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Scale issues in the governance of water storage projects

Pieter van der Zaag[1,2] and Joyeeta Gupta[1,3]

[1]   In the face of global change, which is characterized by growing water demands and increasingly variable water supplies, the equitable sharing of water and the drought proofing of rural livelihoods will require an increasing physical capacity to store water. This is especially true for the semiarid and dry subhumid regions of sub-Saharan Africa and Asia. This paper addresses the following question: What criteria should policymakers apply in choosing between centralized storage capacity in the form of conventional large reservoirs and large interbasin water transfer schemes and decentralized and distributed storage systems in the farmers' fields and in microwatersheds and villages (tanks, microdams, and aquifers)? This exploratory paper uses an interdisciplinary framework encompassing the natural and social sciences to develop four indicators that are considered critical for understanding the biochemical, physical, economic, and sociopolitical dimensions of the scale issues underlying the research question. These are the residence time of water in a reservoir, the water provision capacity, the cost effectiveness of providing reliable access to water per beneficiary, and the equity dimension: maximizing the number of beneficiaries and compensating the losers. The procedural governance challenges associated with each indicator are dealt with separately. It is concluded that water storage and the institutional capacity to effectively administer it are recursively linked. This implies that if the scale of new storage projects gradually increases, a society can progressively learn and adapt to the increasing institutional complexity.

1.   Introduction

[2]   Global fresh water supplies are limited and water availability varies largely in space and time. Many people still lack reliable access to adequate amounts of fresh water of sufficient quality for domestic and productive purposes [*United Nations*, 2005; *World Water Assessment Programme (WWAP)*, 2006]. Their access is constrained by the natural spatial and temporal variability of rainfall and river flow, which is likely to be further jeopardized because of the impacts of climate change [*Intergovernmental Panel on Climate Change*, 2007]. Rising population levels, sustained positive economic growth rates in many countries, strong urbanization trends and recent calls for increased production of biofuels are likely to significantly increase the demand for water. This obviously will add to the pressures on water resources in water stressed regions of the world [*United Nations Development Programme*, 2007]. While water use in excess of natural supply on an annual basis at present is limited to small although densely populated regions of the world, the seasonal challenges facing humans is much higher

[*WWAP*, 2006, p. 2]. In many parts of the world, water availability is highly variable over time. Whereas on average sufficient water may be available, periods of excess are followed by periods of deficit. Shortages of water have not only direct impacts on domestic requirements but also on food production and other productive uses of water, whereby often food production is the largest water consumer. Greater rainfall variability is thus correlated with lower per capita GDP [*Brown and Lall*, 2006]. Water storage is required to buffer livelihoods and insure families, communities and societies against shortages [cf. *Dey et al.*, 2006] Such stores of water transport water in time, from periods of excess to periods of deficit [*Keller et al.*, 2000; *Grey and Sadoff*, 2007].

[3]   There is thus a need for innovative solutions to ensure water security on a day-to-day basis globally and especially within the semiarid areas of the developing world. While in the 1960s and 1970s the focus of development cooperation was on infrastructure, this was followed by a focus on changing policies and governance patterns in the 1990s [*Meier*, 2001; *Wuyts*, 2002; *Pronk*, 2001, 2003]. In the water field this implied a shift away from constructing dams and large hydraulic works to an emphasis on improved water management and enhanced allocation and water use efficiencies in the 1980s and 1990s [*Pahl-Wostl*, 2002, 2007]. The focus on improving governance processes was meant to ensure that policymakers were empowered to make context relevant choices. However, in situations where the physical capability to control water flows and to buffer water systems against increasing seasonal and annual variations in water

[1]UNESCO-IHE Institute for Water Education, Delft, Netherlands.
[2]Water Resources Section, Delft University of Technology, Delft, Netherlands.
[3]Institute for Environmental Studies, Vrije Universiteit, Amsterdam, Netherlands.
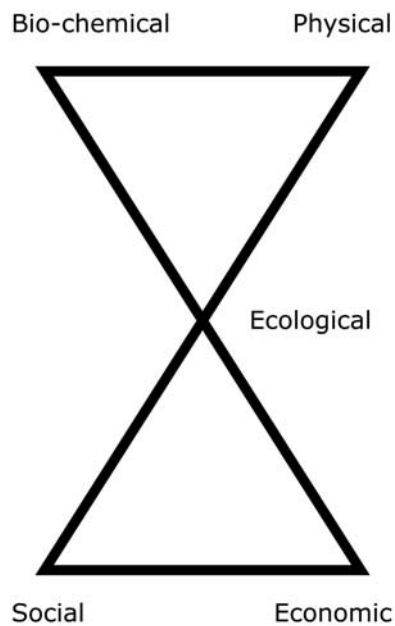
Figure 1. The hourglass representation of sustainable development.

availability is lacking, improving the water management "processes" has little or no impact. There is thus a renewed emphasis on investments in physical interventions as reflected in the new water resources strategy of the World Bank [*World Bank*, 2004], which is a marked change compared to its previous water management policy [*World Bank*, 1993]. Biophysical interventions that aim at increasing the capacity to store water volumes will, if successful, enable households, communities and societies to effectively cope with the seasonal and annual variation in fresh water supplies and enhance the resilience of their water systems to climate shocks [*Koudstaal et al.*, 1992; *Savenije and van der Zaag*, 2000; *Shah and Van Koppen*, 2006; *Grey and Sadoff*, 2007] (see also M. Moench and S. Stapleton, Water, climate, risk and adaptation, unpublished working paper, Cooperative Programme on Water and Climate, 2007, available at http://www.climate-transitions.org/node/748). This may form a "tipping point" that will enable rural people to lift themselves out of the poverty trap [*Swallow et al.*, 2006]. This paper attempts to contribute to the identification of some criteria that will help policymakers make such choices.

[4] It is unclear whether additional storage capacity should be centralized in the form of conventional large reservoirs and large interbasin water transfer schemes, or decentralized and distributed in the farmers' fields and at the level of the microwatershed and village or some combination of these two extremes. The policy choice between developing centralized and distributed water storage therefore requires critical analysis. Such analysis needs to take into account that the choice will be highly contextual in character and needs to be made on the basis of clear criteria. We assume first, that there is need for enlarging the number of beneficiaries as opposed to enlarging water storage per se or the profits from such water storage. Second, we focus on a set of indicators that could assist national policymakers in decision making (see section 3). Third, the institutional and physical complexity of each choice is dealt with separately (section 6).

[5] While water buffers can take different shapes and forms, biophysical interventions normally have nonphysical ramifications, including social consequences and implications for governance. These nonphysical implications are assumed to be nonlinearly related to the size of the storage facility. The paper thus investigates the key criteria policymakers may use to determine the preferred storage options in a specific context: many small storage reservoirs distributed in the landscape or fewer larger reservoirs that are more centrally managed, whereby both options may have large externalities.

