an undeniable trend towards increased variability of rainfall events in much of SSA. Adaptation will thus require additional resilience to dry spells, much of it through increased (and better distributed) water storage. It will also require adapting to more frequent floods and intensive rainfall. This calls for designing more “adaptable systems” focused on livelihood resilience, as a response restricted to 'raising' the height of the dam has already showed its limits and its incremental cost.

Indeed, on the donors' side, the concern for the adaptation to climate change has been instrumental in renewing the interest for sound AWM investments that include water storage as a way to mitigate the impacts of increased rainfall variability.

The case for a new approach to water storage

Adapting to a changing environment

Everywhere, changes affect farmers and their production. New market opportunities, in particular, influence farming practices. On the technological side, the advent of cheap drilling and pumping technologies has revolutionized irrigation. Farmers can increasingly rely on their own resources to mobilise and manage water, and become progressively independent of the model of community-based, gravity irrigation. The AgWater Solutions Project has documented these changes, and the findings from the project suggest new thinking and highlight new opportunities as discussed below.

Rice-dominant irrigation downstream of a small reservoir is not necessarily the best or the only agricultural water management option anymore.

There is a growing recognition that irrigated rice (a thirsty crop[1]) is often not the best economic use of scarce water. To the extent that market linkages favour it, growing high-value crops such as vegetables are a much sounder use. In many places, rice production can be pursued with rain-fed rice (new NERICA varieties are significantly more productive under rain-fed conditions than traditional ones), or with improved management techniques – such as SRI[2]– using water-saving irrigation methods rather than continuous flooding as shown on research plots. However, the low cost of imported rice on the market makes it increasingly difficult for locally produced rice to compete.

Options exist to replace conventional gravity irrigation by pressurized irrigation systems.

It has long been a quasi-dogma that gravity irrigation was the option of choice, on the ground that its costs were inferior to those of individual or pressurized systems. However, conditions have changed, and the following points must now be taken into account:

1. Gravity irrigation is totally constrained by the topography and is therefore confined to the often narrow valley downstream of small reservoirs. Individual irrigation based on individual motor-pumps also has to take the topography into account for its design, but has the potential to overcome it as a constraint; in particular it allows for irrigation around a reservoir instead of only downstream. Besides, when extended to on-farm distribution (such as with localized irrigation) and pressurized, such systems can save more water than gravity irrigation.

2. Gravity irrigation infrastructures on flat lands are quite costly; their unit cost is often higher than that of pressurized systems; actually the respective costs have been going in opposite directions over the last decades: the costs of concrete works have been steadily increasing while the costs of plastic pipes and pumping have been decreasing.

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[1] Typical conventional rice cultivation uses 15,000 to 20,000 m^3/ha. Modern rice cultivation (thanks to appropriate varieties and water management practices) can use significantly less water; they however are more difficult to master and not easily transferred to traditional farmers.

[2] System of rice intensification (SRI): An integrated rice production system where yield increase is obtained through changes in management practices rather than by increasing inputs. Central to the principles of SRI are soil moisture management (no use of continuously saturated soils), single planting and optimal spacing, and transplantation within 15 days after germination.

3. The recurrent costs of gravity irrigation have been systematically underestimated (assuming unrealistic lifespan for the concrete works); as a result, insufficient routine maintenance allocations lead to considerable periodic (deferred) maintenance costs, and no satisfactory funding mechanism has been found so far to finance these recurrent costs.

4. On the other hand, there are nowadays technological solutions for small-scale low-pressure piped systems that require little or no fuel consumption for pumping/pressurization, hence considerably reducing recurrent costs.

5. Gravity irrigation implies a certain level of organization among water users to ensure satisfactory levels of operations and maintenance. The model of water user associations promoted in most cases has often shown to be much more difficult to implement than initially planned (see next section). Individual irrigation in many cases reduces the need for joint management and maintenance of irrigation infrastructures.

6. Surprisingly, donors and governments have been ready to finance costly SR-fed gravity schemes (in a bracket of 5,000 to 20,000 US$/ha), allocating sizable plots (0.2 to 1 ha) of irrigable land for free or at a nominal price to farmers – an actual subsidy of several thousands of dollars per beneficiary family - on the ground that these were "collective" infrastructures, the externalities of which would justify the high level of subsidy. In contrast, they were – until recently - adamant not to subsidize individual small-scale irrigation equipment that would allow irrigation to spread in many more places at a much lower cost. There are growing investments in pressurized irrigation. However that option requires discussion and good feasibility and benefit-cost studies to ensure that they are suitable.

Water user associations need to adapt to today's reality.

With the on-going societal, environmental and technological changes in SSA, a definite trend is emerging in the irrigation sector: the move from collective, gravity-fed, management-demanding schemes focusing on the production of staples, towards water-saving, on-demand, individually-managed irrigation installations increasingly dedicated to high-value crops (vegetables mostly). One system is not abruptly replacing the other; rather multiple systems coexist complementarily in various forms[3].

The old paradigm of small reservoirs, which were single-purpose, spatially-concentrated, collectively-managed systems, is progressively being replaced by a system which is multi-purpose, spatially more diffuse and "de-facto" poly-centrically-managed. This new pattern of irrigated agriculture is felt to be all the more manageable as interdependence among users is reduced to the minimum.

In reality, the emerging model for small reservoirs is probably located somewhere between the old model and the new model of fully individually-controlled irrigated agriculture that is progressively imposing itself (Table 2). This "new" SR model strives to combine the spatial flexibility and modularity allowed by pressurized irrigation with the economies of scale in principle derived from collective storage.

[3] For instance, in Burkina Faso, farmers have spontaneously occupied the reservoir shores of some SRs (or natural lakes/ponds) to engage into intensive vegetable production while in many cases, downstream gravity irrigation continues as before.

Table 2: The evolving paradigm of smallholder irrigation

Old model: Collective gravity irrigation with SR	Individually-managed irrigation with collectively-managed SR	Individual irrigation
Spatially concentrated in a few economically favourable sites if for irrigation or in suitable areas often remote when for livestock or soil and water conservation.	Irrigation is developed both upstream and downstream of the SR	Scattered
Minimum storage volume and/or minimum discharge required both for storage and for gravity irrigation	Storage in scattered downstream ponds may be fed from the SR	Discharge from the water source may be very limited
Rigid water distribution infrastructure	Irrigation equipment is much more "portable" and flexible	The irrigation equipment and service are not tied to the plot but rather can be moved from place to place
Unit investment[4] cost varies with scheme size and ranges between 0.5 and 2.5 US$/m^2 of crop.		Unit investment cost fluctuates around 1 US$/m^2
Scheme initially conceived for one purpose: either livestock watering or staple crop irrigation; it strives to reconcile *de facto* uses	As far as irrigation is concerned, dry season is dedicated to high-value crops; other water uses (livestock, fishing) are catered for thanks to water management rules to be elaborated.	Irrigation mostly dedicated to high-value crops. Irrigation water supply is separated from other agricultural uses

A variety of technical options

In this paper, we consider that there exists a **continuum** of water mobilization and storage measures, from on-farm soil and water conservation (SWC) to water harvesting (WH), to full water control, as in reservoirs (Table 3, Figure 3), of which SR[5] represent a range of water storage types. In this report, we exclude both extremes: on-farm soil and water conservation, and large dams, and focuses on intermediate storage options (types 3 to 6, with an emphasis on 5). More technical details are given in Annex 1.

[4] Economics should be assessed with a multiple use perspectives and not 'brought back' to only an irrigated area unit. Research should be done on that element.

[5] For the sake of simplification, SRs are referred to here as: ponds, water tanks and small dams

Table 3: A typology of water storage options with main uses

	Type of water collection and storage infrastructure	Main impact on agricultural water	Staple crop production	Vegetable and fruit production	Livestock	Fish	Domestic water wse	Energy	Other uses
Focus of this report	1. Soil and water conservation at field level such as: zai, half moons, contour stone bunds, etc.	Runoff collection for soil moisture replenishment	++	+	+				
	2. Seeping rock dykes ("digues filtrantes")	Local soil moisture and water table recharge	++	++	+		+		
	3. Water harvesting impluviums and hafirs; Charco dams	Runoff collection and reuse; minor water storage	+	++	++		++		
	4. Ponds and water tanks	Runoff collection and reuse; intermediate water storage	+++	++	+++	+	+		
	5. Small dams	Runoff collection and reuse;	+++	++	+++	++	+		
	6. Subsurface dams and sand dams	Groundwater recharge	+	++	++		++		
	7. Medium to Large dams	Multi-purpose water storage and management	+++	++	+++	+++	+++	+++	++

Note: OTHERS: i.e. handicrafts, brick making...
The number of "+" is an indication of the relevance of the measure for a given use

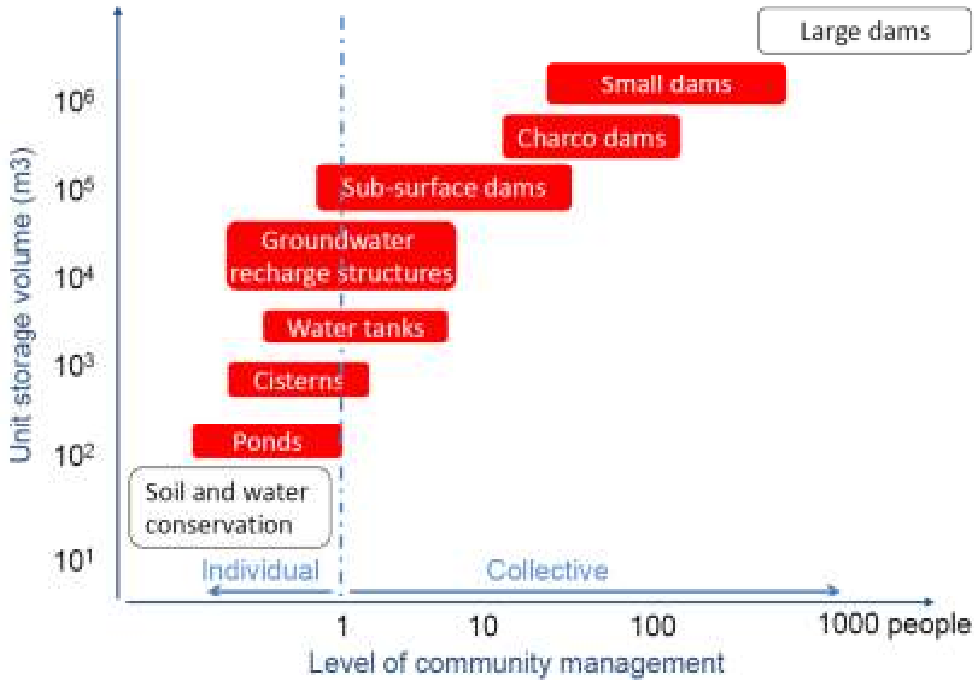

Figure 3: A range of water storage options

These different options have different characteristics in terms of volumes of water stored, reliability of water supply and costs. A rough estimate of cost per stored m^3 for various options is shown in figure 4.

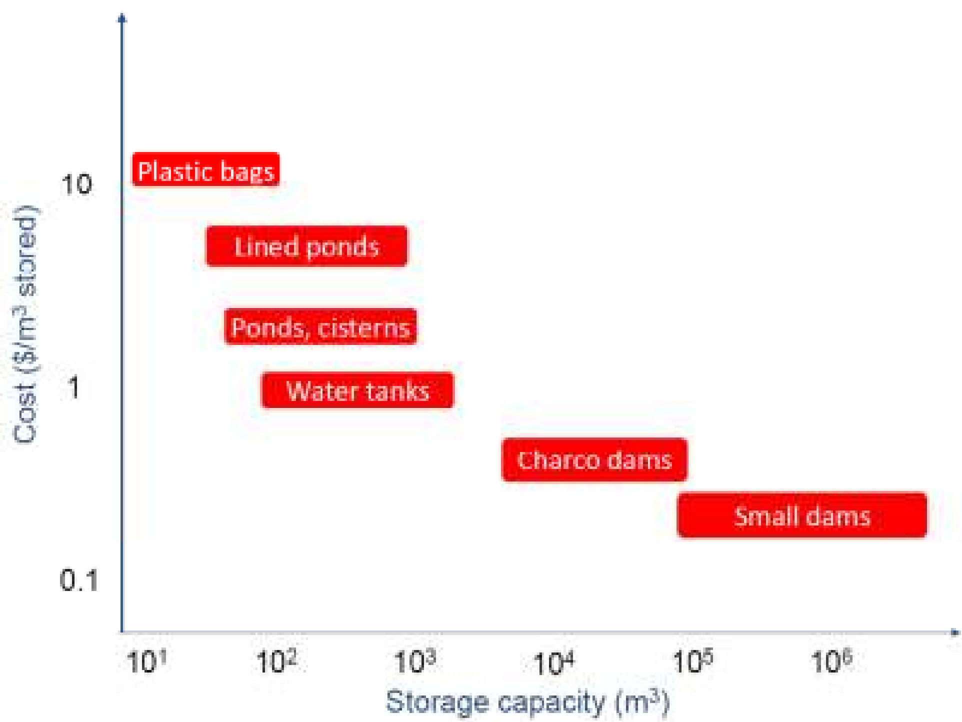

Figure 4: Comparing unit costs for different water storage structures

The need for a comprehensive approach

A series of conditions must be met to ensure successful investments in small reservoirs and other storage structures. They range from actions at the planning phase, through design and construction, to management and maintenance. Table 4 lists the major pitfalls that may be met at each stage in the process of planning to implementing and managing small reservoirs. The example is from Ghana but these types of problems can be found in many other countries.

Small reservoirs are often constructed in a series of projects funded by different agencies, at different times, with little or no coordination among the implementing partners. Collaboration, information exchange and stakeholder participation are now identified as key ingredients for success. While going through the series of iterative assessments of: costs, economic and social benefits, environmental impacts, that constitute a proper feasibility study, diversified and updated knowledge on many topics is mandatory.

Table 4: Deficient relationships for the planning, design, construction and management of SRs[6]

	Macro-level inadequacies	Daily working circumstances
Policy-making and regulation	• Non conducive Institutional/legal setting • Two-speed bureaucracy • Lack of transparency/ information	• Allow for, and cover up, fraudulent practices as they allow for "minimal functioning" of projects.
Identification, Planning and Financing	• Big-bang approaches • Pressure to disburse funds • Bias towards capital intensive options • Weak transparency and accountability –notably downwardly • Discrepancy between projects and national priorities and strategies	• Individuals are assessed in relation to the volume and numbers of projects rather than their outcomes • Projects buy-in political support • Covering up fraudulent practices (kick-backs) through design/overestimation of costs and complex procedures
Management & Program design	• Weak interactions, accountability and information flows between multiple nodes of decision making • Weak transparency and accountability –notably downwardly • Little attention/low quality of feasibility studies	• Project buy-in political support (influence site selection) • Covering up fraudulent practices (kick-backs) through design/overestimation of costs and complex procedures

[6] The second column of the table echoes the analysis of Morardet et al. (2005) in which a comprehensive list of failures in planning and implementing processes of irrigation projects is presented on the basis of an analysis (desk review and key informant interviews) of 23 irrigation projects funded by multiple donors.

