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A Compact to Revitalise Large-Scale Irrigation Systems Using a Leadership-Partnership-Ownership 'Theory of Change'

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ABSTRACT: In countries with transitional economies such as those found in South Asia, large-scale irrigation systems (LSIS) with a history of public ownership account for about 115 million ha (Mha) or approximately 45% of their total area under irrigation. In terms of the global area of irrigation (320 Mha) for all countries, LSIS are estimated at 130 Mha or 40% of irrigated land. These systems can potentially deliver significant local, regional and global benefits in terms of food, water and energy security, employment, economic growth and ecosystem services. For example, primary crop production is conservatively valued at about US$355 billion. However, efforts to enhance these benefits and reform the sector have been costly and outcomes have been underwhelming and short-lived. We propose the application of a 'theory of change' (ToC) as a foundation for promoting transformational change in large-scale irrigation centred upon a 'global irrigation compact' that promotes new forms of leadership, partnership and ownership (LPO). The compact argues that LSIS can change by switching away from the current channelling of aid finances controlled by government irrigation agencies. Instead it is for irrigators, closely partnered by private, public and NGO advisory and regulatory services, to develop strong leadership models and to find new compensatory partnerships with cities and other river basin neighbours. The paper summarises key assumptions for change in the LSIS sector including the need to initially test this change via a handful of volunteer systems. Our other key purpose is to demonstrate a ToC template by which large-scale irrigation policy can be better elaborated and discussed.

KEYWORDS: Irrigation, food security, water security, ecosystem services, theory of change

INTRODUCTION

The unexceptional performance of large-scale canal irrigation systems (LSIS) in countries with developing and transitional economies is a sizeable policy challenge in the global governance of environmental and societal goods and services (CAWMA, 2007; Turral et al., 2010; de Fraiture et al., 2010). Comprising about 115 million hectares (Mha) in these countries (or approximately 45% of their total area under irrigation; Table 1 and Appendix 1), large-scale irrigation is central to a wide spectrum of existing and potential benefits (Schultz et al., 2009). These systems produce significant quantities of calorie-rich and agro-industrial crops that include rice, wheat, cotton and sugar cane with implications for local and global economies and poverty (Hanjira et al., 2009; Faures and Mukherji, 2009; Hussain and Hanjra, 2004) and food supply (Rosegrant et al., 2009). LSIS also greatly alter the hydrology and water quality of rivers through the diversion, consumption and return flows of water (Wisser et al., 2010), and thus significantly impact the timing and nature of water-based ecosystem services (Crossman et al., 2010; Gordon et al., 2010). Furthermore LSIS, managed effectively and distributing water by gravity, use far less energy than equivalent pressurised sprinkler and drip systems (Rothausen and Conway, 2011) and thus help mitigate global carbon dioxide emissions. Together these aspects put LSIS firmly and substantially in the nexus between food, climate change, rising energy costs and environmental accountability (Hellegers et al., 2008). In addition, LSIS can substantively contribute to the Sustainable Development Agenda (UN, 2015) to end poverty (Sustainable Development Goal (SDG 1)) via addressing food security (SDG 2), water management (SDG 6), energy access (SDG 7) and the sustainability of terrestrial ecosystems (SDG 15).

Notwithstanding the importance of LSIS in terms of rural employment and contribution to food security, the sector is experiencing deficiencies in management and governance leading to underperformance of substantial investments.[1] These deficiencies are evidenced in six ways: (i) donor and government funding of large-scale irrigation have witnessed commonly repeating cycles of irrigation 'build-neglect-rebuild'; (ii) the financial performance of these systems is below par; (iii) the water, land and labour productivity of LSIS is generally recognised to be below what it could be; (iv) large volumes of water diversion, combined with variable, but generally poor, irrigation efficiency within the systems, mean the presence of LSIS adversely impacts water governance in river basins and limits allocation of water for other users including the environment. Associated with these four factors, we also note that (v) capacity building in irrigation has declined; and (vi) spending on irrigation research is substantially less than the significance of the sector warrants.