[6] Although domestic use is the most vital and often given the highest priority in global policy making such as reflected in the Millennium Development Goals, it requires relatively small amounts of water; i.e., between 20 and 150 L of water per person per day. By far the largest water user (i.e., about 70% world wide) is agriculture. We therefore focus on agricultural water use, with the understanding that stored water often has multiple uses, and that it may also serve domestic needs or animal husbandry and other productive purposes [*Van Koppen et al.*, 2006]. Whereas municipal and industrial uses need relatively high levels of storage because of the higher levels of supply assurance required, these sectors normally have a much higher ability to pay compared to the agricultural sector, which explains that these sectors normally have fewer problems securing access to such storage capacity [*Savenije and van der Zaag*, 2002]. Although water can be stored in the unsaturated zone as soil moisture, or deeper down in aquifers, this paper focuses on small and large surface reservoirs, despite the potential advantages of the former [see, e.g., *Falkenmark and Rockström*, 2004]. Further, it focuses on the semiarid and dry subhumid regions of the developing world. In Africa and Asia alone this would affect the livelihoods of 100 million rural families (implying a total population of about 600 million). Improving their access to reliable sources of water for productive purposes has a high economic and social benefit [*Rijsberman*, 2004] and can lead to sustainable development. This creates a strong social bias in our indicators toward focusing on the number of beneficiaries of such storage systems, as opposed to the amount of water stored or the economic productivity generated.

[7] In order to address the research question, we develop a coherent framework. The starting point is elaborating on the concept of sustainable development [*World Commission on Environment and Development*, 1987; *Beg et al.*, 2002; *Cohen et al.*, 1998; *Banuri et al.*, 2001; *Markandya and Halsnæs*, 2002], which conventionally consists of three pillars, namely, the economics, social and ecological pillars [cf. *Hildering*, 2004]. This incompletely represents the natural system side of the sustainable development concept. In our extended framework, we incorporate the natural system dimensions and include biochemical and physical processes. Various authors, river ecologists in particular, have described how physical and chemical disturbances not only affect ecological systems [*Hildrew and Giller*, 1994; *Resh et al.*, 1988] but may be constituent parts of such systems [e.g., *McClain et al.*, 2003]. We thus propose an hourglass image that posits the natural system and social system aspects as two complementary dimensions of sustainable development with the ecological

Table 1. Different Types of Water Storage

	Water Source	
Storage Medium	Rainfall	Surface Water
Unsaturated zone	Rainwater harvesting through plant spacing, plowing along the contour, ridges and bunds, and terracing	Runoff harvesting from adjacent uncultivated plots, compound areas, roofs, and roads directly onto cropped fields
Saturated zone	Aquifer storage of seepage "losses" from impoundments	Aquifer storage from artificial recharge; sand dams
Container	Runoff harvesting from adjacent uncultivated plots, compound areas, roofs, and roads into a pond, tank, or reservoir	Impounding river flow in small, medium, and large reservoirs, both in stream and off channel

component being common to both (Figure 1). Criteria that fit each of the key aspects of the hourglass representation of sustainable development are presented, although we did not look explicitly for ecological criteria, since this was implicitly taken into account in the economic, social, biochemical and physical dimensions.

[8] This exploratory paper first introduces some basic aspects of water storage (section 2). It provides a brief theoretical discussion of scale from the natural and social science perspectives (section 3) to elicit criteria for evaluating the two policy options (section 4). It compares the small and large storage options (section 5) and discusses the complementary institutional structure needed to deal with this (section 6). Finally, it assesses these options and concludes that increasing access to water storage requires investments, triggers economic growth but may also generate negative social and ecological externalities, in particular in the case of large reservoirs. The institutional capacity of societies to effectively deal with these effects may be as much a result of developing storage projects as a prerequisite. This conclusion seems to imply that the scale of new storage projects could gradually increase so that a society can progressively learn and adapt to the increasing institutional complexity it faces (section 7).

2. Water Storage

[9] Before moving further it is relevant to briefly list the various available water storage options. Table 1 provides an overview of different types of water storage, by distinguishing the source of water (capturing rainfall directly, or capturing surface water) and medium of storage (a container like a tank or a surface reservoir, the unsaturated zone of the soil (the upper layer of the soil), and the saturated zone (deeper underground in aquifers)).

[10] The type of water use (domestic, animal husbandry, arable agriculture, and other productive purposes such as for industry, cooling water for energy installations, and the service sector) is frequently related to the source of water and the medium of storage, such as rainwater harvesting to enhance soil moisture (agriculture), and the collection of water from rooftops (domestic).

[11] Any surface reservoir system whether large, medium or small divides a catchment area into three distinct parts, and thereby also pushes its residents into three distinct roles (Figure 2).
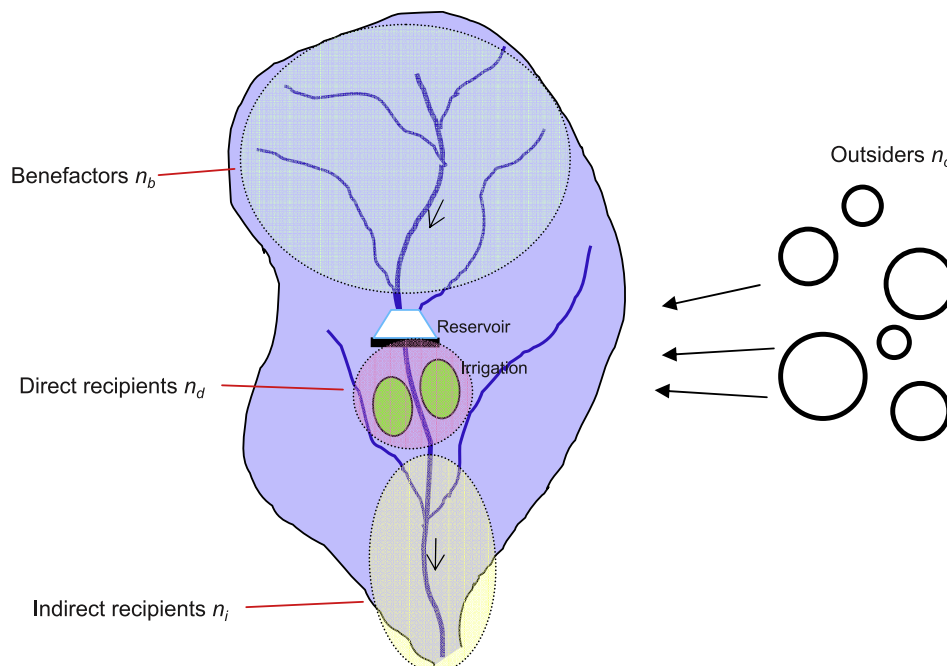
Figure 2. A reservoir divides a catchment area into three parts and its residents into distinct roles.

[12] 1. Upstream of the reservoir is the catchment area which generates the surface water that will flow into the dam. The owners or land users in this area, and those displaced by the reservoir itself, will not (directly) benefit from the reservoir but their actions may be constrained by the needs of the reservoir. Since they provide a service to the reservoir they could be considered the "benefactors" of the reservoir. The number of benefactors in a storage project will be denoted by n_b.

[13] 2. The center is formed by the command area of the reservoir, which receives water from it, and whose owners are supposed to directly benefit. They can therefore be considered the "direct recipients," denoted by n_{dr}.

[14] 3. Those located further downstream find themselves at the receiving end and feel the consequences of whatever has occurred upstream. They may thus be considered the "indirect recipients": they are not intended to directly benefit from the reservoir but may feel its impact because of a changed hydrological regime; this impact may be beneficial or harmful. The number of indirect recipients is denoted by n_{ir}.

[15] In any decision on a new water storage project, there will also be other stakeholders involved apart from the residents in the area. These include distant actors who have the power and/or interest in improving the water facilities in the area (e.g., those who invest; those who wish to purchase the products produced from the use of such water for further marketing; those who want to deal with general poverty reduction strategies for the country, etc.); and those who fear that the project may have negative repercussions that resonate beyond the catchment (e.g., NGOs concerned with the environmental consequences on a biotope in the catchment that provides the habitat for unique species). This paper explores whether there is a fundamental difference between smaller and larger reservoirs, with respect to their socioeconomic as well as ecological and political effects, taking the four categories of actors identified above into account.