	Macro-level inadequacies	Daily working circumstances
Tendering and procurement	• Procedures look good on paper but are complex and hardly enforced; • Absence of downward accountability and low levels of local empowerment • Low quality of design/bidding document • Lack of time/capacity to evaluate bids and manage contracts	• Award of contracts is a political action; not a bureaucratic one (selection of unsuitable contractors; covering of fraudulent documentation) • Tight network of actors, leading to collusion between public servants, contractors and consultants • "A token for our appreciation" is commonly accepted practice • Bribery (speed money) allows for decreasing transaction costs
Implementation, construction and supervision	• Weak interactions, accountability and information flows between multiple nodes of decision making • Delays (work and payment) • Little attention to supervision • Failure to comply with contracts specification and clauses • Absence of downward accountability and low levels of local empowerment • Low capacity and knowledge of contractors/consultants/supervisor	• Allow for, and cover up, fraudulent practices as they allow for "minimal functioning" of projects. • Supervising entities rely on contractors to conduct their work (leniency) • Tight network of actors, leading to collusion between public servants, contractors and consultants (leniency, kick-backs, overbilling, etc.) • Project buy-in political support (influence site selection)
Operation, maintenance & management	• Poor maintenance and low performance • Inactive/nonexistent Water User Associations (WUAs) • Inequitable/non respect of land and water allocation rules	• Project buy-in political support (influence users selection) • Opportunistic behaviors (WUAs set up to acquire project benefits) • Local practices favoring local elites

Source: Venot et al. 2012

The next sections of this note outline the elements of a comprehensive approach (figure 5) to enhance the benefits to smallholders of existing and planned storage, and hence to the society at large. The solutions are aligned along the following mutually-reinforcing axes of intervention:

1. **Ensure proper planning:** more strategic and better informed planning is needed to ensure the highest return on investment in water storage for agriculture. Donors and government-level decision makers must be aware of the variety of available technical options and their experts must consider this at early stage in the planning process. Small storage systems, distributed in the landscape, may be more effective in terms of livelihood support than larger structures where investments and benefits are concentrated over small areas. Cost-benefit analyses must consider the costs and livelihood impacts of a multiple uses of water approach, and integrate processes for stakeholder valuation. National-level planning must be based on a good understanding of the demand for storage, as well as on water availability, through an effective water accounting approach applied at watershed level. Finally, budgets for investment in water storage must provide resources for participatory planning/design and allocate sufficient time for it.

2. **Raise design and construction quality:** many storage investment programs fail because of poor design or implementation. Design must be done in close consultation with beneficiaries and multiple uses and users must be taken into account in the design of the structure, in particular for small dams. Engineers in charge of design should be aware of the range of possible options and of the importance to consider management issues in the design. In particular, designing to reduce the operational constraints and build flexibility in the use of water should be preferred even when implying higher investment costs. In arid areas, hydrological analyses must be conducted more systematically to avoid flood-related damages as well as over-dimensioning of reservoirs. Finally, much more efforts must be done to ensure the quality of construction processes through more effective procurement and better supervision. That element requires **time** even when the SRs designed are small.

3. **Make best use of storage infrastructure:** for both existing and future reservoirs, return on investment will be positive only if sufficient efforts are made to ensure their productive use by the intended beneficiaries. Multiple uses of water around reservoirs must be considered and encouraged and the right operational arrangements worked out so as to avoid conflict of usage. In particular, in the case of small reservoirs, upstream users of water (for farming, animals, domestic and other uses) must be supported and integrated with downstream users through sharing modalities that are both equitable and ensure high productivity of water use. Farmer knowledge on technologies, production systems and practices must be strengthened through appropriate extension modalities like the farmer field school.

4. **Adopt new water governance and management approaches:** institutional models for the governance of small reservoirs often do not match the reality on the ground and in particular, do not take into account the variety of stakeholders and beneficiaries. Customized arrangements must be designed that are anchored in the local context and make the best use of it. Existing or potential use of water must be taken into account and addressed. When instead of one SR, distributed systems of water control are designed, more attention needs to be given to the governance of the investment (planning phases) and the water structures that are built/rehabilitated. Finally, SR water management rules must include consideration for environmental impacts and be linked, when needed, to watershed and river basin level water management.

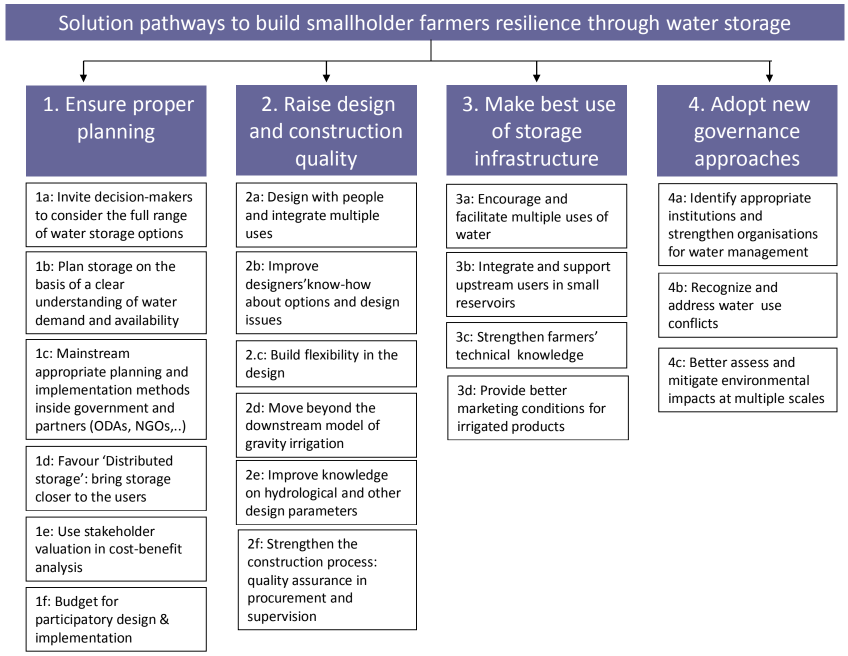

Figure 5: A set of mutually supporting axes of intervention

Axis 1: Ensure proper planning

What needs to be fixed?

It is widely acknowledged that there is room for improvement in the planning, management, operation, and maintenance of SRs. A good deal of action-research has been dedicated to various aspects of SR performance, but this process must be continued, starting from the initial stages of planning: awareness of available alternatives must be shared at all levels of decision-making, more time to be given to planning; and in particular time required to ensure good governance from the planning stage and enable downward accountability.

Solution 1a: Invite decision-makers to consider the full range of water storage options

Small reservoirs have often attracted donors' and governments' attention as they represent a relatively easy and *visible* investment and are usually in high demand from populations. However, they are not the only possible option for providing agricultural water to rural populations, and it is important that a careful review of all possible alternatives for water storage[7] is carried out to ensure that the most cost-effective and suitable solutions are selected. Decision-makers at all levels (especially within local government entities) have to be encouraged to make choices that will serve the interests of the intended beneficiaries more than provide short-term political rewards. In other words, it takes political determination to promote less impressive infrastructures for the sake of a more equitable distribution of benefits.

In today's prevailing conditions in SSA, small-scale irrigation schemes offer significant performance advantages over large-scale systems within irrigation investment projects. Therefore, large irrigation

[7] Annex 1 gives a simple description of the storage options earlier mentioned in Table 3.

investment projects supporting many small-scale irrigation schemes are likely to lead to the best results. This sounds like a revival of the "small is beautiful" motto. "Small" however does not mean un-ambitious: it is a large programme of "small" schemes that is advocated here. This implies to plan for a long time horizon and sustained commitment of both donors and government for impact.

Besides, the "smallness" referred to has more to do with the principle of subsidiarity than with size. There is a common understanding that "small-scale irrigation" essentially means "farmer-managed" – whether individually or collectively, with minimal or no involvement from external actors apart from the initial investments for some of them. The fact that the direct users are in charge of water allocation and distribution is assumed to result in 1) better management of the resource, 2) more benefits and 3) a more equitable distribution of them. In practice, this may occur, although not necessarily all these three aspects are improved.

As a matter of fact, there appears to exist a trade-off between the economies of scale derived from a collective water storage and the benefits associated with a simplified and more effective O&M (as a result of smaller scale individual structures). The cumulative (economic) costs of investment and cumulative benefits follow similar trends on a per ha basis (figure 6) due to the fact that economies of scale are associated with increased management complexity (hence less benefits).

This general trend of course displays different optimum, minimum and inflexion points according to the prevailing local conditions. The key questions then become: just how small is the storage infrastructure that will provide the best B/C ratio in a given setting? and What will change if multiple uses are considered?

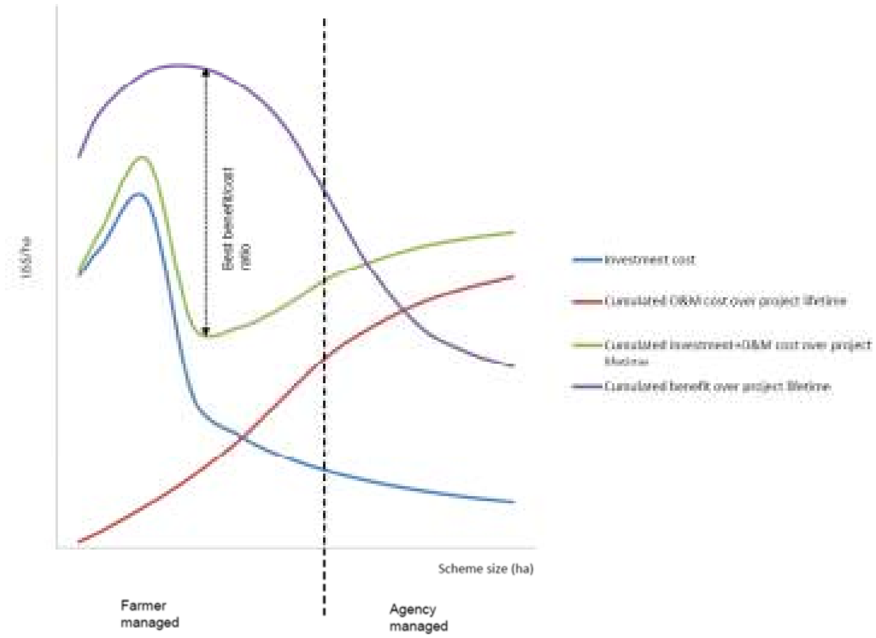

Figure 6: Evolution of costs and benefits of irrigation schemes in relation with scheme size

Decision makers must also start becoming accountable to users for their policy choices. Development of water storage is usually a costly investment, and the choice among different options, impact on people, issues of efficiency in the use of financial resources, and of equity in terms of distribution of benefits need to be made in a transparent and objective way. This is valid for all stages of development of storage infrastructure, from planning to design, construction and management.

Solution 1b: Plan storage on the basis of a clear understanding of water demand and availability

It should stand to reason that the first step in planning is to make an exhaustive inventory and balance of agricultural water demand and supply sources. Then, both the demand and the supply have to be thoroughly examined: demand must be commensurate with the necessities of local food security; supply comes from rainfall (which can be made more efficient through SWC on- and off-farm), from harnessed surface water (*inter alia* thanks to existing SRs), finally from groundwater (quite often, a neglected source in SSA for lack of appropriate water - lifting devices; water-table recharge structures can help make groundwater more readily available). All feasible sources of supply should be combined to match local demand. This step is particularly important as there is a very high local demand for SRs.

As the number of water users increases in a catchment, the need for careful water accounting becomes increasingly important. The use of participatory geographic information systems, combined with a rigorous water accounting, allows greater understand of the interactions between water users, and to take these into account in planning. Without such a review, the risk is that new investments in water storage will increasingly (negatively) impact existing water users and disrupt the existing balance of water allocation.

Solution 1c: Mainstream appropriate planning and implementation methods inside government and partners' agencies (ODAs, NGOs, etc.)

It is not enough of course to carry out the training of individuals and update their knowledge on water storage options and appropriate planning/selection methods; the improved procedures have yet to be streamlined in the administrative processes of the government and of donors alike.
The flowchart in figure 7 underscores some of the strategic technical questions which should be asked during the planning phase. In addition to those, this step requires building the basis for "good governance" of SRs to prevent potential corruption in procurement of other aspects highlighted in table 4.

Solution 1d: Favor distributed storage (bring storage closer to the users)

Some practical solutions to the planning issues as well as the willingness to give due consideration to the principle of subsidiarity[8] clearly suggest that it is preferable to locate – to the extent possible - the water storage as close as possible from the place of its use and/or of its users, that is: the hamlet or even homestead for domestic water and home gardening, the fields for irrigation, the pastures for livestock etc.

The design should thus tend to "deconcentrate" the uses and facilitate the autonomy of the users (make them the least interdependent as possible – in contrast with the situation of a downstream-of-the-dam gravity-fed irrigation scheme).

Although this approach will often not appear cost-effective in terms of investment costs, as larger structures usually benefit from scale economy, their lighter management costs often compensate for higher investment costs. However, distributed investments also would increase governance complexity at the planning stage.

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[8] The Oxford English Dictionary defines subsidiarity as the idea that a central authority should have a subsidiary function, performing only those tasks which cannot be performed effectively at a more immediate or local level.