Although the food price spikes in 2007 and 2008 triggered an upturn in investments (G8, 2009) to enhance food security, there are a diminishing number of official development assistance investors in irrigation. In addition there are few examples where private-sector investments have been effectively mobilised alongside public investments.[2] Therefore, acknowledging the significant local, national and global roles and challenges associated with LSIS, the authors argue that revitalising these systems should be uppermost in the minds of policy-makers when considering how to resolve future national and global challenges related to economic, food, water, energy and environmental security (Birendra et al., 2010; Mukherji et al., 2012). However, the combination of the six factors introduced above has left national and global policy-makers short of new insights and clear strategies for LSIS to meet challenges posed by climate change and a world with a growing and increasingly urban population.

[1] For example, the Government of India has invested about $60 billion in major and medium irrigation systems, in the years from 1960 to 2007, to develop and maintain a canal irrigated command area of approximately 17 Mha (Shah, 2010).

[2] While we are aware of the growing trend of public-private partnerships (PPP) surrounding public goods and infrastructure including irrigation (Faures et al., 2007; Bernier and Meinzen-Dick, 2015), we have been careful not to use PPP-type concepts or phraseology in this paper. This is because our argument is for strong diverse leadership-partnership-ownership models tailored by individual irrigation systems that in many instances might go beyond current policy formulae for PPP.

In recognition of the fact that traditional approaches to upgrading and reforming LSIS and irrigated agriculture have fallen short of expectations, the authors propose the adoption of a 'theory of change' to assist global, national and local actors discuss the transformational changes required to improve the performance of large-scale irrigation.

A THEORY OF CHANGE FOR REVITALISING LARGE-SCALE IRRIGATION

In recent years development agencies and organisations have been reflecting upon societal and environmental problems via a 'theory of change' (ToC) approach. In her extensive review, Vogel (2012) tracked the rise of the idea and its place in development theory and practice, and examples of the application of ToC include: the CGIAR Research Program on Climate Change, Agriculture and Food Security (Schuetz et al., 2014); the International Climate Fund examining adaptation (Brooks et al., 2014); Non-Governmental Organizations (NGOs) such as WaterWitness International and TWAWEZA; and on diverse topics such as social justice advocacy (Klugman, 2011) and peace building (Ober, 2012).

Theory of change – A four-element structure

We have followed Vogel (2012) in that a 'theory of change' commonly incorporates four key elements: (i) an analysis of the context in which desired changes are to occur; (ii) definition of the long-term aims that are desired, providing a direction of travel; (iii) definition of the process and sequence of change, allowing users to more sharply express change mechanisms; (iv) analysis of binding constraints and assumptions that determine whether the changes can happen and that shape outcomes and success. Vogel (ibid) also recommends that a particular ToC is expressed in a diagram and narrative summary.

The paper’s authors restate that we aim to stimulate a macro-level debate on how to approach the revitalisation of large-scale irrigation systems by arguing for a compact around a closely supported farmer-leadership model utilising a four-part theory of change framework. Nevertheless, the challenges of transforming different systems are numerous, heterogeneous and to be worked out in detail. The risk is that the ToC framework, especially within the word limit of a paper, makes the task seem more straightforward and formulaic than it will be.