3. Some Theoretical Considerations on Scale

[16] A common theoretical framework for assessing different water storage option is developed around the concept of scale. Scale is an analytical ruler against which one can measure [*Gibson et al.*, 2000; *Institutional Dimensions of Global Environmental Change*, 1999, 2005; *Young*, 2002]. In environmental and water related issues relevant scales include the spatial scale, the time scale, the resource scale [*Gupta and van der Zaag*, 2008] and the scale of governance [*Gupta*, 2007b, 2008]. Levels are points along each scale. Scaling up and down is the process of moving up and down levels within scales. Cross-scale interactions refer to movements or relationships between different scales. Cross-scale interactions would pose fewer challenges if scales were in general involving linear processes. However, since many of the processes involved in water and environmental management are nonlinear, this means that upscaling and downscaling (increasing or decreasing the temporal and/or spatial level) of interventions may have unanticipated results.

3.1. Scale Issues in the Natural Sciences

[17] Many hydrological processes are nonlinear, an example being the sudden transition between laminar and turbulent flow of water. Many processes are determined by thresholds, such as the partitioning of rainfall into interception, surface runoff, infiltration and evaporation: rainfall below a certain value will only result in interception losses and will not generate surface runoff [*Savenije*, 2004]. Increasing the intensity of rainfall radically changes the proportions in which the water is partitioned. Such nonlinear processes exist in space and time. This means that observations made at a certain level cannot automatically be deduced from observations made at other levels, and thus that extrapolating data sets is not unproblematic. For example, soil loss measured from a 10 m^2 trial plot may not be multiplied by a factor 1,000 to estimate the net soil loss from a 1 ha field, or by a million for a 1,000 ha watershed. This is because at the (1,000) hectare level some redeposition of soil particles within field (watershed) may occur [*Bagayoko*, 2006]. *Swallow et al.* [2002] call these areas of deposition "filters." Similarly, hydrological processes at the plant level (1 m^2) are dominated by discontinuities within the topsoil, such as absence or presence of cracks and root systems of plants, which determine the magnitude of preferential water flow patterns. These discontinuities make it difficult to adequately model micro processes. At a larger spatial level, however, such processes are often much easier to estimate as some of the discontinuities may be averaged. At this level other processes dominate [*Uhlenbrook*, 2006].

[18] At increasing spatial and temporal levels the interactions between the various parts may give rise to new, emergent, phenomena. This is probably the major reason why upscaling and downscaling is problematic. One could argue that in trying to upscale or downscale biophysical processes, the systemic properties of those processes come to light. Sometimes the emergent phenomenon is that of self-similarity and self-organization, whereby the processes occurring at smaller spatial or temporal levels are repeated at a larger scale. The shape and form of river channels and alluvial estuaries, for example, may not always be surprising [*Savenije*, 2003], as is the dendrical shape of some rivers that is repeated at various levels. These may be considered fractals [*Rodríguez-Iturbe and Rinaldo*, 2002]. Here the large temporal dimension (millennia) has shaped the spatial dimension (features of the landscapes) leading to a certain dynamic balance between various biophysical processes which give rise to certain coherent forms but not to a static equilibrium.

[19] The above implies that a certain physical intervention in the landscape at a given level that causes a small disturbance of certain biophysical processes, could cause a disproportionate (or negligible) disturbance at another. Similarly, such an intervention could yield large benefits if appropriately scaled and small at other levels.

3.2. Scale Issues in the Social Sciences

[20] Within the social sciences different disciplines deal with scale differently. There is however a growing convergence that there is neither an optimal scale nor an optimal level at which environmental and water related issues can be managed. There are no "objective" criteria that can help determine what this optimal level is. There are however a range of criteria and arguments that can be used to scale up or scale down a problem and solution [*Gupta*, 2007a]. Examples of reasoning given to scale up a problem include

the need to take into account externalities, to make policies cost effective, to promote the common good, to gain control, or to bypass other government agencies. There are a number of reasons for scaling down; sometimes it is to understand local causes, patterns and interests and the desire to improve the resolution of the solution; or the need to both mobilize and empower local actors to address their own problems. There may also be other reasons for downscaling: sometimes to transfer responsibility, avoid liability for externalized effects, to protect local actors, to implement budget cuts of central governments and/or to bypass the nation state [*Gupta*, 2007b].

[21] This implies that actors are often making conscious choices about which sets of reasoning they would like to use to argue whether a particular scale or a particular level should be used. Thus, economists often tend to focus on the resource scale and argue in terms of economies of scale. This would imply a choice in favor of relatively large storage works in the area of water. Policymakers may tend to focus on the administrative/jurisdictional scale and focus on guiding principles such as subsidiarity and decentralization which focus on empowering local actors to address their own problems. Subsidiarity is the policy principle adopted primarily within the European Union that focuses on transferring certain powers and responsibilities to the lowest appropriate policy level. Decentralized governance systems are often supposed to enhance legitimacy by including a larger number of stakeholders and their context relevant knowledge. Such systems are expected to have a higher compliance pull since a larger number of local actors are involved in the decision-making process. However, in practice this may not always be the case. Policies of decentralization are often linked to neoliberal reforms such as trade liberalization, deregulation and privatization that started in the 1980s [*Nuyten*, 2004]. Such reforms imply a shifting role of government in development processes: from state-led development toward the strengthening of both civil society and the "invisible hand" of the market. This type of discourse may obscure the highly political content of such reforms [*Shore and Wright*, 1997]. The danger is, that decentralized democratization may lead to "decentralized despotism" [*Mamdani*, 1996], especially in countries where large power differences exist.

[22] In the context of water resources management there are at least four aspects that further complicate processes of decentralization. The first is that the new watershed and catchment institutions that are being established in many countries often are too weak to withstand their "capture" by local elites [see *Waalewijn et al.*, 2005]. The second is that these new institutions often compete with already established local government institutions at the District level and may debilitate them [*van der Zaag*, 2005]. The mismatch between administrative and hydrological boundaries has thus added significantly to institutional complexity. The third problem is that the subsidiarity concept in water resources management, as with many other environmental and resource management issues, tends to be a hollow promise. As more and more externalized causes and impacts are to be taken into account, decision making is "naturally" concentrated again at higher levels of authority, since certain decisions (e.g., concerning the allocation of scarce water; enforcement of water quality regulations) cannot be left to local stakeholders alone. Moves toward harmonization of policy and integration with other policy areas also lead to scaling up of decision making to higher levels. The fourth problem is that processes of decentralization often fail to allocate adequate resources and capacity to those levels with new responsibilities. The key message is that in the social sciences, scaling is seen as a highly political activity; a tool used by different actors to promote their own interests. This implies that scale and level related choices can never be isolated from the context in which they are made and that such choices are never "objective" but constructed on the basis of perception.