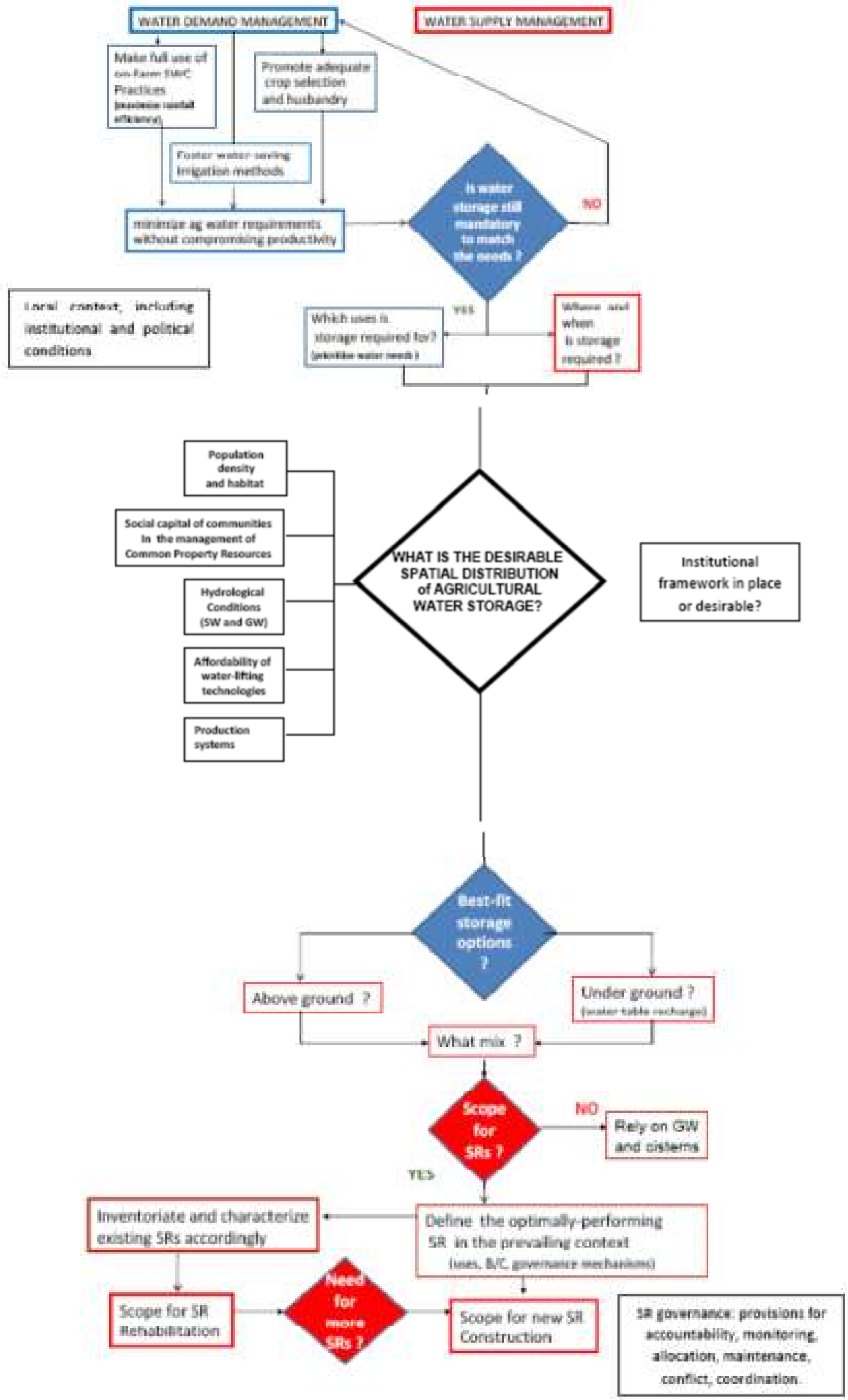


Figure 7: A flowchart for the planning of water storage investments

Solution 1e: Use stakeholder valuation in cost-benefit analysis

Conventional benefit-cost analysis falls short of capturing the actual value of stored water in all its economic, social and environmental dimensions. It is advocated that valuation needs to combine subjective stakeholder judgments with expert inputs, responding to stakeholders' needs and supporting communication, learning and negotiating among stakeholders.

As highlighted in FAO (2006): "Water valuation means expressing the value of water-related goods and services in order to inform sharing and allocation decisions. It covers both use and non-use values, extractive and in situ use values and consumptive and non-consumptive use values. The notion of scarcity is central and this can refer to aspects of water quantity and quality and can have both temporal and spatial dimensions. This scarcity may be induced by limitations of the physical water resources, the means to access them, or by inadequate management of the resource base. [….] A stakeholder approach to valuation requires stakeholder involvement throughout the process. The main aim of water valuation will not be to find the "true" value or the "right" answer to a problem but rather to help stakeholders reach a point at which they feel confident to take action. This involvement can be supported by tools for participatory problem analysis, especially visual modelling and diagramming tools. This gives local stakeholders a share in the creation and analysis of knowledge, providing a focus for dialogue which can be sequentially modified and extended".

Solution 1f: Budget for participatory design, implementation and monitoring

With the acknowledgement that community input is important at all stages of the design, construction and maintenance of any collectively-used infrastructure, the so-called "participatory" approach is nowadays considered mandatory (re. solution 2a). Indeed, even the construction process should mobilize the intended beneficiaries, at least in its monitoring. Participation implies dialogue and negotiation, time-consuming processes that also require specialized expertise. This has to be accounted for, both in the timetable of the implementation phase and in the investment budget.

Similarly, monitoring is often overlooked in planning, construction and implementation processes. Yet, without monitoring there is no possibility of feedback, and learning from successes and errors.

Potential benefits

<u>For planners and designers</u>

- A better understanding of the design process for storage infrastructures and of implementation constraints—and their remedies—will lead to sounder and more cost-effective choices for agricultural water storage.

<u>For farmers</u>

- Involvement in the design and implementation of the planned infrastructures will lead to a better match of the selected options with the felt needs as well as an improved understanding of the rationale for the choices made, hence a better sense of ownership and willingness to maintain the benefits stream.

Axis 2: Raise design and construction quality

What needs to be fixed?

The impact of SRs is manifold and their perceived complexity has greatly increased over time. A small reservoir is nowadays understood as an intricate social/environmental/economic entity with multiple forward and backward linkages (figure 8). Therefore, in spite of a wealth of experience and references in a variety of environments, the design and construction of a small dam still poses technical, environmental, organisational, governance challenges, particularly in increasingly decentralized political contexts. It requires multiple skills and should be the collaborative work of a team of experts in various disciplines, able to understand each other. It is essential to foster such open attitude and aptitude among the students in rural engineering and current practitioners.

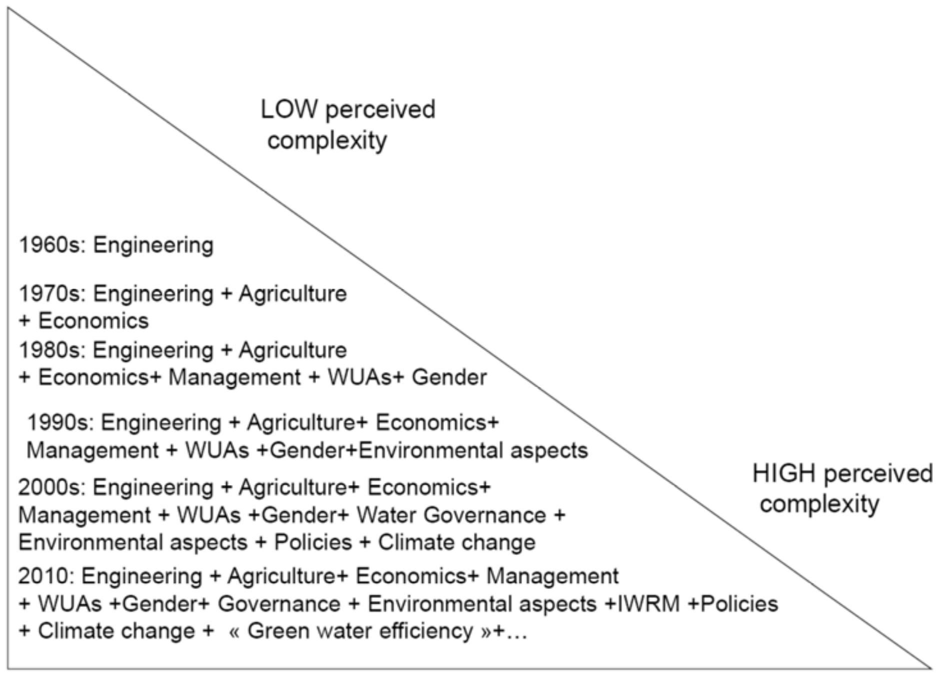


Figure 8: How the perceived complexity of water investments has evolved over time
Source: Huppert, 2006

Solution 2a: Design with people in order to integrate multiple uses

A water storage facility is quite often used for different purposes other than those originally planned. Much reflection has been dedicated in recent years to the concept of *Multiple Use Systems* (MUS) and its actual and expected benefits (see **www.musgroup.net**). However practical experiences with "MUS-by-design" systems – where multiple uses have been planned in an integrated manner from the beginning when designing and implementing a water storage investment –are still not common. Undoubtedly this approach should be more systematically developed. Multiple uses should be considered and catered for–even though the conclusion of the analysis may be that the planned type of water storage cannot serve several of the needed uses, which in that case, additional water-related infrastructures must then complete the provision of necessary water services (a typical case in point is that of the domestic water supply). Such an approach requires continuous interchange with relevant stakeholders (figure 9). It may also require inserting enough flexibility in the design to cater for latent future uses.

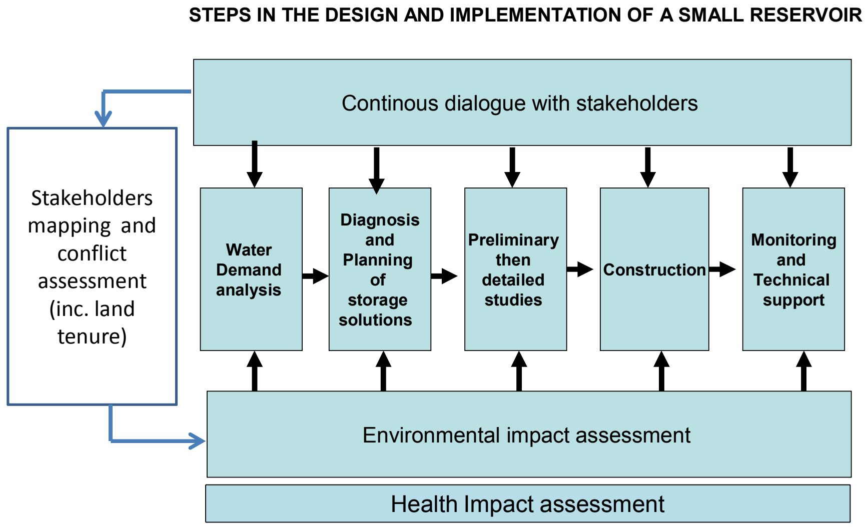


Figure 9: steps in the design and implementation of a small reservoir

The Small Reservoirs Project[9] recently produced a “toolkit” that comprises 30 documented tools, useful at various stages of the design, planning, construction phase of a new or rehabilitated small reservoir (Box 1).

[9] http://www.smallreservoirs.org/full/toolkit/tools.html#planning

Box 1: The Small reservoirs project "Toolkit"

I. Intervention planning

- participatory Impacts Pathway Analysis
- Stakeholder and Conflicts Analysis
- Creating common ground for Dialogue
- Monitoring change and adoption: Outcome Mapping

II. Storage and Hydrology

a. Reservoirs Ensembles measurement

- Reservoirs inventory mapping
- Small Reservoirs Capacity Estimation
- Near real-time Monitoring of Reservoirs with Remote Sensing
- Hydrologic Impact Assessment of Ensembles of Small Reservoirs

b. Hydrology and physical measures of performance

- Calibration of run-off models with remotely-sensed small reservoirs Rainfall-discharge relationship for monsoonal climates
- Deep seepage assessment in Small Reservoirs
- Evaporation losses in Small Reservoirs
- Water Quantity assessment of silted-up reservoirs
- Radionucleide tracer methods to quantify soil erosion and sedimentation at hilltop and reservoir scale
- Soil Erosion (computerized) Modelling at reservoir sc ale
- Identification of siltation rates by bathymetric surveys

III Ecosystems and Health

- Participatory health impact assessment
- Health Questionnaires
- Epidemiological survey
- Water-based diseases "vectors" survey
- Water Quality assessment
- Potential health hazards in tropical small reservoirs (cyanobacteria blooms)
- Agricultural intensification and ecological threats around Small Reservoirs
- Small reservoirs Water Quality Monitoring
- Indicators of performance
- Environmental flows in Small Reservoirs
- Fisheries in Small Reservoirs

IV Institutions and Economics

a. Water Allocation

- Water Evaluation and Planning (use of WEAP computer model)
- Financial Accounting Model
- Water-limited Yield Model
- Water Allocation Strategy for Small Reservoirs

b. Institutions and governance

- Institutions of small-reservoir water resources
- Influence Network Mapping
- Social Capital Assessment

Solution 2b: Improve designers' know-how about options and design issues

There will be no change in the design of small reservoirs if those in charge of it are not sensitized to the new design options. Engineers in charge of design of small reservoirs, both at government and consultant levels, need to be aware of the emerging trends in small reservoir utilization. Much more emphasis must be put, in education and training, on the necessity to adapt design to future uses and ensure that design responds to specific requirements imposed by local conditions. Obviously, this means that the design needs be context-specific (by "context" we mean the conditions prevailing in a relatively homogeneous zone in terms of agro-ecological and rural production systems).

In constant dialogue and interaction with the decision-makers and with the community of intended water users, designers have to address practical questions like:

- How much water must be stored? Where? For how long? What for (uses)?
- Who are the stakeholders / beneficiaries of the water storage (users)?
- Would the poorest (including women and youth) and marginalized groups be benefitting equally? (explore gender implications)
- What type of water storage (fully explore the alternatives)?
- How to implement the storage structures?
- Who will be the actors in the implementation process? What role can they play in the management of small reservoir? How to mobilize them?
- What will be the requirements for operation and maintenance of the created facilities? How will responsibilities be distributed? What are the short/medium/long term capacity building needs?

What are the steps from the current situation to the projected desirable situation: how to avoid the pitfalls and downsize or mitigate undesirable externalities? More broadly, there seems to be a need to train decision makers and engineers to community mobilization and participation techniques (i.e., include compulsory module in their curricula).

Whenever small reservoirs are envisaged as an option, the following design principles should apply:

- Minimize operational interdependency among water users of a single use (e.g., among irrigators);
- Enable/Strengthen any feasible combinations of uses (e.g., livestock + irrigation+ fish +...) and facilitate collaborative operation among users groups so as to gain synergies;
- Make most cost-effective use (including no use if deemed best) of every possible source of water. This includes minimizing the need for storage whenever possible through appropriate technology choices. For instance, low volume/ low discharge sources of water can be used with micro-irrigation equipment and the development of micro-scale but highly intensive crop production (home garden with vegetable cropping);
- Optimize the spatial distribution of water supply, so as to serve more people, and bring the supply closer to the homesteads;
- Try to minimize the influence of land tenure insecurity prevailing in many countries. For instance, the “portability” and size modularity of low-pressure irrigation equipment makes its users less vulnerable to tenure changes and more flexible in his/her search for irrigable land - as compared to the situation within a gravity scheme where the irrigation service is completely tied to the plot.
- Make sure that the users validate the design of the future works.