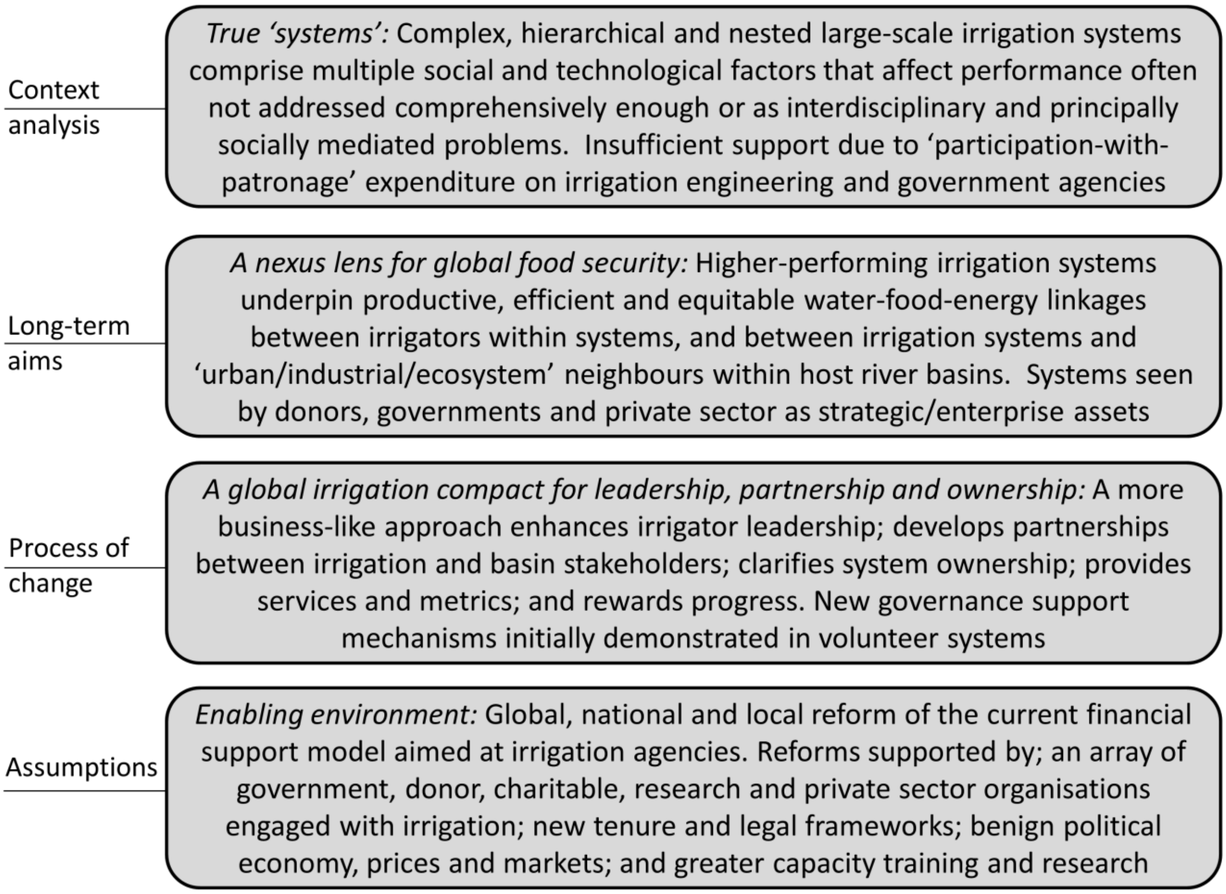
Narrative description and diagrams of ToC for LSIS

While a fuller expression of the theory of change is provided in further sub-sections, the theory of change is summarised in this narrative description:

> *The technology, institutions and ecosystems of large-scale irrigation systems (LSIS) present complex and nested challenges to local, national and international agencies seeking to reform and revitalise those systems. The long-term objective is to achieve better-performing and sustainable systems that efficiently and equitably underpin a range of irrigator- and water-food-energy-urban-ecosystem goods and services. To achieve this objective, 'leadership-partnership-ownership' (LPO) reform is required that results in a more comprehensive and business-like approach tailored to individual irrigation systems. This reform, termed a 'global irrigation compact' (GIC) targets farmer-led leadership; recognises strong mutuality between actors, systems and host river basins; considers new arrangements for system ownership and services; and rewards improved irrigation performance also covering ecosystem services. Success depends on many assumptions, including; a commitment to reform institutions and leadership of organisations tailored towards LSIS; the establishment of appropriate incentives for agency staff, farmers and other stakeholders to support change; and the creation of sufficient provisions for capacity development, training and research to support the desired changes. The change process would initially be tested in selected volunteer systems.*