## 4. Indicators for Assessment

[23] This section elaborates on an appropriate set of indicators to evaluate whether water storage should be large or small and dispersed to fit each corner of the hourglass model of sustainable development. For the physical aspect, a useful indicator is the residence time T_r of a water particle in the reservoir, which is the quotient of the storage capacity and the average amount of water flowing into the reservoir. If the water flow is expressed as the mean annual runoff, then the residence time would have as its unit year. Many reservoirs have residence times in the range of 0.2–2 years [*Vörösmarty et al.*, 1997]. Residence time is an intriguing indicator. It expresses the claim a storage project makes into the future, as a kind of temporal footprint. It also expresses in a temporal unit its spatial dependency and area of influence. The larger the residence time of a reservoir, the greater its dependence on the water resources generated in the upstream catchment area, and the larger the impacted area downstream [cf. *Vörösmarty et al.*, 1997]. It could further be argued that the larger the residence time of a reservoir, the larger the disturbance of the natural flow regime, and thus its environmental impact.

[24] Water withdrawals for irrigation in semiarid climates, characterized by distinct wet and dry seasons, alter a river's natural hydrological regime. As the need for irrigation water is highest during the dry season, the base flow is first captured. In order to augment water availability during the dry season reservoirs are built that capture runoff water during the wet season. As a result, first the base flow rapidly decreases (Figure 3a), after which small flood flows that would normally occur every second or third year occur much less frequently as these flows are absorbed by the reservoir (Figure 3b). Note that both processes are nonlinear. Note further that shutting out small floods has large ecological as well as socioeconomic consequences. Figure 3b shows that this latter phenomenon appears to be S shaped: beyond a certain residence time a reservoir, and the water withdrawals related to it, becomes the dominating factor in a river's hydrology, and starts to create significant and measurable upstream-downstream interdependencies. In the example given, this turning point occurs when the reservoir has a residence time of some 0.3–0.5 years; i.e., when it can capture 30–50% of the annual natural flow. The value of this critical residence time differs for different flow regimes, and for different levels of reliable water supply.

[25] The residence time of a reservoir is typically related to its function. If its function is to satisfy the requirements of
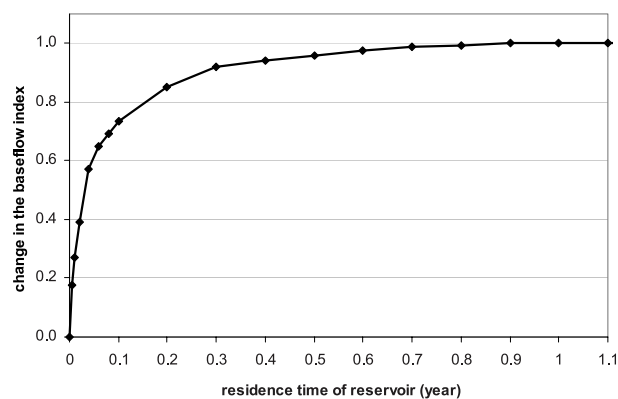
(a) impact on base flow
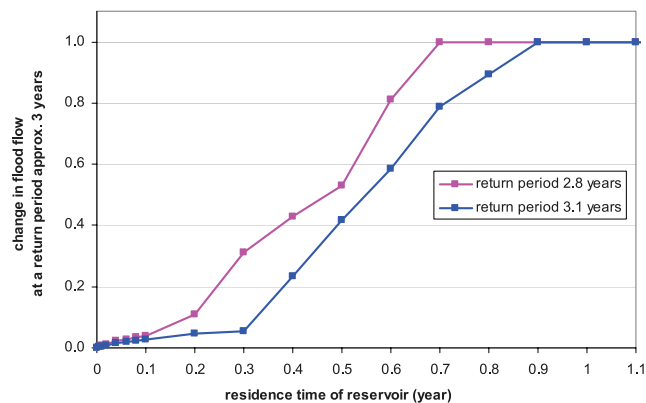
(b) impact on small flood flows

Figure 3. The relation between residence time of a reservoir upstream and downstream; impact (0, negligible; 1, complete) is nonlinear. (a) Impact on base flow. (b) Impact on small flow floods. The example is derived from the Mupfure River (a tributary of the Sanyati River, which forms part of the Zambezi basin) in Zimbabwe on the basis of monthly discharge data covering a period of 21 years (October 1969 to September 1990) as measured at gauging station C70 and naturalized by the Zimbabwe Department of Water Development in 1998. The coefficient of variation of annual flow was 122%, and the base flow index (average flow during the 3 driest months (June–August) divided by the average flow during the 3 wettest months (January–March)) was 0.028; the upstream reservoir stored and withdrew water for irrigation use, achieving an assurance of supply of exactly 80%.

a city's water supply, high levels of reliability (higher than 95%) are required and in semiarid environments, over-year storage is the norm (large storage capacity enables long-term buffering), which necessarily translates into large residence times. Full-scale irrigation would require large amounts of water supplied at much lower levels of assurance (75–90%) [*Savenije and van der Zaag*, 2002], whereas for supplementary irrigation water storage aims to bridge short periods of dry spells, and reservoirs for the latter typically refill more than once during the rainy season, implying relatively short residence times. The example given in Figure 3 is based on agricultural water use (irrigation) supplied at a reliability of 80%.

[26] For the biochemical aspect, we use an indicator specific for agricultural water use. This is the water provision capacity W expressed as the depth of water layer (m), which is the storage capacity S divided by the command area of the reservoir (irrigated farm area) A_f. A value in the range of 0.1–0.2 m would indicate that the reservoir may provide supplementary irrigation water only [*van der Zaag*, 2007a; see also *Rockström et al.*, 2003, 2007] or that it is used as a balancing weir or a night storage reservoir, whereas values of 0.8–1.2 m and beyond would be typical for conventional full-scale irrigation during the dry season; given that net irrigation water requirements of a full dry season crop range between 500 and 800 mm and irrigation efficiencies between 50 and 90% [see, e.g., *Cakmak et al.*, 2004]. Values in between (0.5–0.7 m) would be typical for schemes that are based on the concept of protective or deficit irrigation, as found in India and elsewhere, as well as for supplementary irrigation of wet season rice crops. One may generalize to state that the larger the water provision capacity of a storage project, the larger the disturbance of the natural flow regime and the larger its ecological impact.

[27] In relation to the economic aspect of sustainable development, we focus on the cost effectiveness of achieving reliable access to a certain amount of water per beneficiary M_{dr}, which is the total investment cost of the storage project M_t divided by the number of direct recipients n_{dr}. This indicator has two functions: it leads to a focus on the beneficiaries and it helps to estimate how much each beneficiary would potentially have to invest in order to obtain reliable access to water. The policymaker can decide on the basis of this criterion whether the project is viable and can be funded (in cash or kind) by the state, by the direct beneficiaries themselves, or by other commercial or noncommercial funding agencies.