Solution 2c: Build flexibility in design

One of the main challenges for designers of water infrastructure is to find the right balance between cost-effectiveness and flexibility. On the demand side, farmers look for the highest possible level of flexibility and independence and view any management rule as a constraint. Typically, the need for joint management of water infrastructures, through water user associations, is usually seen as a burden by farmers. In the same way, rotations, or the sharing of pumping equipment, usually pose problems to users who prefer the flexibility offered by independently owned and managed systems. On the other side, increased flexibility in management often translates into higher investment costs. A good example is provided by rotation in water supply: less rotation and more on-demand access to water means higher discharge capacity for water conveyance systems and subsequently higher investment costs. The designer will therefore need to carefully assess the level of flexibility that is acceptable, both in terms of investment costs and farmers management capacity. An open process of consultation with future water users is necessary.

Solution 2d: Move beyond the downstream model of gravity irrigation for small reservoirs

The “downstream model” (figure 10) - currently prevailing in much of SSA - is that of a SR only supplying a gravity-fed surface irrigation scheme equipped downstream, most generally for rice production during the rainy season thanks to supplemental irrigation. In many instances and for a number of reasons, not all potentially irrigable land is actually farmed. During the dry season, the reservoir level is too low and its volume too reduced to serve the irrigation scheme, so that it is used mainly as a watering point for livestock; very limited vegetable cropping is done downstream as a result of temporary – seldom permanent - wells. In contrast with this, current knowledge and available technologies suggest a different development pattern (figure 11) – actually already pioneered by some entrepreneurial farmers:

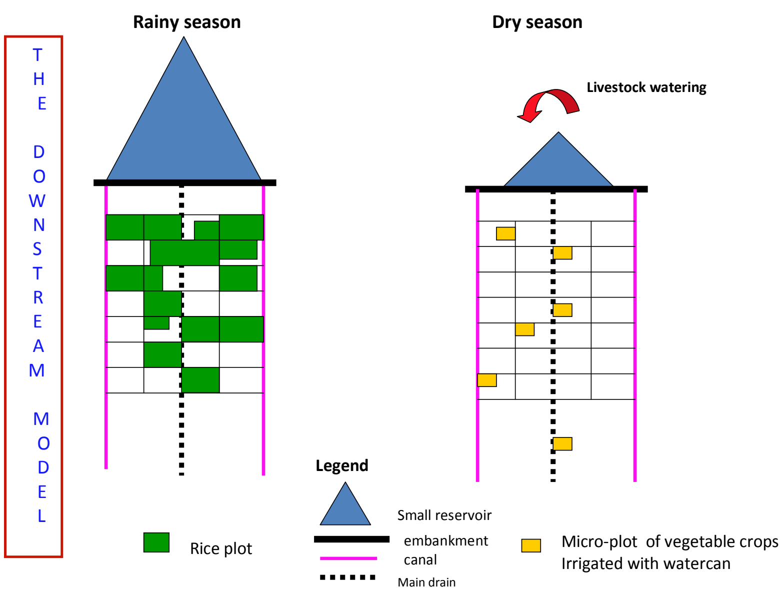


Figure 10: The “downstream” model of SRs

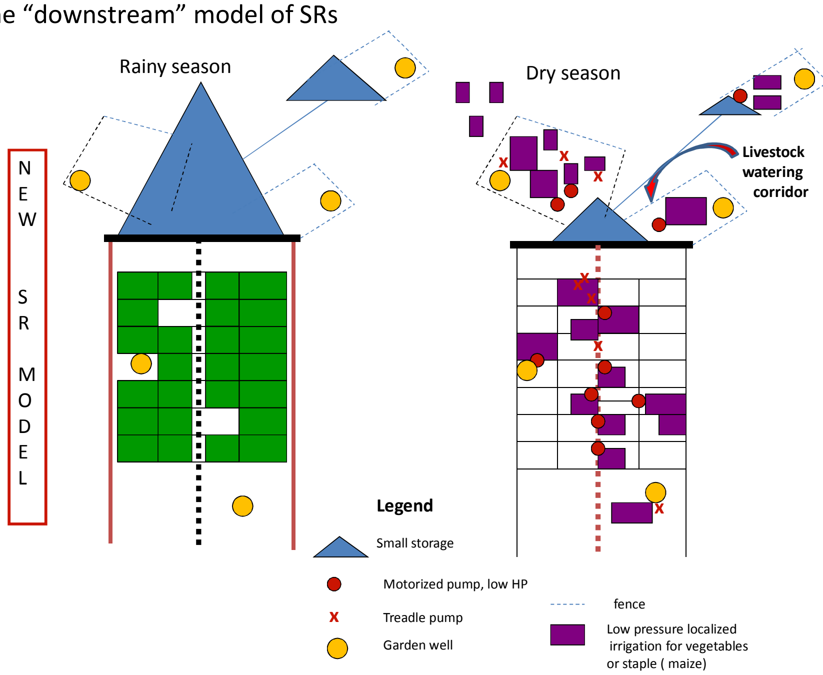


Figure 11: A more diversified model for SR development

In this “new” model – made possible thanks to the increasing affordability of water-lifting devices - the water storage is used in a more productive and more equitable way, including (through some permanent wells) the groundwater recharge generated by the presence of the water body. Since water lifting is not an obstacle anymore, the reservoir banks can be utilized, preferably for high value crops (vegetables) and with water-saving low-pressure localized irrigation.

In this model too, the flexibility in water management and reduced interdependence among irrigators are conducive to improved governance and conflict resolution over land and water rights issues, allowing both a more complete use of irrigation facilities during the rainy season and a larger number of irrigators to take advantage of the water storage during the dry season, both upstream and downstream. During the dry season, the central drain in the downstream area is actually used as a low discharge canal from where motorized and treadle pumps get the supply water.

However, promoting this new 'model' requires **more attention to governance and management issues (see Axis 4)**. Indeed, such a model goes together with potential conflict between downstream and upstream water users as pressure over the resource increases. In addition, there will be a need to mitigate negative externalities due to upstream use (health and water quality), the classic pastoralist/agriculturalist conflict and tension around land allocation close to the SRs.

Solution 2e: Improve knowledge of hydrological and other design parameters

Although a good deal of knowledge is available about the design of small dams (see e.g., Box 2 below), there may still be considerable challenges in a given set of circumstances, such as:

a) Technical challenges

(i) *Hydrological forecasts:* the standard calculations for the main hydrological design parameters (especially the design flood) are based on methods developed a few decades ago, very much on the basis of then available hydrology statistics. Unfortunately, in SSA particularly, the hydrological time-series data sets collected over the last 20 years or so - when available – are much less reliable and complete than they used to be (as a result of lack of funding of the rain and river discharge monitoring networks). Inter-annual and seasonal fluctuations of rainfall and runoff are not well captured, to which the climate changes (and changes in land uses) experienced in the region add substantial uncertainty.

(ii) *Lifespan assessment*: the soil erosion pattern in the water catchment has an important bearing on the siltation rate in the reservoir and consequently the evolution of its useful storage capacity over time, obviously impacting the quality and duration of the reservoir services (inter and intra-annually), hence its financial/economic feasibility. Likewise, the ex-ante estimation of losses from evaporation and –above all–deep percolation is not straightforward.

(iii) *Increasing variety of uses and users.* Quite a few SRs, originally designed as single-purpose infrastructures (in SSA, livestock watering has historically often been the primary function, followed by downstream irrigation) are now *de facto* used for multiple purposes, combining livestock watering, downstream and upstream irrigation, fisheries, occasionally domestic water, etc. To design a SR – or adapt an existing one – explicitly for MUS is an emerging concept (as described above), with few experiences available.

b) Environmental challenges (including health)

(i) *Environmental Impact Assessment and Management Plan.* There is still much to learn about the long-term ecological impact of SRs. The presence of a water body has numerous repercussions on the local biodiversity as well as on the health of nearby communities (prevalence of water-borne diseases, vectors etc.). Likewise, the changes induced in river regimes have to be assessed whenever the density of dams is very high and/ or the tapped watercourse has limited discharge. Again, a good understanding of a wide array of disciplines is required.

(ii) *Mitigation design.* Improving the assessment of the environmental impact of SRs will highlight both potentially negative and positive impacts. The negative impacts should not deter intervention but force the development of mitigation measures. For instance, knowing that the reservoir waters will not be drinkable without treatment, it may be advisable to either provide separate drinking supply (e.g. through adequately located boreholes) or to provide home treatment (filtering devices). Again, complementary investment in both hard and software will be mandatory. An environmental and health management plan has to be designed in parallel to the SR infrastructure design.

c) Organisational and governance challenges:

Both the infrastructure and management components of irrigation projects are critical. It is now well recognized that savings on investments in the design and construction phase often lead to higher management costs and more complex operations. Similarly, poor maintenance leads to rapid degradation of infrastructure and needs for frequent rehabilitation.

What kind of WUA should be promoted and what for? Since the early 80's, conventional wisdom has been that strong Water User Associations (WUAs) had to be established to manage the water use for irrigation and the collection and use of irrigation water service fees. This solution, initially conceived for medium to large-scale irrigation schemes as a substitute for the unsatisfactory and budget-hungry management by government agencies has been applied to SRs with little adaptation. It is now necessary to rethink the issue (see solution 4 a). Moreover, the slow and lengthy process of institutional strengthening often takes more time than initially planned.

All the aforementioned technical and managerial difficulties converge to make a strong argument in favour of simple-design, easy-to-build, easy-to-operate structures – (e.g., scattered, lined small ponds instead of one conventional, dammed small reservoir). Besides, the "MUS by design" concept may not be realized through a single reservoir/storage structure but rather require a combined storage system /network or cascading systems (figure 12).

Standard design issues for small dams/reservoirs in semi-arid areas are described at length in numerous recent valuable publications (Box 2):

Box 2: Selected references on the design of small dams

In English:

- 2010. FAO Manual of small earth dams. A guide to siting, design and construction. Irrigation and Drainage Bulletin n° 64 (also in Portuguese)
- 2009. FAO. Farm Ponds for Water, Fish and Livelihoods
- 2006. DANIDA/ASAL Consultants. Water from small dams by Eric Nissen-Petersen
- 2001. FAO Small dams and weirs in earth and gabions materials. Misc.Publ. AGL n° 32
- 1991. FAO. Water harvesting - A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production
- 1975-1982. FAO. Small Hydraulic Structures.

In French:

- 1999. EIER (now 2iE). Technique des petits barrages en Afrique sahelienne et equatoriale by J.M Durand, P. Royer, P. Meriaux.
- 1995. FAO. Crues et apports - Manuel pour l'estimation des crues décennales et des apports annuels pour les petits bassins versants non jaugés de l'Afrique sahélienne et tropicale sèche.

In Portuguese

- 1992. ORSTOM /SUDENE Manual do pequeno açude by F.Molle, E.Cadier
- 2011. FAO. Manual sobre pequenas barragens de terra. Guia para a localização, projecto e construção

In Spanish:

- 2007 Diseño de pequeñas presas. E. Martinez et al.

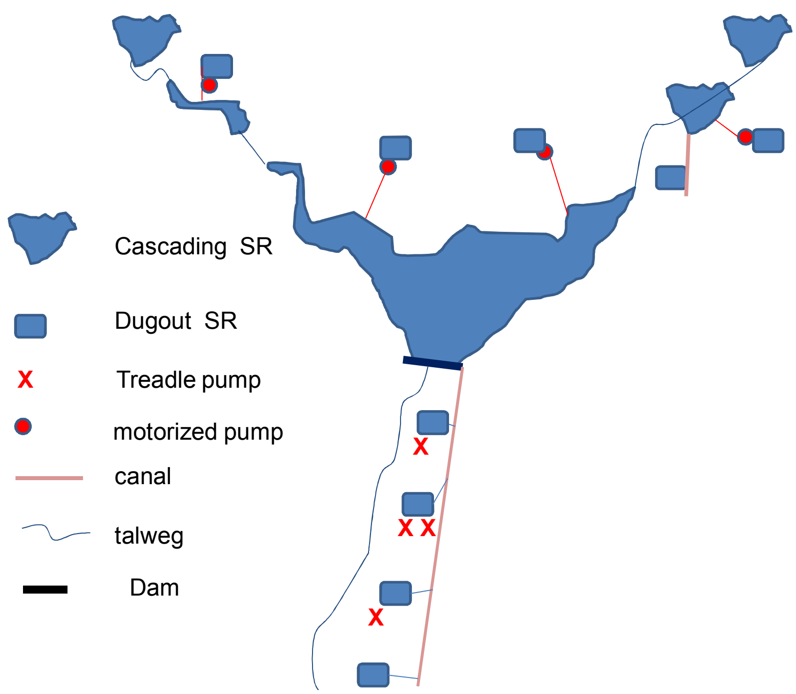


Figure 12: Schematic concept of a water storage network based on a small reservoir

Solution 2f: Strengthen the construction process: quality assurance in procurement and supervision

The design and implementation of a SR is a lengthy process. Implementation issues earlier mentioned in Table 4 are not specific to small reservoirs and may be experienced with about every construction project, particularly in rural areas (e.g. rural roads, and even buildings …) where the checks and balances exerted by the civil society are less. Possibly the phenomenon is somewhat exacerbated in the case of SRs in SSA, in as much as nowadays few local contractors and administration agents alike have significant experience with these kind of works, making quality control and financial monitoring even more challenging than with other types of works.

Unfortunately, to combat and resolve these difficulties linked to the construction process is a medium-to-long term undertaking that requires capacity building and change of attitude of the contractor community, consulting firms, civil servants in charge of technical and financial controls and the judiciary process (to monitor the implementation of procurement laws, of contract compliance, and apply sanctions when needed). This challenge has to be addressed on a national scale, and significant changes in this respect can hardly be relied upon in the short-to-medium term. One must still anticipate delayed implementation and cost overruns in SR construction and thus contingency measures must be planned in order to maintain the deviation within “acceptable” limits.

Damage limitations measures essentially include: (i) train administration and project officials on procurement, (ii) improve the preliminary costing of works, (iii) strictly apply prequalification criteria for contractors, (iv) strengthen the capacity of the supervisors, (v) enforce contractual clauses on delays, penalties etc. and, (vi) systematically opt for design options that are simpler and shorter to construct.

Implementation challenges is another strong argument in favour of “simple” infrastructures (which does not necessarily mean simple design), for instance replacing or complementing one small dam with a network of smaller tanks (with lower embankments and shorter construction times - see figure 11). With increased accessibility of affordable water-lifting equipment, this alternative infrastructure is increasingly feasible and attractive to farmers.

Potential benefits

For all stakeholders:

Better designed and constructed SRs (and other water storage infrastructures) will obviously render better services over a longer time period. Investing in capacity building - and in continued work on operational hydrology – is still needed to achieve this objective, and has the potential to give high returns in terms of securing the profitability of future investments in SRs.

For the farmers:

New design options provide more flexibility in the location of irrigated plots and more autonomy for each irrigator, which match farmers’ expectations. In addition, new SR design models may also support a more equitable distribution of the irrigation service and eventually contribute to livelihood improvements for a greater number of people.