An overview of the ToC for revitalising large-scale irrigation systems is presented in Figure 1 including brief expressions of; the context; long-term aims sought; the change process; and key assumptions. Figure 2 introduces the two models of irrigation governance (discussed later in the paper) and the argument that the current 'patronage-with-participation' model (Vermillion, 2005) where donors and governments fund irrigation agencies and formal engineering should be replaced by a leadership-partnership-ownership 'ecology' where a greater variety of stakeholders closely support an executive-type body comprising farmers or farmer-employed professionals who manage irrigation systems. While we accept that not every large-scale system falls easily into this characterisation, we are persuaded of the need to move LSIS towards endogenously-derived, yet collaborative, pathways of self-determination (Theisohn and Lopes, 2003).

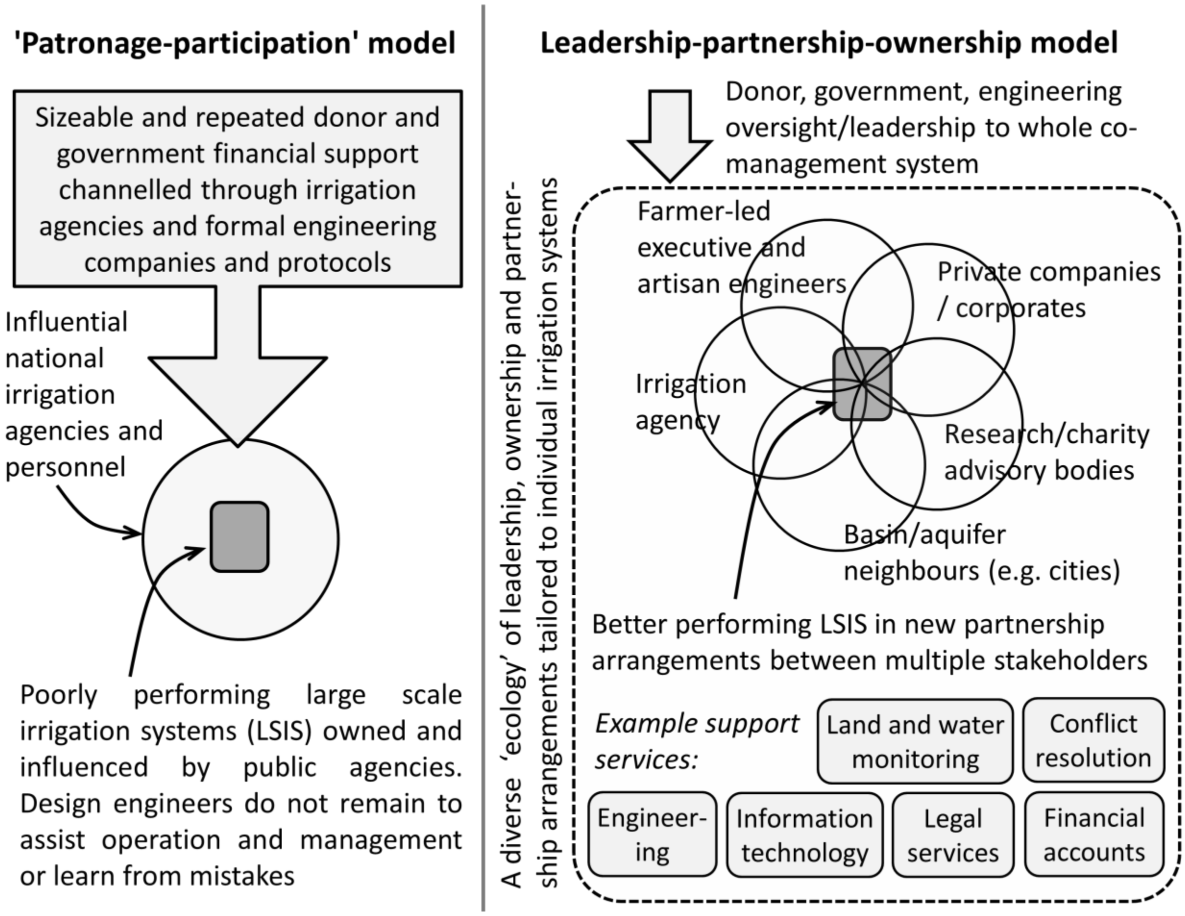
Figure 1. A four-part theory of change to revitalise large-scale irrigation systems.