[28] As the size of the resources needed grows bigger, the lump sum investment required may often lead to complex institutional relationships. In general, small distributed reservoirs can be partially funded by small investments in cash or kind by the direct beneficiaries, creating greater local involvement and ownership and a greater incentive to maintain these reservoirs. The establishment of large hydraulic works, however, often implies that local users get caught in a complex web of relations with outside players, be they government, financial institutions, non governmental organizations and private companies. The larger the hydraulic work, the larger the investment required and the more complex this web will become, including the entry of foreign players on the scene [see, e.g., *Gumbo and van der Zaag*, 2002]. The effect of increasing the investment of a storage project on local users' access to stored water is complex and difficult to predict. It often results in limiting or circumscribing the decision-making capacity of local stakeholders, while those responsible for the investment either want to maintain sociopolitical control or are concerned with how the investment costs can be recovered [e.g., *Easter and Liu*, 2007].
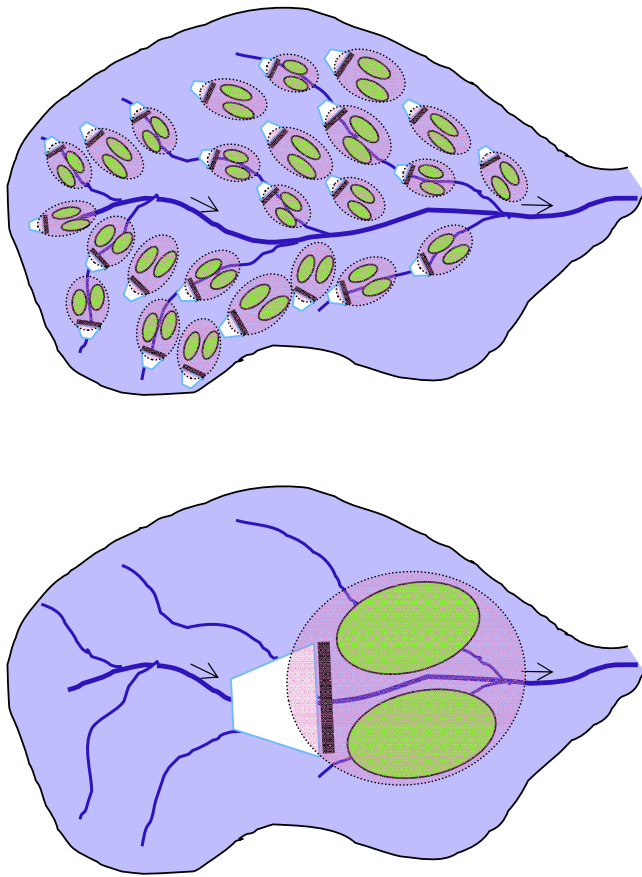
Figure 4. Different policy options: a centralized and a decentralized approach.

[29] Above certain investment values, lock-in may set in. Projects may become too complex, not only technologically but also administratively, such that their planning horizons, and useful life, are stretched far beyond the usual planning periods of 5–10 years corresponding sometimes to the periods of political parties in power. This implies that where projects are very large, societies tend to make decisions simply because the existence of such projects influences the perceived decision space [*Janssen and Scheffer*, 2004; *Pahl-Wostl*, 2002]. In such situations, the changed environment caused by such large projects may even be viewed as having become part of that society's habitat; the ecological impact having been internalized.

[30] A key social principle is equity. "Equity as a legal concept is a direct emanation of the idea of justice" as the International Court of Justice stated in the Tunisia versus Libya Continental Shelf Case, ICJ Report 1982 [*International Court of Justice*, 1982, p. 18]. Equity has an intergenerational element and an intrageneration element. Principle 2.1 of the International Law Association's New Delhi declaration on the law of sustainable development explains the intrageneration element as: "the rights of all peoples within the current generation of fair access to the current generation's entitlement to the Earth's natural resources" [*United Nations General Assembly*, 2002, p. 4]. As resources are limited, providing access often implies that there are winners and losers, and equity also calls for compensating the losers. In this context we interpret equity as maximizing the number of beneficiaries while compensating the losers. Note that this equity criterion also has an institutional dimension, as it requires significant institutional resources to implement effective compensation mechanisms. We propose here as the social criterion an indicator that could be coined the "normalized externality" E_n of a storage project, which is the number of all actors involved in a storage project (both positively and negatively affected) divided by the number of positively affected actors. Here we could simplify the definition as being the number of affected actors of a storage project ($n_b + n_{dr} + n_{ir}$) divided by the number of direct recipients (n_{dr}), assuming that the benefactors and indirect recipients are all negatively affected, which need not be the case.

[31] Assuming that there will always be at least one direct recipient, the minimum value that the normalized externality indicator can take is 1. At this value there are no losers, the externalities are minimal and likewise the social and institutional complexity of the project. With an increasing value of E_n, for each direct recipient there will be an increasing number of actors who are indirectly, and often negatively, affected by the storage project, and the more complex it will be to adequately compensate the losers such that equity is restored.

[32] Distributed small reservoirs will in general have a large number of beneficiaries. The impact of these small reservoirs on the benefactors will be relatively small, displacement will be minimal and the ecological and social impacts downstream will also be quite small for each small reservoir. However, as the size of the reservoir increases, the number of benefactors and displaced people increases and the ecological and social effects downstream will increase substantially implying considerable numbers of losers who have to be compensated.

[33] This section presented two indicators that encapsulate key biophysical dimensions of water storage, and two indicators that reflect key socioeconomic dimensions of water storage. (1) residence time T_r (average time a water particle resides in the reservoir), (2) water provision capacity W (gross water layer that a reservoir can supply to its command area), (3) investment M_{dr} (investment cost of providing reliable access to water per direct recipient), and (4) normalized externality E_n (the number of positively and negatively affected actors of a storage project divided by the number of positively affected actors).

5. Centralized and Distributed Water Storage

[34] This paper compares two choices for the national policymaker in semiarid and dry subhumid areas: one centralized large-scale storage reservoir for full irrigation and many small-scale storage structures distributed throughout the catchment with a similar number of beneficiaries but meant for supplementary irrigation (Figure 4). Table 2 presents typical values of design parameters of these two alternative water storage options: 2,000 on-farm tanks with a capacity of 500 m³ each and one large reservoir with a capacity to store 50×10^6 m³ of water. The particular characteristics of both options are explained below. For the latter (centralized) case we used values derived from *Malano et al.* [2004] and *Cakmak et al.* [2004], but for the distributed case we had to infer values that were based

Table 2. Typical Design Parameters and Values of Tanks and Small and Larger Reservoir Systems[a]

Aspect	Unit[b]	Individual Farm Tank[c]	Distributed Tanks System[d]	Centralized Reservoir System[e]
Number of units		1	2,000	1
Catchment area A_c	1,000 m^2	20	40,000	150,000
Runoff Q	1,000 m^3/a	3	6,000	25,000
Reservoir storage capacity S	1,000 m^3	0.5	1,000	50,000
Residence time $T_R = S/Q$	years	0.2	0.2	2.0
Presence of sluice gate/valve G		no	no	yes
Command area A_c	1,000 m^2	5	10,000	25,000
Number of benefactors n_b	household	0	not known	8,000
Number of direct recipients n_d	household	1	2,000	2,000
Number of indirect recipients n_i	household	0	not known	6,000
Storage capacity per direct recipient S_d	1,000 m^3/hh	0.5	0.5	25
Farm area per direct recipient A_f	1,000 m^2	5	5	12.5
Water provision capacity $W = S/A_c$	m	0.1	0.1	2
Annual water use per beneficiary	1,000 m^3/hh	1	1	12.5
Estimate of total investment cost M_t[f]	1,000 U.S.$	2	4,000	20,000
Unit investment cost	U.S.$/m^3	4	4	0.4
Investment per beneficiary $M_d = M_t/n_d$	1,000 U.S.$/hh	2	2	10
Sustainable gross return per beneficiary per year	U.S.$/hh/a	150	150	600
Sustainable net return per beneficiary per year at 5% capital cost; excluding externalities	U.S.$/hh/a	50	50	100
Sustainable gross return per m^3 per year	U.S.$/m^3	0.15	0.15	0.05

[a]Cf. *Keller et al.* [2000, Table 3].
[b]Here hh means household.
[c]Typical values are derived from tanks being constructed in South Africa in connection with the "water for food movement" of Ma Thsepo. Values are consistent with data published by *Falkenmark and Rockström* [2004] and *Rockström et al.* [2003, 2007].
[d]Data of the distributed tanks system are mainly inferred from the individual tanks.
[e]See, e.g., *Malano et al.* [2004] and *Cakmak et al.* [2004].
[f]Includes compensation for the loss of production from the area inundated by the reservoir and the cost of compensating displaced persons.

on published and unpublished sources of individual small tanks. These data therefore need empirical verification.