Overall, the performance of SRs designed according to the “new” principles should be improved in terms of: (i) response to felt needs, (ii) benefits distribution, (iii) cost effectiveness, and (iv) sustainability.

Axis 3: Make best use of storage infrastructure

What needs to be fixed?

Obviously, though the reliable provision of water through storage may be a necessary condition for improving the livelihood of rural communities, it is not a sufficient one. Water may have been the prominent limiting factor but as soon as the constraint is lifted, the next-in-rank limiting factors repress productivity. A wide range of inputs is often needed so that farmers can reap the full benefits of the improved access to water.

Figure 13 illustrates this point in the case of farmers gaining access to irrigation through water storage, by showing a simplified causal relationship. It is clear that improving the performance of SRs requires improving the knowledge of the water users on how to optimize the use of water for their productive activities.

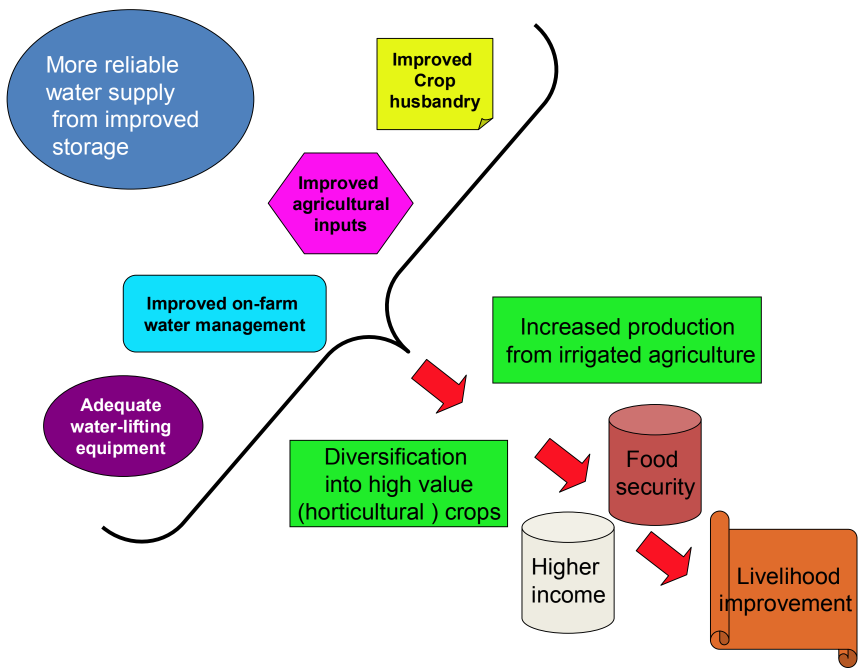


Figure 13: Improved water storage leads to better livelihood in as long as complementary inputs are provided

An alarming proportion of existing small reservoirs exhibit disappointing results in terms of livelihood improvements and benefits distribution. Sometimes the potential for storage and profitable water uses is still there, unexploited. In other instances, the potential has been more or less severely degraded as a result of reservoir sedimentation, infrastructures disrepair, lack of continuity in the capacity-building efforts, etc. Quite often, the situation can be substantially improved through (i) a more systematic diversification of water uses; (ii) the integration and support to upstream water users in small reservoirs; (iii) the introduction of appropriate irrigated farming technologies and know-how and better access to other production factors; and (iv) better access to markets for irrigated products.

Solution 3a: Encourage and facilitate multiple uses of water

Introducing new uses (see Table 1) can definitely be a way of changing the dynamics. In particular, the introduction – or expansion - of dry season vegetable cropping, not only downstream but also upstream of a small dam (see solution 2 c) is a major change with far-reaching implications and effects.

Any introduction of a new use will require significant capacity-building to absorb the consequences, not only in productive but also in organizational terms. Fishing in SRs is a case in point: the sustainable management of the fish resource will require technical and financial support in order to encourage appropriate equipment and non-predatory fishing techniques on top of clear and rigorously monitored reservoir management rules, accepted by all.

Solution 3b: Integrate and support upstream users in small reservoirs

To foster individual initiative in the framework of a multipurpose collectively-shared resource may require the combination of various technological "solutions": the new approach to SR development advocated here is made possible primarily thanks to the emergence of affordable small scale water lifting devices, whether motorized or hand-powered. These devices are necessary to allow significant agricultural development around the water bodies upstream of the dyke - or around a water tank.

Another complementary technological "revolution" is the emergence of affordable small-scale gravity-fed micro-irrigation systems (GMS – see Annex 3). These irrigation systems provide localized irrigation – a technique previously considered as quite sophisticated – on small plots, without resorting to pressurization other than by gravity, and using simple drippers (such as micro-tubes). GMSs currently exist that are quite easy to use for farmers, cheap enough so that their return on investment is of less than a year, and that can adjust to a large range of irrigable areas – from very small (20 or 50 m^2 for a home garden) to medium-scale (1000 m^2 or more for commercial vegetable cropping). These systems allow considerable water and labor savings compared to conventional surface irrigation. These GMSs can be quite versatile too, as they are comprised of independent, portable modules than can be supplied from a variety of sources.

These systems are particularly well suited in places where the topography offers opportunities for gravity fed water provision from small tanks located higher elevation than the irrigated plot. When this is not the case, care must be taken to ensure the additional labor required to raise the water level (e.g., through storage in a drum at a few meters elevation) is offset by the labor reducing micro-irrigation systems. Farmers will only adopt such systems if they are less labor intensive than more classical water cans.

Solution 3c: Strengthen farmers' technical knowledge[10]

Technical information and knowledge on technologies, production systems and practices in rural areas are currently deficient. Typically:

- NGO and government programs often promote a single "packaged" technology.
- Input and implement dealers sell what they happen to have in stock and are seldom active sellers.
- Quality control of inputs (seeds, fertilizers) and implements is inadequate as regulations are seldom properly enforced; and

[10] This paragraph draws on a companion text Supporting Smallholder Private Irrigation" produced by the AgWater Solutions Project and available at http://awm-solutions.iwmi.org. The two discussion papers clearly interface on the thematic of the productivity of irrigated agriculture and the profitability to farmers of high-value perishable produce such as vegetables.

- Extension workers nowadays only reach a very small portion of the farmers and don't have an adequate background on irrigation methods, management and equipment and have limited knowledge of horticultural crops and their requirements.

As a result many farmers hesitate to take any risk for fear of failure and falling into indebtedness. Others purchase whatever input or equipment is available in the nearest store and pay a price that is too high for the quality they get. For instance farmers tend to purchase motorized pumps that are ill-suited to the size of their land, and end up with high operation and maintenance costs.

Possible steps for remediation of these hindrances include:

- Encourage the establishment of a viable equipment supply/after sales chain and of a network of irrigation service providers (ISP)[11]. This entails:
    - Training local dealers, ISPs and farmers on technical aspects, brands and price ranges of pumps (both motorized and human-powered).
    - Training irrigation equipment dealers in better marketing / promotion and after-sales services provision.
    - Establishing – with dealers' contributions – demonstration plots where farmers can try out a variety of technologies before buying.
    - Developing illustrated manuals on equipment maintenance and repair in local languages.

- Team up with existing initiatives (such as AGRA, IFAD and other donors-sponsored projects) and build up on existing knowledge gained by NGOs to improve farmers' access to relevant agronomic and water management information with special emphasis on high-value crops.
- Support the farmer's field school approach that has proven beneficial for capacity-building in promoting good agricultural practices (pest, soil fertility management) and expand to land and water management.

Solution 3d: Provide better marketing conditions for irrigated products

Often, the performance of small reservoirs is constrained by the difficulties farmers face in marketing their production at an acceptable price. In areas that are relatively far from a marketplace, smallholders depend on middlemen (or women) to commercialize their produce. The lack of knowledge on up-to-date prices and the shortage of alternative buyers undermine the farmers' negotiation position. The lack of storage facilities for their products and the lack of cash force farmers to sell when everyone else does and prices are low.

A better organization of producers for marketing products can go a long way towards increasing the productivity of water in small reservoirs. There is a need to promote and assist farmers' organizations in strengthening their negotiation skills for effective commercialization, particularly of high-value perishable produce. Information on market prices is a powerful element of negotiation for farmers when selling their products. Access to (refrigerated) storage facilities is also an important element of a comprehensive strategy for promoting high value crops in irrigation.

Potential benefits

For smallholder farmers:

- Better technical information in the hands of smallholder farmers will empower them to make better decisions on what technology to use, and what price range, quality and type best fit their

[11] The concept is further explained in the AgWater Solutions business model on Irrigation Service Providers (ISP), available at: http://awm-solutions.iwmi.org. While the business model focuses on ISPs for motorized pump irrigation, the same concept could be applied for Gravity-fed Micro-irrigation Systems (GMS).

needs. This will lead to higher satisfaction rates and longer use as well as to lower running and maintenance costs and longer equipment life.

- Better agronomic information and more adequate on-farm water distribution lead to higher yields and less risks of crop losses. Better information on prices and training on marketing strategies should lead to a higher profit margin for the farmers

For all stakeholders:

- Improved profitability of existing and planned SRs.

Axis 4: Adopt new approaches to the governance of small reservoirs

What needs to be fixed?

"Governance is about effectively implementing socially acceptable allocation and regulation [...]. The concept of governance encompasses laws, regulations, and institutions but it also relates to government policies and actions, to domestic activities, and to networks of influence, including international market forces, the private sector and civil society" (GWP 2003). In the case of small reservoirs, water governance can be divided into the following four main elements, combined with the need for improved governance of investments and planning, as highlighted in Axis 1 (see figure 14):

- physical (hydraulic) system maintenance
- water allocation between uses and users
- coordination among users' organisations
- conflict management

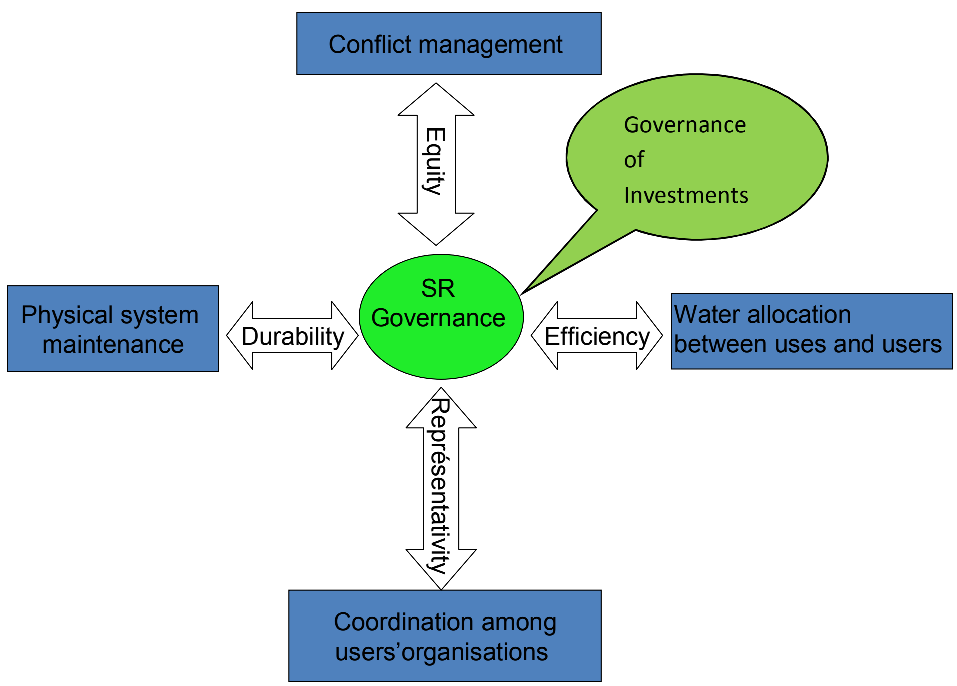


Figure 14: Water governance in small reservoirs

There is now a consensus that water resources development – in as much as it involves the exploitation of a common property resource – needs to be accompanied by appropriately-scaled social and economic institution-building so as to achieve more efficient, equitable and sustainable outcomes. In an increasing number of countries, an integrated water resources management (IWRM) strategy is being promoted, that is meant to set up the water governance structures at different levels**.** The desirable characteristics of these water institutions are context-specific and still remain in many instances an unresolved issue.

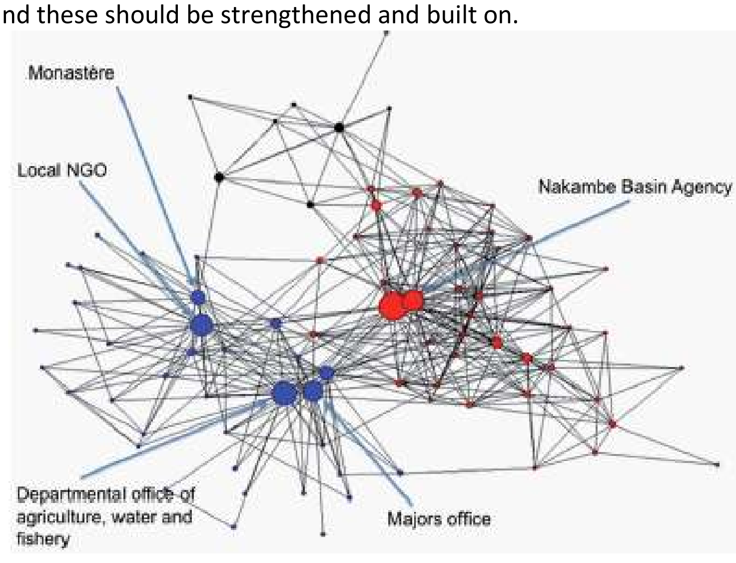
Although the most common case is that no "water governance" institution as such is in place where a small reservoir is planned, it is very likely that some sort of rules and agreements exist among the categories of water users over the use of common property resources. The existing social and cultural cohesion of the local groups should therefore be taken into account when crafting "water-focused" institutions. For example in Sub-Saharan Africa, traditional authorities (not focused on water) have an essential role to be considered in terms of land allocation and therefore should be involved (Box 3). Where traditional institutions pre-exist (such as in ancient farmer–managed irrigation schemes, a rare occurrence in SSA) there is compelling evidence that they should be taken into account, and "modern" institutions should be built upon them to the extent possible.

Box 3: Water storage in the *Nariarlé* watershed, Burkina Faso (Annemarieke de Bruin, 2011)

A diverse set of mainly informal institutional arrangements has emerged around the numerous small reservoirs in the *Nariarlé* watershed. Typically each reservoir has a small reservoir maintenance committee, as well as a gardening-, fishing-, livestock- and irrigation- group.

Sometimes formal organizations complement or overlap with informal arrangements. Over several decades the key actors have shaped the biophysical landscape and the institutional landscape.
The various committees and groups reservoirs tend to have rather localized interaction. It appears that there is currently no single organization that coordinates the diverse land- and water-related activities across the entire watershed.