Clarifications

Four clarifications are necessary at this point. This paper offers one interpretation of a theory of change for large-scale irrigation. We acknowledge others may draw different conclusions about the context, objectives, process and assumptions and how to intervene to improve LSIS performance. The objective of this paper (our second clarification) is to present a transparent template on how to engage with large-scale irrigation. We believe separating out the four elements of the theory of change reduces the risk of different stakeholders misunderstanding each other and talking at cross purposes. This dialogue-objective means that this theory of change is not a strict formula or blueprint. Thirdly, we specifically address the challenges represented by LSIS and do not consider irrigation in general or all types of irrigation technologies (which include pressurised systems and small-scale farmer-owned systems – although they may be connected to, and embedded in, larger systems). We seek to deal with large-scale systems that have a specific history of troubled investment and underperformance and yet are strategic national agricultural assets. Fourthly, in framing a wholly new change process, the authors have not been able to readily locate new systematic approaches to irrigation that inform our analysis. On the contrary, our ToC stems from our view that irrigation policies have underestimated the complexity of large irrigation systems. Put another way, and as explained in the paper, we argue for wholly new levels of comprehensiveness, mutuality and inclusivity presently lacking in irrigation policy and investment strategies.

Figure 2. LSIS 'theory of change'; from patronage to a leadership-partnership-ownership 'ecology'.



CONTEXT AND SITUATIONAL ANALYSIS

The first part of the 'theory of change' is an analysis of the context in which change is to be implemented. We present this now starting with definitions, statistics and an analysis of the background to LSIS and donor policy. We also discuss how the multiple properties and nested nature of LSIS shape their performance response to interventions.

Definitions of large-scale irrigation systems (LSIS)

A single definition for 'large-scale irrigation' is not easy to derive or is globally applicable. In terms of command area, large-scale are generally those systems over 3000 hectares (ha). However, in parts of Asia, irrigation systems larger than 10,000 ha are considered large-scale (some exceed 0.5 Mha). In sub-Saharan Africa systems over 1000 ha are usually classified as large-scale (Underhill, 1990). More accurately 'large-scale' is defined as any system where there is a formal, usually government-sponsored, irrigation organisation responsible for O&M of the upper tiers of the distribution system and which is, at least nominally, responsible for provision of a water delivery service to farmers or groups of farmer/irrigators. This contrasts with small-scale systems that tend to be built, owned and maintained by farmers and their local communities.

Water sources for LSIS are varied and may include one or more rivers, storage dams, and shallow groundwater or deeper aquifers. Water distribution is primarily by gravity through canals, earthen ditches and field-to-field transmission of water controlled by a variety of gates and turnouts often designed via formal engineering procedures. In some places water distribution may also involve pumps, pipes and additional local storage. Large-scale systems include a mix of full and/or supplementary irrigation depending on seasonal rainfall to produce food and agro-industrial crops including rice, wheat, oilseeds, cotton, sugar cane and pulses.