5.1. Centralized Large Storage

[35] The centralized storage approach is one in which a (small, medium or large) reservoir collects surface water and farmers downstream of the dam can access the stored water through an open canal or closed pipe system. This option conforms with the conventional irrigation development approach. Most existing irrigation developments are designed for irrigating a dry season crop, which have net irrigation requirements on the order of 500–800 mm/a, leading to gross irrigation requirements of between 800 and 1,200 mm/a. (These same irrigation schemes also allow for supplementary irrigation of a rain-fed crop, but the additional water requirements involved normally do not affect the design parameters in major ways, except perhaps when supplementing the water requirements of a wet season rice crop.) As a consequence, relatively large reservoirs are needed, which displace people and valuable crop land and require a relatively large catchment area from which water is captured. Irrigation schemes differ in size from 5 to 10,000 ha and beyond (a global sample of 129 irrigation schemes had a median size of 5,200 ha [see *Malano et al.* [2004]), the smallest requiring a reservoir with a minimum capacity on the order of 20,000–100,000 m^3, and a catchment area from which water is captured of some 20–100 ha, depending on the precipitation and runoff patterns in a region. The largest reservoirs may have a storage capacity of 50–100 × 10^6 m^3 or more and would be located on relatively larger rivers. Investments are typically done by development (domestic, regional or international) banks in conjunction with contributions by the government

as well as by the beneficiary households. However, the latter may be very small.

[36] The gross benefits to each irrigator will normally be significant. Because of the large volume of irrigation water supplied the gross return per unit of irrigation water is however low (in Table 2 we give a value of 0.05 U.S.$/m^3). Similarly, because of the large investments required the net returns (after deducting annualized capital cost) will normally be very modest and sometimes even negative.

[37] The operational requirements of the centralized options are often complex. First, reservoirs are normally equipped with gates or other devices that can be opened and closed. Since the stored water is supposed to benefit a large number of beneficiaries, some implicit or explicit arrangements regulate who decides when the gate is opened and closed, and how the water will be allocated over the plots in the command area. Second, maintenance, such as canal repairs, desilting of canals and reservoirs, fencing etc. have to be arranged. Third, given the size of the reservoir and its hydrological, ecological, economic and social impact it is possible that downstream actors, including those concerned with the environment, would put forward certain demands on whether the reservoir should be built and/or how the reservoir should be operated. Upstream benefactors and especially those displaced will demand some form of compensation, if not oppose the construction of the dam. Fourth, the magnitude of the investment requirements for large reservoirs is likely to be significant, and tends to have large power effects [*Adams*, 1992; *Reisner*, 1993; *McCully*, 1996].

5.2. Many Small-Scale Storage Structures

[38] In the decentralized distributed approach [*van der Zaag*, 2007a, 2007b; *Liniger and Critchley*, 2007; Moench

and Stapleton, unpublished working paper, 2007], policy-makers choose to provide access to additional water through storage that is decentralized and distributed in the farmers' fields (e.g., storing rainwater in the soil of nontilled or ripped fields or fields that are ploughed along the contour or on terraced fields, and "harvesting" runoff water by storing it in small farm tanks), and at the level of the microwatershed and village (microdams and aquifers).

[39] In many semiarid and dry subhumid savannah zones rain-fed agriculture needs a water storage capacity of around 200 mm [*Rockström et al.*, 2003, 2007]. Note that this capacity can be utilized more than once during one growing season. Part of this capacity is in the soil profile but many farmers have to make do with poor soils with low water holding capacities that can only effectively store around 100 mm. This means that additional storage capacity is required on the order of 100 mm. A typical smallholder plot of 0.5 ha thus requires 500 m^3 of additional storage capacity.

[40] Here we consider the option that each farm plot would have its own small storage tank (50–500 m^3) that would drought proof (part of) the rain-fed crop, as well as other domestic and productive uses of water of the farm household. The tank would capture ("harvest") surface runoff from relatively small uncultivated catchment areas (0.5–2 ha), including from roads and the farm compound. The water could be hauled from the tank simply with a bucket or using a small pump. The investment required is partially done in kind (labor, locally available construction materials by the farming household; other construction materials, tools by an NGO), and partly in cash (projects and training funded by governments, investors or donors). This option is currently pursued, for example, in South Africa (the "water for food movement" of Ma Thsepo and the "war on hunger" program of the Department of Water Affairs and Forestry) and Kenya.

[41] The gross benefits to a household equipped with a tank will be much lower than those for a household with access to full-scale irrigation. Because of the relatively small volume of supplementary irrigation water used the gross return per unit of water (in Table 2 we use a value of 0.15 U.S.\$/m^3) is higher than for the full-scale irrigation alternative.

5.3. Comparing Both Storage Options

[42] We compare both storage options using the four criteria defined in the previous section. The residence time of both options differ fundamentally. Each tank captures on the order of 20% of the surface water generated from a small 2 ha catchment area ($T_r = 0.2$ years, see Table 2). The 2,000 tanks taken together as one system have the same residence time, since it was assumed that each individual tank had its own small catchment area. The large reservoir, in contrast, captures all the surface water generated in a 15,000 ha catchment, with a residence time that is likely to be on the order of 1 or more years. In our example we arrived at $T_r = 2$ years. In the latter catchment area there seems to be little place for small tanks, since all the surface water is required to fill the large reservoir. It therefore lays a strong claim on the water resources generated in the upstream catchment. Any additional water capture and withdrawal by other upstream actors directly competes with the requirements of the large project downstream [cf. *Duflo*

and Pande, 2007]. Moreover, with the much larger residence time also the downstream hydrological, ecological, social and economic impacts are much greater. Because of the shorter residence times of the small tanks, their claims on the upstream catchment and the downstream impacts are modest. Since rural landscapes normally consist of cultivated areas interspersed with noncultivated areas, there will be sufficient space to accommodate many such small runoff harvesting structures.

[43] An important difference between the two storage options is their water provision capacity, and indicates whether water is used for supplementing rain-fed crops or whether it is used for irrigating a crop during the dry season. The former will increase water consumption by 100–200 mm per crop, whereas the latter by 600–1,000 mm per crop. In addition it should be noted that supplementary irrigation water has a much larger productivity than irrigation water for a fully irrigated crop (typically 2 kg of grain per m^3 versus 0.5 kg of grain per m^3 [*Rijsberman*, 2004; *van der Zaag*, 2007a]). In water scarce landscapes it may therefore be prudent to invest in supplementary irrigation for rain-fed agriculture during the wet season combined with very small market gardening during the dry season, rather than in round-the-year irrigation (dry and wet season).

[44] The economic indicator would reveal that the cost effectiveness of water storage per unit of water is much higher in the large reservoir than in the small reservoir. While a centralized system would cost around 20 million USD (an indicative figure), the cost of 2,000 tanks would be about 4 million USD. The investment per direct recipient farm would be USD 2,000 in a distributed scheme and USD 10,000 for a centralized reservoir. Because the large reservoir will be able to provide greater access to water, the economic returns per beneficiary may be higher as shown in Table 2. In addition, a large-scale reservoir also has the potential for electricity generation and can therefore create additional benefits.