However, there is a rich and diverse network of collaborative relations around land and water management and these should be strengthened and built on.



In Nariarlé formal-informal network analysis showed a clear disconnect between the Nakambe Basin Office (red) and actors connected to the Mayors office and Dept. of Agriculture, Water & Fishery (blue). Bridging this gap may enhance negotiation space of potential environmental impacts

Reasons for a suboptimal outcome of investment in SRs are many. The numerous case studies undertaken by the AgWater Solutions Project highlight the diversity of situations. Often, failures are rooted in the insufficient recognition of pre-existing land and water "rights" and customary uses.

Improving the state of affairs requires a diagnosis – sometimes already existing - for which tools and means are available. Correcting the situation, when needed, will take a good deal of consultations with the potential users, and an imaginative approach so as not to get trapped in models that have failed so far.

The necessary conditions for success of a SR could be described as:

1. The economic and social utility of the water stored by the SR (or network of SRs) has been durably optimized. This means that the uses for which the SR is (qualitatively and quantitatively) in a position to supply water, in a technically, environmentally and financially sustainable way, have been fully inventoried and acknowledged by the beneficiary communities. Ideally, complementary infrastructural and capacity-building inputs have been provided to cater for other water needs that the SR alone cannot fulfill.

2. The various users groups are: (i) organized by line of water-based production (e.g. irrigators, herders, fisher folk, etc.), (ii) adequately represented in an entity (a Water User Committee) recognized by all stakeholders and which has the authority and legitimacy, as well as the means to enforce agreed-upon water management rules (including financial contributions from individuals and groups), as well as conflicts resolution mechanisms. The Box 4 proposes specific roles for the "water users".

3. Other stakeholders (the administration, the supporting NGOs if any, the private sector actors) are engaged in partnerships with the users, seeking mutual benefits (figure 15).

4. The governance of investments and planning are in place with appropriate downward accountability mechanism among planner, government and communities.

Box 4: Rethinking the involvement of users

For the new model proposed, there is also a need to rethink the Water User Committee (WUC).

1. The WUC should have participated to the planning/design/feasibility phase of the project (while the WUAs are still set up *a posteriori*, even though they may exist on paper from the project start, they never actually input in the initial stage of construction/rehabilitation).

2. The WUC should incorporate (or at least be tightly linked to) not only users but also traditional authorities (notably for land conflict), public services (extension, technical expertise), decentralized government and possibly NGOs/market based institutions (traders, etc...).

3. The WUC would bring together government, users, user organizations, private sector and civil society/NGO. The details of the coordination would have to be designed based on context. This would facilitate the link to IWRM structures as well.

4. The spatial area overseen by the committee should be flexible and based on an assessment of water sources and uses at the landscape level (i.e. reservoir; reservoir + catchment; reservoir + catchment + downstream; watershed.... etc.)

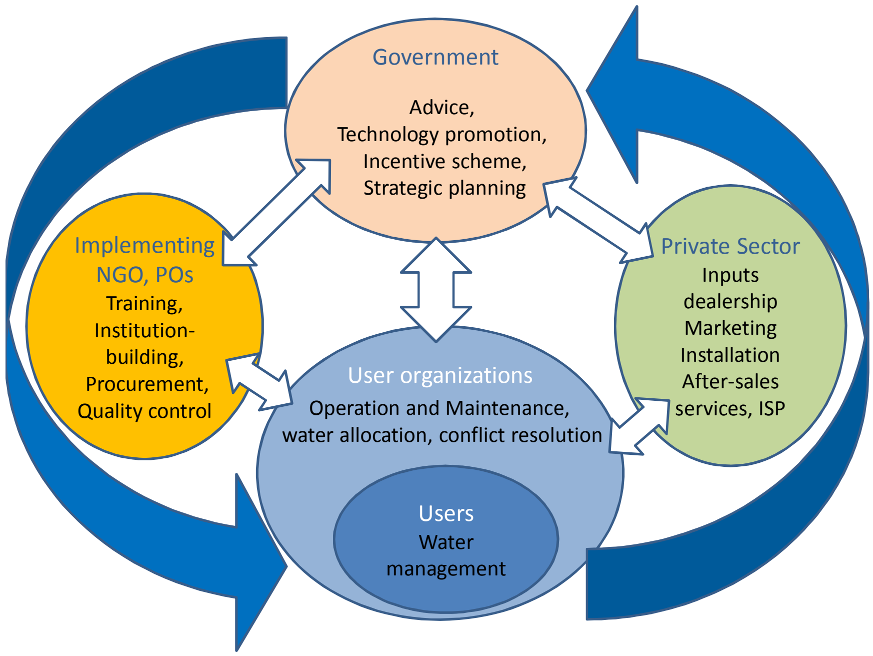


Figure 15: A possible distribution of roles for small reservoirs

Note: A key role of the water user committee is to strengthen the relationships between the users and the other actors - on a spatial area that needs to be defined based on the context.

Reaching the above-mentioned conditions is the leading thread for any undertaking, both in development of new small reservoirs, and in the rehabilitation of existing ones. Indeed, in SSA, a number of SRs have already undergone one or several cycles of “rehabilitation”. As a matter of fact, rehabilitation should not be limited to bringing the infrastructures back to their original state: instead, the opportunity should be taken to question past management models with the objective of establishing new relationships among the SR users as well as between the users, the local administration, and other stakeholders. In so doing, it is very likely that a new distribution of roles, rights, and responsibilities would be worked out. Regarding the devolution of responsibilities to the users, the key points are to match responsibility with authority and to ensure that sufficient time is given to the capacity development efforts needed to establish new governance mechanisms. This will only be achieved through building legitimacy and downward accountability.

Solution 4a: Identify appropriate institutions and strengthen organizations for management

As far as institution building is concerned, the standard response over the last two decades has been to create a “Water Users Association” –WUA, or Committee –WUC[12]. The roles devolved to the Water User Committees are in general terms to:

- coordinate with authorised provincial departments, local authorities, academic centres, private sector and NGOs for scheme development and maintenance

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[12] In most of the literature, the term WUC is used to designate organizations meant to manage domestic water, whereas WUAs refers to irrigation–related institutions. Actually, WUAs would be better labeled as “Irrigators Associations-IAs” while the WUC would correspond to the overarching executive body dealing with all water uses.

- act as a “point of call” for water users when issues of water management arise that they cannot resolve among themselves and to discuss these issues with local / sub-national administration in order to resolve them
- manage water allocation and resolve minor conflicts within the community
- encourage and promote participation of all users categories in decision-making
- organise the collection of service fees for O&M.
- disseminate government policies (e.g. on environmental issues) and report/share information with water users and other concerned stakeholders

Regarding the use of the water for irrigation, there is a wealth of literature on “participatory irrigation management- PIM” as well as on the formation of Water User Association for irrigation management. It is beyond the scope of this note to attempt a synthesis of such a vast corpus of experiences. Besides, cultural idiosyncrasy results in a significant context-specificity of the best practices in this respect. Among the detailed case studies carried out by the AgWater Solutions Project, there was no clear correlation between the level of satisfaction of local users and the presence or absence of a WUA. This may be because the WUAs often were more formal entities than functional ones.

However, in addition, the challenge for SR governance is not only to set up a WUC for irrigators, but also an institutional structure that will associate all users groups and have prominence over each single-use association. The IWRM-inspired institutional construction for water governance – ongoing in some countries (e.g. Burkina Faso) – is usually focused on a catchment scale that is well above that of a typical SR.

Consequently, there is no model yet for the typical WUC and the adequate institutional setup is still largely on the drawing table. One thing is certain: building a functional WUC takes time (several years) and a good deal of dialogue and capacity-building as many parties are involved: during the research carried out by the AgWater Solutions Project, at least eight groups were identified as contributors to the governance of small reservoirs by assuming different and complementary roles (table 5). Best practices should thus include:

- The provision of multiple organizational options (instead of one blueprint solution);

- Promoting an integration of traditional authorities and ensuring the representation of all stakeholders groups.

Table 5: Stakeholders involved in small reservoir construction and management

	Line ministries	Donors	Contractors	Local government	Traditional authorities	User committees/WUAs	Community	Farmers	Others
Construction	37	5	30	7	2	2	3	2	2
Major maintenance	37	12	6	21	2	7	4	2	3
Minor maintenance	4	0	0	5	5	37	43	6	2
Setting of management rules	4	0	0	4	22	43	21	6	2
Implementing, monitoring rules	5	0	0	4	13	50	22	5	4
Relation with other actors	11	1	0	9	12	42	18	3	5
Conflict resolution	6	0	0	9	61	23	12	1	2
Environmental protection	7	0	0	4	10	36	34	9	2
Extension role	58	2	0	2	2	5	2	0	6
Agricultural practices and marketing	13	0	0	1	5	14	12	46	6

Source: Venot et al, 2012

Solution 4b: Recognize and address land and water use conflicts

There are numerous reasons for promoting stakeholder participation, consensus building, conflict management, and dispute resolution in water resources management, the major ones being (IIED, 2011a; 2011b) to:

1. help meet the ethical dimensions of water management;
2. meet legal or formal policy requirements;
3. find and build common ground and move from extreme positions;
4. promote equity and efficiency and sustainability in water use;
5. reach durable agreements.

Creating irrigation facilities and allocating water rights raise land tenure issues that vary substantially depending on the size of the irrigation scheme and the legal regime applicable to it. Village-level irrigation schemes raise very different land tenure issues from large-scale, state-owned schemes. Projects designed and implemented by outsiders – whether government or development agencies – are more likely to be prone to manipulation by local actors and to produce unintended consequences.

It is thus essential to identify potential resource conflicts: many arise because of a failure to discuss and agree upon rules in advance among all stakeholders. The existence of some rules dictated by tradition and others by the national legal framework leads to different understandings and different responses and hence potential conflict. A lack of transparency when defining a rule (for example, plot allocation or water distribution criteria) reinforces the suspicion that this rule is neither legitimate nor fair. The existence of written documents helps prevent different interpretations of the rules and agreements arising between stakeholders. Once established, rules should only be changed with the consent of all stakeholders.

To be effective, the rules must then be accompanied by monitoring and enforcement mechanisms. Often, it is the failure to enforce a particular rule that leads to conflict. Once a conflict has arisen, mediation mechanisms are needed to find a solution between the different parties.
A smooth management does not mean that there will be no conflict but that whatever conflicts arise can be resolved at the local level without external intervention. Addressing and solving conflicts requires substantial capacity-building but can very positively influence the performance. Thus the time and money invested in it will likely have high returns. Traditional authorities have a key role to play in conflict resolution but care has to be given so mediation does not occur at the benefit of the local elite.

Solution 4c: Better assess and mitigate environmental impacts at multiple scales

Taking water from its natural course will generally have impacts on downstream users and the environment. In some conditions, the presence of ponding water can turn into a health hazard. Hence the importance of having a health and environmental impact assessments performed when planning small reservoirs. Though formally mandatory in most countries, the exercise is seldom carried out thoroughly enough. This state of affairs must be rectified (re Axis 1).

Potential benefits

Water governance mechanisms at the scale of a SR are still very much in the test stage. However, a wealth of knowledge has been accumulated on the topic and the understanding of the issues at stake has improved considerably. It is important to keep experimenting on how to improve the participation, accountability, legitimacy and sense of ownership of the users, necessary conditions to trigger a successful development and benefits sharing from the SRs.

Conclusion

A critical look at their current performance shows that small reservoirs-particularly in SSA- perform well below expectations when it comes to irrigation. By contrast, they provide multiple benefits that are often unaccounted for to multiple users.

With on-going societal, environmental, technological changes, a definite trend is emerging in water management for agriculture: a move from collective, gravity-fed, management-demanding schemes focusing on the production of staples, towards pressurized, on-demand, individually-managed irrigation installations increasingly dedicated to high-value crops (vegetables mostly). One system is not abruptly replacing the other; rather they coexist in various forms of complementarity.

In today's prevailing conditions, small-scale infrastructure offers significant performance advantages over large-scale systems within AWM investment projects. Therefore, in SSA where there is ample room for water development in agriculture (in terms of land and water availability as well as demand), large investment projects supporting a distributed system of water control are likely to lead to the best results. These small-scale schemes will generally have to be fed by water storage structures.

However, such large investment projects supporting distributed system of water control are more difficult to plan and monitor than large investment in a single place (i.e. large dams). This means that particular attention must be given to planning stages of investment and governance (both of the investment and the water control structures, once they would have been build/rehabilitated).

In recent decades, the dominant option has been to resort to small dams to create small to medium-sized reservoirs. There is a growing recognition that these are not as simple to design, construct and manage as earlier perceived, and that they would be more efficient if all potential uses and users were taken into account from the planning stage onwards. Besides, for equity and efficacy purposes, water storage structures should be better spatially distributed so as to be as close as possible to the users.

The model of gravity irrigation downstream of small reservoirs that has prevailed for many decades is progressively being challenged. A number of technologies are available nowadays – particularly cheap and easy-to-use water-lifting devices as well as affordable localized irrigation equipment - that can take advantage of smaller water discharges and volumes in a much more distributed way. They allow for irrigation units to be smaller and more spatially scattered and free water users from most of the burden of collective water management. The design and management of water storage structures have to adapt to these new potentialities.

Both the investment (hardware) and the governance (software) components of agricultural water storage projects are critical. Underinvesting in software can lead to significantly higher hardware costs and lower project performance. This report proposes a series of actions to improve the performances and return on investment of small reservoirs. This includes investing in good planning, design, construction supervision, training for water management, capacity building for institutional development for the benefit of users and managers of agricultural water storage systems. The performance of both existing and future SRs will greatly benefit from such efforts, ultimately helping rural people to enhance their food security and improve their livelihoods.

Expert opinions on the appropriateness of small reservoirs and of the options presented in this paper may vary; as a development practitioner, one may subscribe to the statement that “the events become secondary to their interpretation; projects do not fail (or succeed); they are failed (or made successful) by wider networks of support and validation” (Mosse, 2004). From the intended beneficiaries’ viewpoint, however, the assessment is more straightforward: to them, a water storage project will succeed or fail, depending on the benefits they perceive from it. In evaluating a SR’s performance and valuing the water services they get from it, they will have the last word.