Quantifying areas of large-scale irrigation systems (LSIS)

In calculating global statistics of large-scale systems we focus on countries with developing and transitional economies. It is these countries that a) have significant areas of irrigation with sizeable proportions categorised as large-scale systems; b) have a history of public ownership of LSIS; c) are home to government departments and agencies focussed on supporting large irrigation systems; and d) are, or have been, recipients of international aid intended to reform their LSIS sectors.

Determining the scale and areal proportions of LSIS is not straightforward because the World Bank and Food and Agriculture Organisation (FAO) do not categorise their irrigation data using a size label or area criteria. Using multiple searches on the internet examining national and international online publications (see Appendix 1) we estimate there are approximately 115 Mha of large-scale irrigation in countries with developing and transitional economies. This represents about 45% of the total area under irrigation in the countries included in the calculations (255 Mha; Table 1). However, as Table 1 and the footnote below show, in addition to our principal interest in developing and transitional economies, we estimate the area of LSIS for the whole globe (all countries) to comprise about 130 Mha or about 40% of the total global irrigated area of 320-330 Mha.[3]

The data in Table 1 and Appendix 1 provide an approximate picture of the contribution of large-scale irrigation to regional and global totals and as such should be treated with caution. We reiterate that there is likely a 10-15% error with published national, regional or global figures, but which are adequate for the purpose of illustrating the significance of LSIS in global agricultural production.

LSIS are found throughout tropical, sub-tropical and temperate continental regions and are prevalent in countries as diverse as China, India, Pakistan, Malaysia, Uzbekistan, Kyrgyzstan, Kazakhstan, Iran and Turkey. South and South East Asia have the largest area under LSIS at approximately 90.3 Mha or about 44% of the total irrigated area (Table 1) whilst Central Asia is notable for having most (>85%) of its irrigated farmland under large-scale canal systems due to the region's history as a part of former Soviet Union and its former policy of large centrally controlled farms. Large-scale systems in sub-Saharan Africa are less common but have been developed in Mozambique, Tanzania, South Africa, Swaziland and Mali to name but a few countries. Large-scale irrigation accounts for about half the irrigated area in the Middle East and the North African Region (including Turkey,

[3] This calculation requires two steps. First we determine the difference between the total global area of all irrigation (estimated at about 320 Mha using FAO Aquastat of 2009 data) and all irrigation in the developing and transitional countries where LSIS exist in Appendix 1 which totals 255 Mha. This number is 65 Mha (Table 2; 320 – 255 = 65). Second, we assume that this 65 Mha contains large-scale irrigation systems but at half the proportion (22.5%) than in countries where LSIS predominates (22.5% is also informed by the proportion of LSIS in SSA and Latin America). Thus; 22.5% of 65 = 14.63 Mha of LSIS in countries with advanced and developed economies. This has been rounded to 15 Mha giving a rounded total LSIS of 130 Mha (115 + 15) or 40% of the total global area under irrigation.

Sudan and Egypt) a region that is considered climatically and politically sensitive to food insecurities and price spikes (Maystadt et al., 2012).

Table 1. Global irrigation and large-scale irrigation systems (LSIS).

Region	Total irrigated area (ha)	Proportion of irrigation under LSIS (%)	Area LSIS (ha)
South Asia and SE Asia	205,669,000	44	90,355,700
Central Asia	11,465,400	90	10,365,400
Latin America	18,952,000	36	6,783,650
Sub-Saharan Africa	4,216,000	17	731,200
Middle East and N Africa	14,652,000	46	6,805,820
All regions [A]	254,954,400	45	115,041,800
Remaining regions and global total and proportions			
Approximate difference [B-A]	65,000,000	22.5	15,000,000
Total global [B]	320,000,000	40	130,000,000

The distinctive history and nature of large-scale systems

While the aggregation of many small irrigation systems within a basin can have cumulative impacts similar to LSIS, small systems generally do not have a national public agency involved in routine O&M. This purposively enables a focus on the specific challenges associated with LSIS in formulating new approaches to revitalising irrigation, including the recognition of four special factors. These are discussed in more detail below:

1. *Historical and ongoing State investments in land and water.* A large proportion of LSIS are the products of investments by development partners, official development assistance (ODA) and public sector spending by national governments (Faures and Mukherji, 2009). Therefore, governments commonly have an ongoing stake in the management of these 'public' systems usually in the form of either small administrative units within agricultural ministries (e.g. Tanzania) or larger agencies and bureaucracies (e.g. Thailand). This relationship creates a strong tie between the fortunes of irrigation systems and the political economy of public ministries. Recognised long ago (Bottrall, 1985; Chambers, 1988), this gives rise to institutionalised opportunities for rent-seeking whereby public servants can capture and shape irrigation funding and modalities in ways that mirror the engineering/hydraulic ideals of the bureaucracy (and/or politicians) rather than those of individual irrigation systems resulting in starkly inferior economic, productivity and ecosystems performance (Molle et al., 2009). By interpreting 'large' as 'public' we note that LSIS have also arisen out of geopolitical processes and antecedent political decisions that are difficult to reverse either by reducing their command area or shifting to new modes of operation or markets for production. An example of this is the ongoing production of irrigated cotton in river basins feeding the Aral Sea (Tookey, 2007; Aldaya et al., 2010).

2. *LSIS as socially, economically and financially complex systems*. While it might be assumed that a single large system operates as an integrated entity, its size often undermines coherence. This is because each system is made up from multiple tertiary and secondary canal units each of which can be relatively autonomous. A simplified key difference between small-scale and large-scale systems is that while small systems can be managed by a single water user association (WUA), large systems require an apex or hierarchical arrangement with farmer groups at the tertiary level and some form of organisation responsible for O&M of the main system to deliver

water supplies to multiple WUAs.[4] Matching tertiary management to main system management to create a single whole entity has proven to be a common problem (Rao and Sundar, 1986; Chambers, 1988). To be managed as a single large unit would require strong institutional buy-in by farmers and by service providers alike. Equally, while large systems are potentially manageable as viable entities complete with rules-based financial and water management accounts and audits, few systems achieve this. Instead a portfolio of hybrid 'informal adjustments' by farmers to circumvent agency rules (Lees, 1987) and rent-seeking behaviours by officials and farmers lead to conditions which obscure transparency and undermine performance (Repetto, 1986; Easter, 1993; Tsur et al., 2004).

3. *LSIS as technologically complex systems*. While any one part of an irrigation system might appear relatively simple (transferring water to crops by gravity through a canal, sluice gate and field), the behaviour of the whole system (with component and nested parts of diversion structures, main and secondary canals and tertiary units) is often characterised by considerable mismatches between supply and demand (Gorantiwar and Smout, 2005). Plusquellec et al. (1994) summarised the design and operation factors underlying these mismatches as constituting technological complexity. The control of water in LSIS is also further complicated in many cases by return flows and infiltration to groundwater, retrofitting of small storage bodies, and subsequent water releases back into the system. Often, these adaptations were not purposefully designed into the original systems but have, nevertheless, become part of the complex water supply systems of LSIS (Foster and Shah, 2012). Moreover, these dynamics and mismatches are subject to social perceptions about water deliveries which in turn are rarely informed by accurate resource monitoring and measurement. This perception gap underscores the institutional problems described in the previous paragraph.