[45] The rules of access to water from a centralized water reservoir, however, may be more complex as investors may claim hydraulic property [*Coward*, 1986] and some of the water users may be disenfranchised in terms of water control. Moreover, in larger irrigation schemes some irrigators, especially those located in the periphery, may fail to access sufficient water to satisfy their requirements. In contrast, the distributed reservoir option entails small local contributions in cash and kind; and hence also a commitment to maintain the reservoirs. Further, several small reservoirs have the potential of meeting the water needs of those located upstream of a potential large reservoir. In other words, those upstream of a large reservoir cannot easily get access to water unless they are able to pump the water upstream; but small-scale reservoirs can be implemented in the upstream parts of catchment areas and can thus potentially reach a larger group of beneficiaries without the need for pumping.

[46] Turning to the equity criterion which indicates the number of affected actors per beneficiary, we find the following. An individual small tank may benefit the farm family. Its catchment area is likely to comprise lands owned/used by the farm family itself, whereas the indirect impacts of the tank are unlikely to be felt by downstream households. This means that the total number of involved actors

Table 3. Indicators and Nonlinearities

Hourglass	Indicator	Explanation	Nonlinearities	Procedural Implications
Physical	Residence time T_r	Average time for a reservoir to fill (year)	Beyond a certain residence time a reservoir becomes the dominating factor within its area of influence and may have higher environmental impacts.	With larger impacts licensing procedures become important and environment impact assessments have to be carried out.
Bio-chemical	Water provision capacity W	Capacity to fulfill specific water need (m water layer)	If the water provision capacity shifts from supplementing rain-fed agriculture to full dry season irrigation, downstream impacts on the flow regime will increase significantly; impacts change with project size, often harmless or even beneficial when small but harmful as size increases.	As projects increase in size, they cross jurisdictions, making the administrative processes more cumbersome.
Economic	Cost effectiveness of reliable access to water per beneficiary M_d	The degree of resources invested (U.S.$ per beneficiary)	Small investments may not lead to change; larger investments may be more cost effective; still larger investments may lead to lock in and large environmental changes. As investments increase, more extralocal actors get involved, which may lead to change in rules of access. With increased access to water, households, communities, and societies may lift themselves out of the poverty trap.	Increased investments tend to be accompanied by heightened political interest and involvement and lead to more complex decision-making processes. If increased costs lead to public-private partnerships that involve nonnationals, international commercial and investment law rules become applicable.
Social	Normalized externality E_n	Maximizing the number of beneficiaries while compensating the losers (number of all affected actors divided by the number of positively affected actors)	Smaller projects tend to have fewer losers, as the command area is smaller and the ecological and social impacts downstream are lower. The tradeoffs are easier to deal with. Beyond a certain size, the number of losers may compete with the number of beneficiaries and make the net benefit difficult to assess.	As projects increase in size, more competing claims and interests get involved, which need to be reconciled. This puts an increasing burden on institutional capacity for legitimate decision-making processes and effective compensation schemes.

of an individual tank project is 1, equal to the number of beneficiaries. Hence for this project $E_n = 1$; that is, there are hardly any externalities, equity is easily achieved and there are no institutional complexities. The aggregate of 2,000 small tanks, however, gives a different result, since the aggregate of many tanks must have some measurable downstream impact. This impact is believed to be relatively small but without detailed empirical research the precise magnitude is unknown. For the sake of the argument we here assume that a similar number of actors may feel the effects downstream as there are direct recipients ($n_{ir} = n_{dr}$), but this assumption may overstate the impact. This means that for the aggregated tanks option the normalized externality $E_n = 2$: for each beneficiary there is one negatively affected actor. For this option equity starts to become an issue, as well as the institutional arrangements required to mitigate externalities. Turning to the large reservoir, it may rely on a catchment area occupied by farms of between by 2,000–10,000 farm households, serving 1,000 to 5,000 direct recipients, while the impact downstream may be felt by 2,000 to 10,000 actors. It should be noted that these numbers are indicative and will differ from case to case. In this example the normalized externality indicator would average $E_n = 5$: for each beneficiary there are four other actors that are negatively impacted by the project. Whereas the aggregate tank option may possibly affect one household somewhere downstream for each direct beneficiary, the large reservoir may impact some three other households per direct recipient household, of whom two may be located upstream and two others downstream.

[47] The normalized externality indicator, as a proxy for the equity criterion, aims to maximize the number of beneficiaries while compensating the losers. Since in our example the distributed small-scale option has a smaller command area, does not cause displacement of people and has lower negative impacts immediately downstream, the compensation element will be relatively small. The centralized large-scale option with a significant command area, displaced upstream populations and negative ecological, economic and social consequences downstream may imply a large number of stakeholders who have to be compensated for their losses. The institutional requirements are significantly more complex than for the distributed tank option. This finding is in accordance with *Duflo and Pande* [2007], who reviewed the socioeconomic impact of dam development in India, and found that the presence of a large dam increased inequity: people located downstream typically benefited from the presence of a dam, but poverty increased in the vicinity of the dam. They thus found that the costs and benefits associated with large dams are unequally distributed, and that in India the institutional capacity is apparently insufficient to mitigate those negative distributional effects or establish effective and fair compensation arrangements.

[48] Two final nonlinear phenomena concerning reservoirs should be noted, namely those related to siltation and

evaporation. The small tanks and reservoirs meant for supplementary irrigation have low residence times, meaning they may fill several times per season and hence silt up relatively fast. This puts a strain on maintenance needs. The extreme case is sand storage dams which are purposely built to silt up and store water underground, so that evaporation losses are reduced [see, e.g., *Lasage et al.*, 2008]. As to open water evaporation: this constitutes a relatively large portion of the water losses incurred by small reservoirs. The larger the reservoir, the larger the average depth and the smaller the evaporation losses relative to the amount of water stored. The large reservoir option is in this respect superior to the distributed small-scale alternative. However, this aspect should not be exaggerated: small reservoirs tend to have small residence times and thus fall dry during large parts of the dry season, minimizing evaporation losses and possibly increasing seepage losses that are not prone to evaporation. A precise comparison of evaporation losses for both development scenarios should therefore be subject of detailed quantitative research.

6. Discussion

[49] We identified four relatively straightforward indicators to identify scaling effects in storage projects. These are residence time T_r, water provision capacity W, the investment cost per direct recipient M_d, and the normalized externality E_n. These indicators hold hydrological, engineering, agronomic and social information and in their combination also contain ecological information. They define and link different scales, each of which has certain degrees of nonlinearity, and as these nonlinearities are not necessarily symmetric, their combined effects in terms of management requirements and governance may be difficult to predict. Table 3 summarizes the major nonlinear processes that these four indicators refer to, and discusses the procedural implications of the different choices.

[50] Good governance calls, among others, for transparency, accountability and participation in decision making. Such participatory decision making calls for taking into account the way in which all direct and indirect stakeholders may be affected by the decision-making process. As the size of a storage reservoir is enlarged more actors are affected. Some of these are beneficiaries (direct recipients n_{dr} and some indirect recipients), others may be negatively impacted (some of the benefactors whose degrees of freedom are constrained because of the storage project, and those indirect recipients who are impacted negatively by it), while still others are involved in funding and designing the project. However, the roles and interests of these actors differ. With increasing storage volume, more people are likely to be impacted and the number of potential tradeoffs and conflicts increases and finding an equitable solution becomes more complex. The decision challenge for the policymaker is to reconcile the differing interests by enlarging the number of beneficiaries and finding some means to compensate the losers and to see which of the two options is easier to implement.