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List of acronyms

AWM	Agricultural Water Management
GMS	Gravity-fed Micro-irrigation Systems
GW	Ground water
INGO	International Non-governmental Organization
ISP	Irrigation Service Provider
IWRM	Integrated Water Resources Management
M&E	Monitoring and Evaluation
MUS	Multiple Use Services
NGO	Non-governmental Organization
ODA	Official Development Agency
O&M	Operation and Maintenance
PO	Producers Organization
ROI	Return on Investment
SR	Small reservoir
SSA	Sub-Saharan Africa
SW	Surface Water
SWC	Soil and Water Conservation
WUA	Water Users Association
WUC	Water Users Committee
WH	Water Harvesting

Annex 1: A brief description of small reservoirs and storage systems

Dugout ponds or "water tanks"

1. The Indian "water tank"

In many parts of India and in the "dry zone" of Sri Lanka the man-made water tank ("johad" in Rajasthan), usually a dugout with a consolidated embankment and sometimes water harvesting structures connected to it, is an essential feature of the villages (photos A1 and A2); generally used for all water needs, it often dries out before the end of the dry season but provides considerable help to the villagers. Such a structure is rare in Africa –especially in western SSA (where it is called "mare" or "bouli"), being considered costly (over 1US$/$m^3$ of storage) and because the topography generally makes water lifting necessary to use its waters. Now that pumps- whether motorized or human-powered (treadle) pumps - are becoming much more available, the dugout tank is a solution that can better serve scattered settlements, rather than a larger dammed SR- the location of which is imposed by the hydrography – whereas the positioning of smaller water tanks is more versatile.

(on the right hand corner, one can see the suction pipe of a treadle pump)

Photo A1: A village water tank in Orissa (Photo: Pradan)

These structures can vary widely in size and can be individual or collective. In Dewas District, Madhya Pradesh, India more and more farmers are building individual tanks on a tenth or twentieth of their land. For medium to large farmers, these storages are large and can be built in cascades. In West Bengal, hapas are small ponds built on a 5th of the farmer lands manually.

Photo A2. A newly-dug farm pond in Thailand (photo IWMI)

2. The "Hafir"

In semi-arid parts of Sudan, the "hafir" is a reservoir designed for storing rain water carried by streams and used for domestic water supply as well as agricultural purposes in rural areas. It is designed to be big enough to cater to the needs of the villagers and their livestock for a whole dry season. Contamination is therefore a major consideration. To prevent livestock and washing contaminating drinking water an outlet can be made to another storage tank/ well, where water can be extracted for domestic purposes. The main body of water is often fenced off.

The average capacity of a Hafir varies from 15,000 to 250,000 m^3. There are different types of hafirs e.g.:

- Conventional hafirs (underground)
- Lined hafirs.
- Over ground storage hafirs. The hafir is then surrounded by earthen embankments and protected by barbed wire fencing against animals. The shape of the hafir is like a truncated frustum of a pyramid (Photo A3).

The hafir consists of the following parts:

- The main reservoir, into which the water is collected;
- The water inlet structure, generally comprised of a settling basin for deposition of the suspended material in the water prior to its entrance to the reservoir, inlet well and pipelines for water conveyance inside the hafir, with a stilling basin at its end to dissipate the kinetic energy of the flowing water ;
- A water outlet, including pipelines extending from the inside to the outside of the hafir, ending with a water distribution well;
- Backfill sides, comprised of the excavated material and put around the hafir to protect it and to prevent residents and animals from contaminating it.

Although primarily designed for drinking water, the Hafir could partially provide water for home-grown gardens using water-saving irrigation methods (e.g. affordable / low pressure/ localized)

Photo A3. A Hafir in Kordofan, Sudan (photo Papyrus association)

The Hafir will usually dry out, after a time that is of course highly dependent on the reliability of its supply as well as of the characteristic of the soil where it is dug, in particular its permeability (percolation is usually a major source of water losses). Modern technology allows some significant improvements, such as the lining with geotextiles (see below).

Some “new” storage devices

3. Small lined ponds

The relatively recent availability of sturdy geotextiles/waterproof plastic sheets makes it now feasible to easily make impervious a pond bottom and sides, thus eliminating percolation losses at an affordable cost. The pond (Photo A4) can be any size and shape, holding from a few tens to a few thousands m^3. The cost per m^3 of storage volume will of course be higher than with no lining, but the cost of the available m^3 of water will be lower. The lining will often need be protected (by a fence) from livestock trampling. Average storage cost will likely be in the range of 3 to 5 US$/$m^3$ stored.

Photo A4: Small lined pond (photo: iDE)

4. The plastic water bag/cistern

iDE India has successfully tested a $10m^3$ plastic water bag that can be used to store water – whether harvested or from a reservoir or tap water – and supply a drip irrigation kit (photo A5). The volume is enough for the drip irrigation of 200 m^2 of full-grown vegetables during 10 days.
The cost of the water bag is around 100 US$, i.e. 10 US$/m^3 of storage) but the device is not yet commercialized because the manufacturers require large quantities to be ordered before launching mass fabrication.

Photo A5: Plastic water cistern (photo: iDE)

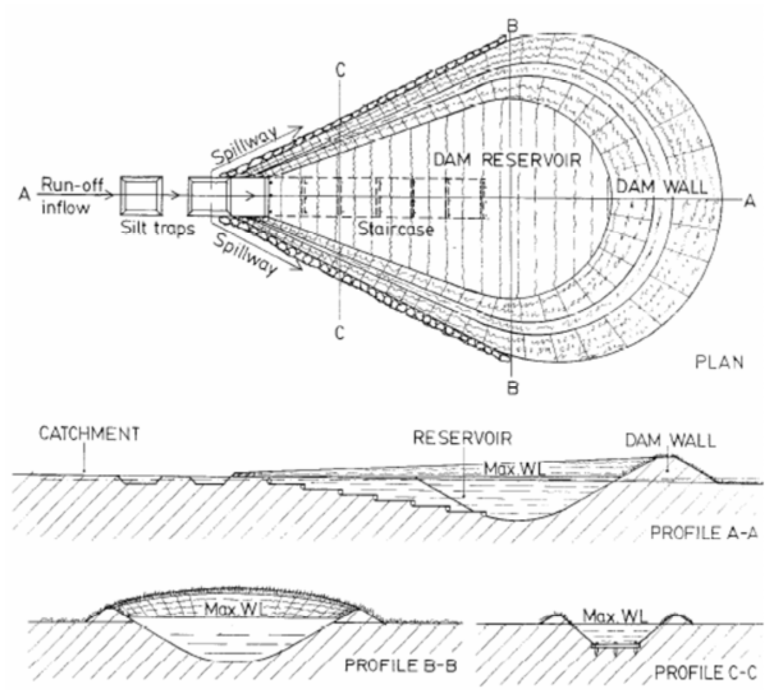
In areas where water is pumped from deep wells or in small irrigation systems with low-pressure supply (the so-called "Californian type" that has been promoted in recent years in some parts of SSA), this may be an efficient intermediate individual storage. The "Californian" network may itself be supplied from a conventional SR.

From the dugout to the dammed small reservoir

Some storage structures, smaller than the average dammed SR built across a valley, are meant to store collected runoff of a volume that goes from a few thousands to sometimes hundreds of thousands of m^3. They have hybrid characteristics between the simple dugout and the small dam.

5. The "Charco dam"

The Charco dam (Figure A1), very popular in countries like Kenya and Tanzania, is built around a natural depression or man-made dugout, with an embankment increasing the available storage volume.



Recommended plan and profiles for a standard design of charco dams.

Figure A1. Layout of a Charco dam (Source: DANIDA/ASAL)

6. The conventional "small earth dam"[13]

A small earth dam can provide a cost-effective method of storing larger volumes of water (Figures A2 and A3). Compared to a dugout, the construction costs for a dam can be much lower per gallon of water stored. The reason for this cost efficiency is that a dam can store water both behind the dam as well as in the excavated portion of the reservoir where earth fill is obtained for its construction. With dugouts, all the water is stored in the excavation itself.

Small dams have a much larger surface area than dugouts and are often shallower. As a result, dams have both higher evaporation losses than dugouts and poorer water quality. Small reservoirs also serve to recharge the water table. Water for drinking purposes is better extracted downstream of the reservoir, from a well (Figure A4).

[13] Ref: Gov. of Alberta, CANADA. Farm and irrigation extension

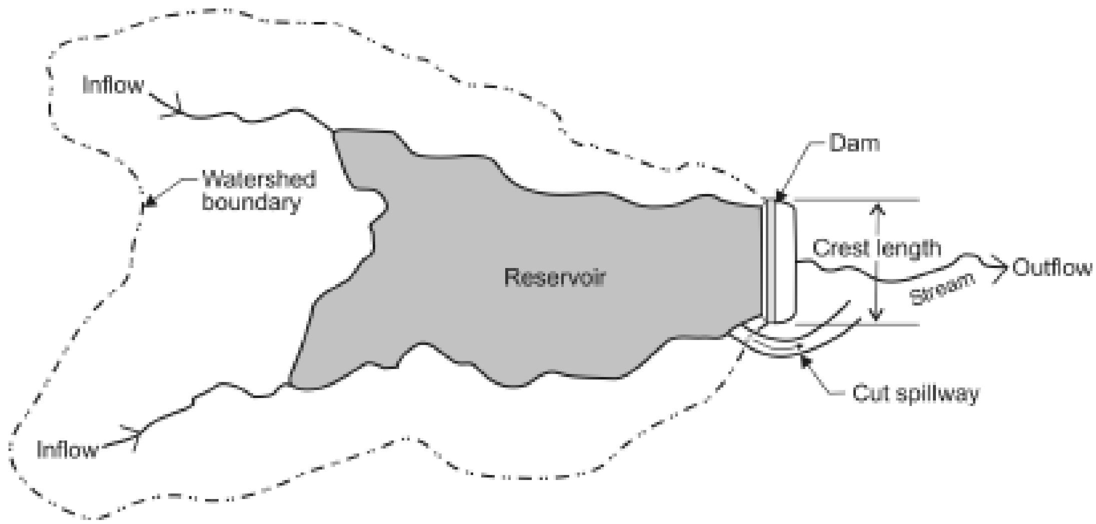


Figure A2: Plan view of dam and reservoir (Source: WEDC, UK)

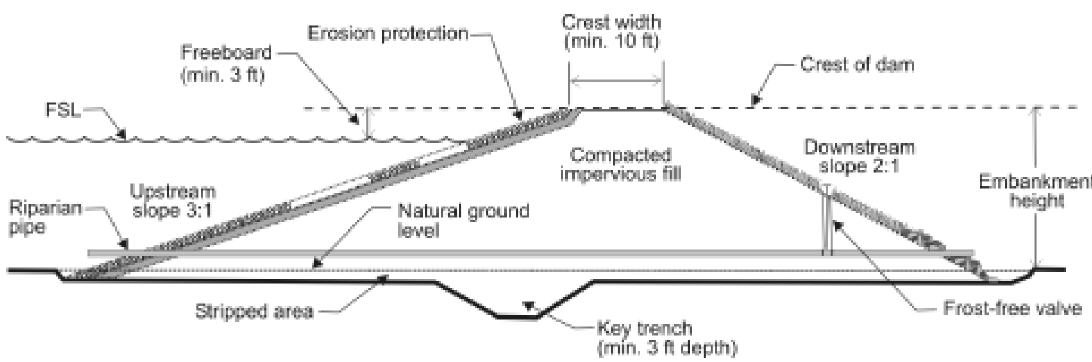


Figure A3: Cross-section of an earthfill dam (Source: WEDC, UK)

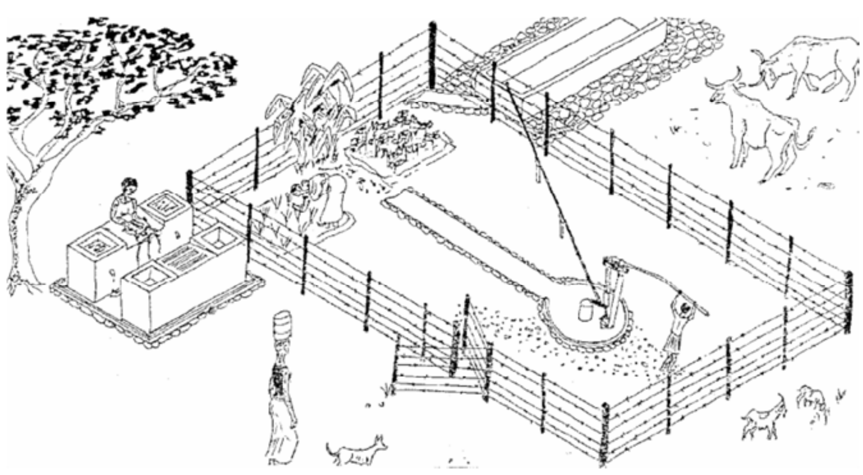


Figure A4: Washing stands and a watering trough at a hand-dug well downstream of a dam
Source: DDE/Zimbabwe, FAO, 2006)

Underground storage

Water for drinking and irrigation purposes in semi-arid/arid areas may be better stored as shallow groundwater rather than surface water. This reduces evaporation losses considerably, and the water stored is both filtered through the soil layers and can more easily be protected from pollution sources. Although the hydrological/physiographic conditions for such storage to be feasible are not commonly found, the option should be fully exploited wherever it makes sense. Technical solutions comprise three types of infrastructures that all must be placed in a thalweg where an ephemeral watercourse occasionally flows. Roughly from the driest to relatively less dry conditions, these are: (i) subsurface dams (blocking underground flow), (ii) sand storage dams (usually partly underground partly above ground, these structures build storage capacity over time in retained sand sediments); (iii) pervious or semi-pervious rock dykes/check dams used to slow down temporary flows and facilitate infiltration in the soil upstream, hence the recharge of an existing perched water table.

7. Subsurface dams [14]

A subsurface dam (Figure A5) is built entirely under the ground; it intercepts or obstructs the flow of an aquifer (or ephemeral river) and reduces the variation of the level of the groundwater table upstream of the dam. A trench is dug across the valley or stream, reaching to the bedrock or other stable layer like clay. An impervious wall is constructed in the trench, which is then refilled with the excavated material.

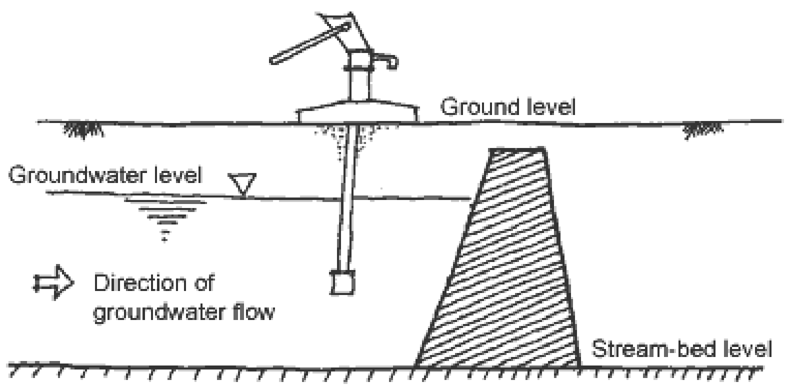


Figure A5: Sub-surface dam

8. Sand storage dams

This structure is constructed above ground. Sand and soil particles transported during periods of high flow are allowed to deposit behind the dam, and water is stored in these soil deposits. The sand storage dam is constructed in layers to allow sand to be deposited and finer material be washed downstream.

The best sites for construction of groundwater dams are where the soil consists of sands and gravel, with rock or a permeable layer at a depth of a few metres. Ideally the dam should be built where rainwater from a large catchment area flows through a narrow passage. In all cases, the stored water can be lifted (with a bucket or a hand pump) from wells dug upstream and close to the dams or, as in the sand dams, from a collector pipe.

[14] Ref. 2.8 gives example of design of such structures

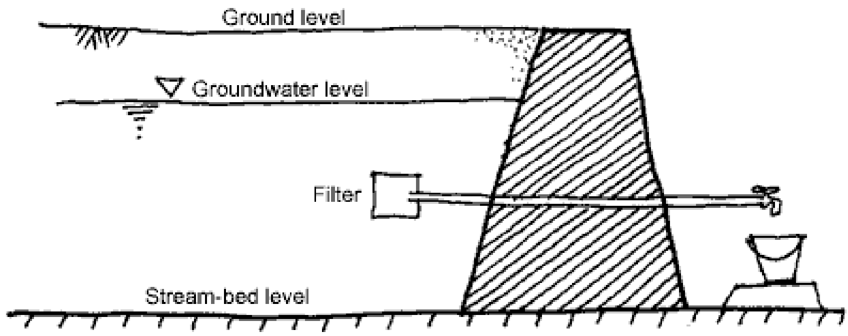


Figure A6: Sand storage dam
Source: Water in dry river beds DANIDA/ASAL Consultants

9. Permeable rock check dams

Mostly used in western Sahelian countries such as Burkina Faso, Niger, Mauritania, these are dykes made of loose rock or occasionally gabions (figure A7), built across a lowland thalweg (or a gully) where runoff water concentrates; the dyke slows down the flow and spreads it in its upstream, reducing erosion and at the same time improving water infiltration in the soil and eventually water table recharge. These belong to a family of soil and water conservation measures that actually go from contour stone bunds to the full-size rock/ gabion dyke (anyway of less than 2m high) to a "semi-filtering dam" that can be built to partially divert the runoff towards a storage structure such as a pond. It is often beneficial to locate this type of dam where there are high sides so as not to risk huge areas of flooding behind the dam and the creation of large shallow pools. Where back flooding does take place it is often necessary to build embankments to protect the village etc.

Where dams are on a prominent slope the dam edges are swept back to follow the contours, on flatter slopes the dam may become straighter acting as a spreader onto the flood plain. Dam designs may also include spillways, sluice gates, channels and embankments to allow control of the water at times of flood. The technique and design parameters are fully described in a series of publications by GRET (in French – ref. 2.9)

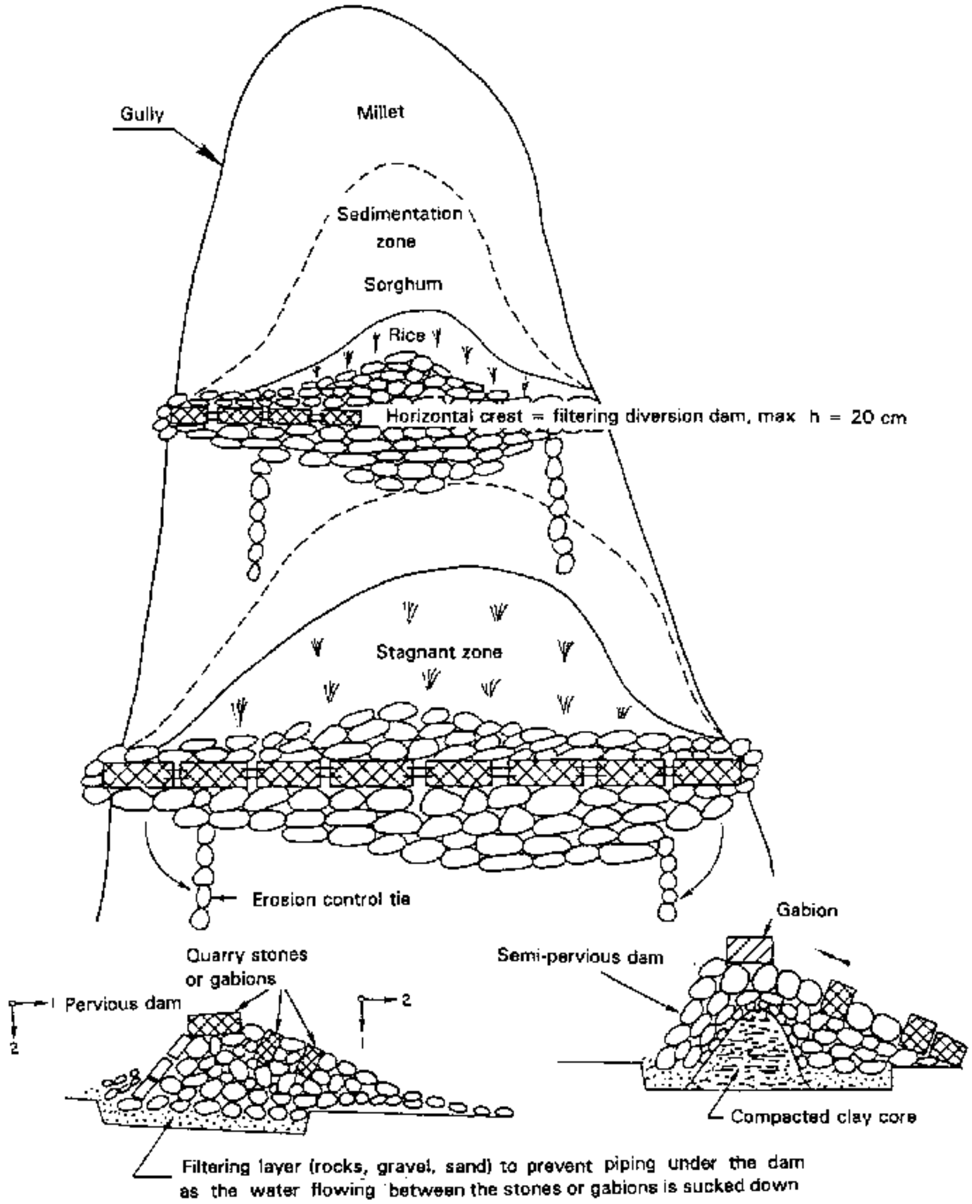
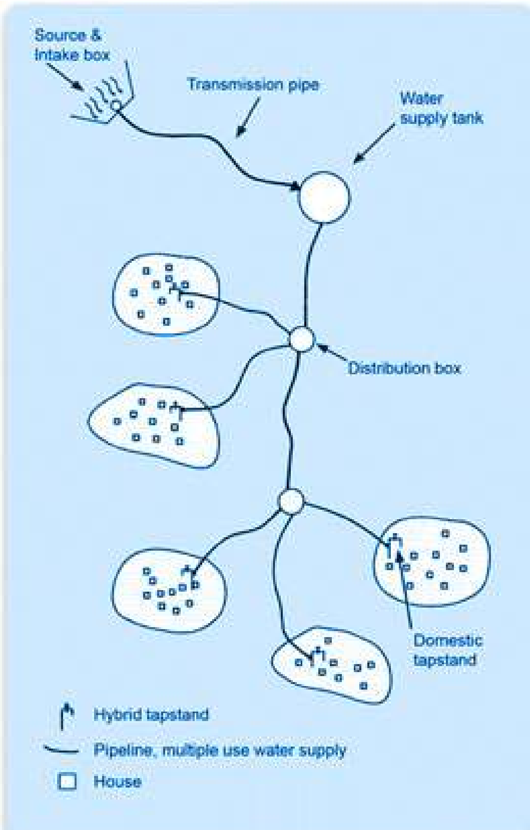


Figure A7: Permeable rock check-dam
Source: FAO Soil Bulletin n° 70 Land husbandry- components and strategy by E. Roose

Annex 2: Applying the concept of multiple uses to small reservoirs

The two main multiple use systems in Nepal tap spring sources and use gravity to convey water to storage by pipe. One system (Figure A8) uses a single tank to distribute water to hybrid taps where domestic water is gathered and a hose can be attached to fill up drip irrigation header tanks.



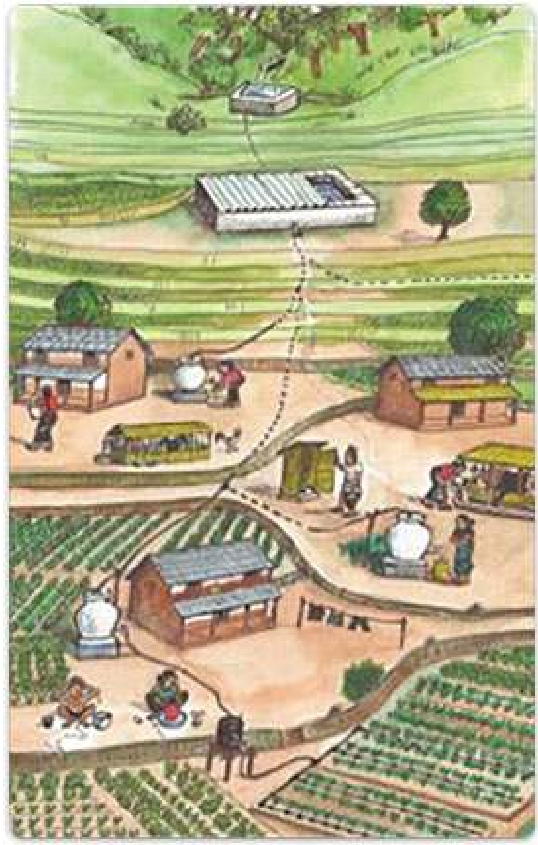


Figure A8: Multiple use systems with single distribution in Nepal
Source: iDE website

The second system (Figure A9) delivers water to a domestic water tank which overflows into an irrigation tank, using two separate distribution lines for domestic and productive water provision. When water is scarce, adding on-farm storage is an option.

In hilly terrain elsewhere (e.g. Ethiopia), this concept can be almost directly transposed by setting up a small reservoir (hilltop catchment small dam or "lac collinaire") where there is no spring as permanent water source.

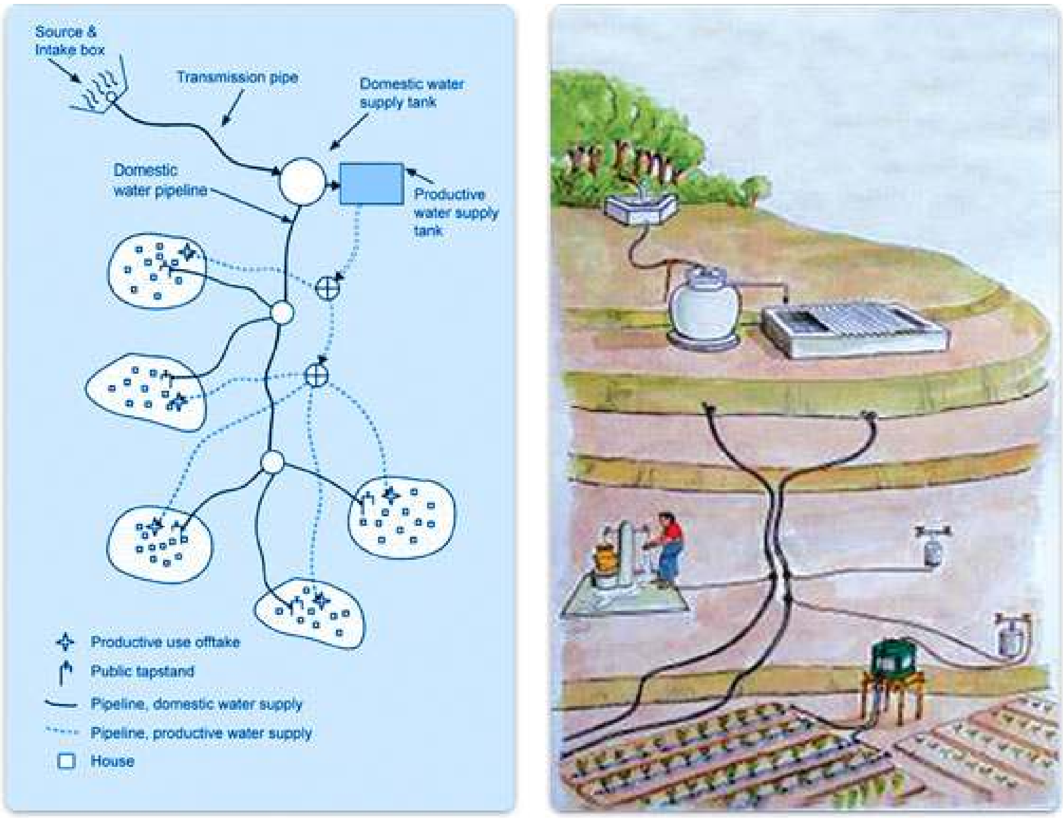


Figure A9: Multiple use systems with separated distribution in Nepal (Source iDE)

In flat or slightly undulating terrain – like in much of SSA – careful consideration of the topographical constraints is needed to assess the local feasibility of conveying water from a SR to a series of smaller water tanks where the water can be used for different –combined or separate - purposes (see figure 13 in main text).

Annex 3: The gravity-fed micro irrigation small-scale system

In the early 1970s, the "bucket kit" (Chapin Watermatics) was proposed as an idea for very small-scale, easy-to-use localized irrigation system to grow vegetables in backyard gardens. It was comprised of a simple water bucket suspended on a pole which supplied two lines of irrigation flat tape, allowing the irrigation of a few tens of plants.

In the late 1990s, big commercial localized irrigation manufacturers started producing their "family kits" using drip irrigation technology over a few hundreds of m^2 (initially 500) under low head provided by an elevated tank. This equipment is of high quality and performance but still too expensive and sophisticated for the vast majority of African or Indian farmers.

Several NGOs tried to come up with cheaper alternatives; the most successful one has been iDE, particularly in Nepal and India. The principle of the family kit is maintained, however the equipment is simpler: the tapes are thinner, on-line drippers are replaced by microtubes, (hence water filtration requirements are less stringent), and -above all - the kits cover lesser area (down to 20 m^2 as a minimum), being supplied by low-volume tanks; all these adjustments result in cheaper equipment and an investment that is affordable even to many of the poor farmers in terms of cost (at around 0.5 US$ per m^2), as well as land, water, and labour availability.

This technology is quite versatile and can be used as part of a multiple use system, in combination with all kinds of supply sources. After years of use at a rather small scale, it is now gaining momentum in SSA (Ethiopia, Zambia, Burkina Faso, etc.). Such kits are particularly appreciated in mountainous or hilly areas where water can be collected from small sources in the mountains and channelled through pipes to the irrigation area. In these cases, the energy needed to fill the reservoir is provided by gravity, and farmers only need to operate the micro-irrigation system.