[51] Larger reservoirs thus require increasing institutional capacity to design and implement decision-making processes that are perceived as fair and legitimate, and that lead to outcomes that will be acceptable and enforceable. Larger reservoirs call for greater scientific and technical capacity.

Environmental impacts change with project size and the larger the project the greater the need for environment impact assessments. A large number of small dams also require considerable institutional capacity but of a different nature; focused on capacity building at local level, providing access to loans at local level and organizing such a process in a decentralized manner. It is difficult to compare the administrative burden of one large intervention with many small, but some elements are clear. The administrative burden increases with size, especially when larger impacts will require certain licensing procedures. As these impacts cross jurisdictions new administrative complexities are added. Finally, if a reservoir requires investments that go beyond the capacity of the direct recipients, these beneficiaries may get involved into new relations with outside financiers. If foreign investors become involved, water governance becomes subject to bilateral investment treaties and international contract law [*Schouten and Schwartz*, 2006].

[52] The analysis may appear to tend toward the "small is beautiful" and is perhaps a reaction to the era of large dams and the outcry against them [e.g., *Morse and Berger*, 1992; *McCully*, 1996]. However, the cumulative effect of very many cascading tanks and small reservoirs spread across the landscapes, in terms of hydrology, ecology and governance are difficult to predict because of the scale effects discussed above and should be an urgent field of research. To exaggerate the point a bit: by now we have a fairly good idea of what the biophysical, economic, managerial and sociopolitical impacts are of a large dam with a capacity of, say, two hundred million cubic meters [*World Commission on Dams*, 2000]; yet we do not know the precise impacts and effects of one million small tanks with a storage capacity of two hundred cubic meters each.

[53] One could argue that the distributed approach of upscaling storage would result in a better spread of access to storage space, and is less easily monopolized as in the case of large reservoirs. In terms of water allocation at the basin level, however, the distributed approach poses nightmarish challenges: would it still be possible (physically and administratively) to release stored water in upstream catchments to satisfy legitimate needs in downstream parts of the basin? The answer hinges on the precise hydrological impact of such an approach, which depends on the average residence time of each of these small structures, which part of the hydrograph is captured by it, and to what extent water is used for full dry season irrigation.

7. Conclusion

[54] As climate change becomes a greater threat to countries in terms of impacts on irrigation water systems [*Fischer et al.*, 2007], all countries, and especially those with semiarid climates, need to think more about how best to manage and store their water resources. Adaptation to global change requires not only changes in the ways we manage water, but also requires new judicious physical interventions, in particular in creating more water storage capacity.

[55] The policy choice is what form the additional storage should take: should the centralized option be preferred with relatively few large reservoirs, or the distributed option with many small reservoirs and tanks, or judicious combinations

thereof. This paper presented the graphic representation of the hourglass model of sustainable development and identified four multidisciplinary criteria for evaluating policy options on a case by case basis. In general, we can conclude that the distributed approach has many advantages, in terms of encouraging investment in cash and kind and local stakes in the project, management and environmental aspects, yet expressed per unit storage it is much more expensive in monetary terms than the centralized option, although the latter involves greater negative externalities that are likely to be excluded from cost-benefits considerations.

[56] Whatever option is chosen, water storage capacity is seen as an asset; and should as such feature in the annual National Income and Production Accounts of all semiarid countries [cf. *Clarke and Islam*, 2006; *Lange*, 1998; *Lange et al.*, 2003]. The average cost of creating 1 m^3 of storage ranges between 0.2 and 4 U.S.\$/m^3 (see Table 2). If as a minimum 700 m^3/capita is required, emulating South Africa and Zimbabwe [see, e.g., *Chimowa and Nugent*, 1993], this would translate into an investment requirement of 140 to 2,800 U.S.\$/capita, figures that are in the same order of magnitude as 1 year GDP of many developing countries located in semiarid regions. This shows the immensity of the challenge.

[57] There are complexities associated with large reservoirs that may be difficult to overcome and that require strong institutional capacity if unwanted consequences, such as unequal access and environmental impacts, are to be mitigated. One would thus have to judge whether this institutional capacity is such a scarce resource and so difficult to build up that for the time being priority should be directed to those storage projects that minimize institutional complexity. This would favor the distributed approach that would create very many small, but per unit storage more expensive, tanks and small reservoirs. Such an approach could incrementally move toward comprehensive coverage of the semiarid agricultural region.

[58] Such tanks and small reservoirs will increase the insurance of livelihoods against dry spells. These would significantly increase the water value through slowing the water flow in the landscape, while having a limited negative impact on upstream and downstream areas. In addition, the managerial requirements of operating those storage structures would be limited compared to larger reservoirs. In terms of managing the entire catchment in which these structures would be located, the precise governance requirements are unknown, but must be limited because only a relatively small portion of the generated runoff would be captured and withdrawn. A positive externality of the small reservoirs would be seepage losses that would recharge aquifers on which those and neighboring farmers would rely and benefit from. Having sources of water scattered across the landscape may also have other benefits, as more water is available for other, high-value productive uses.

[59] Once water availability is significantly enhanced and secured, farmers will be more confident in harvesting a good crop, and thus can afford to invest in improving their agricultural technique likely to lead to doubling or even tripling of crop yields [*Rockström et al.*, 2003; *Falkenmark and Rockström*, 2004; *Falkenmark and Lannerstad*, 2005].

[60] Empirical analysis in a number of different fields shows that it is not always the size of the project that guarantees its success, but the way it is embedded and integrated in the local community that often ensures that such a project is successful. For example, in the area of rural electricity, even small rural electricity schemes may be successful if they are well integrated into a larger rural development plan that stimulates not just consumptive use but also productive use of the electricity leading to the generation of resources to make the whole scheme viable [*Ranganathan*, 1993]. *Swallow et al.* [2006] emphasize that success at one scale increases the return on investment at other scales. They therefore make a case of the need for concerted efforts at various spatial scales simultaneously.

[61] Increased access to water storage will, if properly combined with investments in other fields, such as road infrastructure, markets, knowledge and information, trigger economic growth. Such a development may in turn require a further increase in buffering capacity, and thus the creation of more hydraulic ownership. With such investments the dangers of inequity loom large. The institutional capacity of governments to mitigate these effects and to provide for public good functions, and to defend the public interests must therefore be considered key. But ironically institutional capacity may as much be a result of this development as a prerequisite. This conclusion seems to imply that the scale of new storage projects could gradually increase over time so that a society can learn and adapt to the increasing institutional complexity.

[62] Finally, it is urgently required to conduct research into the cumulative effect of the distributed option, whereby many cascading tanks and small reservoirs are littered across watersheds, both in terms of hydrology and governance.

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J. Gupta, Institute for Environmental Studies, Vrije Universiteit, De Boelelaan 1115, NL-1081 HV Amsterdam, Netherlands. (joyeeta.gupta@ivm.vu.nl)

P. van der Zaag, UNESCO-IHE Institute for Water Education, PO Box 3015, NL-2601 DA Delft, Netherlands. (p.vanderzaag@unesco-ihe.org)