4. *Emphasising the size of large-scale systems*. The previous two factors introduced size as a defining feature of LSIS. We make the point that 'large' is not simply a bigger version of 'small'. To explain this we critique Rockström et al. (2010: 548) who proposed "[a] natural consequence of a reorientation of water resource management, starting from rainfall as the freshwater resource, is to abandon the current (artificial) divide between irrigated and rain-fed agriculture". While we acknowledge that crop watering technologies span from purely rain-fed to fully irrigated, we believe that 'a continuum' is not an appropriate starting point from which to view large-scale systems. A different starting point is to consider that the difficulty of water control increases geometrically as systems go from 1 ha to 10 to 100 to 1000 to 10,000 ha (and on through to >1 Mha). This nonlinear effect of system size on water control asserts that an inflexion or tipping point exists and that remarkably different types of systems exist on either side of this point. At the smaller scale, farmers are more likely to be socially connected, more likely to own the whole of their irrigation system, more able to meet to discuss water, and more likely to be able to distribute water equitably. But in large hierarchical systems these phenomena are very different; accurate water control is difficult, infrastructure ownership overlaps and irrigators cannot socially connect except to close neighbours. A 'continuum' cannot inform large-scale irrigation policy (or indeed policy about large coalesced areas of small-scale systems). On the contrary, it is the recognition of differences in size, structure and ownership that is the premise for a new approach to large-scale irrigation systems.

The significance of these four factors is that LSIS are highly complex inherently heterogeneous systems (Gorantiwar and Smout, 2005); and that each system is unique. Each is moving on along an individual evolutionary pathway within highly dissimilar river basins (Shivakoti, 2003 quoting Coward). Each

4 In order not to be prescriptive about what form this might take, we term this body the 'apex irrigation office' (AIO).

system sits between, and is influenced by, multiple organisations and broader forces. Either by omission or commission, irrigation systems are shaped by multiple actors including irrigation engineers, water user associations and irrigators, irrigation donors and bureaucracies, markets and prices, and other ministries and lobbies competing for their own priorities and shares of the national budget. Thus, large irrigation schemes are authentic 'systems' that require comprehensive, integrated and often iterative and adaptive remedial action.

Donor and government policies to large-scale irrigation

Regarding policy responses to address factors described in the previous sections, it can be argued that with respect to large-scale irrigation, donor strategies have not adequately overcome and solved the commonly repeating cycles of irrigation rehabilitation, cast as the 'build-neglect-rebuild' syndrome (Shah, 2009). This syndrome is symptomatic of a deeper 'flaw' namely the ongoing deployment of a 'patronage-with-participation' aid model which insufficiently devolves rights and authority to water users (Vermillion, 2005; Bruns, 2013) and resolves underlying factors (e.g. the tenure of the irrigation system) that motivate key stakeholders such as irrigators and government irrigation officers to invest in irrigation performance.

Furthermore, although countries and donors spent many millions of dollars in supporting LSIS in the 1970s, 1980s through the early 1990s there was a significant downturn in investments thereafter (World Bank, 2006). Despite this reduction in public investments, in South Asia the irrigated area continued to expand primarily due to the expansion of farmer-driven groundwater withdrawals. While we accept that in the last five years, food price spikes have goaded the donor community into revisiting agricultural spending, public investments in large-scale irrigation have not accelerated to the same extent and have arguably reversed since the food crisis in 2007.

However, historically and recently, it is not simply the volume of spending that is under question but also the channels, principles and modalities employed. We exemplify this issue via two policy themes although there are many other issues at work. First, the widespread policy instrument of handing over irrigation responsibilities to irrigators via irrigation management transfer (IMT) and participatory irrigation management (PIM), originating from Wade's (1988) and Ostrom's (1990, 1992) analyses has not resulted in significant or consistent performance gains (Vermillion 1997; Meinzen-Dick, 2007; Merrey et al., 2007; Mukherji et al., 2012). While the authors of this paper do not fault the principle of inclusive co-management via IMT/PIM, we are critical of an overreliance on this alone. There are two concerns; in general, IMT/PIM held back from transferring full ownership of systems to irrigators in order to reconcile performance gaps arising between main canal system management and tertiary canal/'below the outlet' water distribution.[5] Second, follow-up support to farmers was usually insufficient for them to lead and drive further technical and institutional reform. The result of conventional PIM/IMT was that government agencies continued to adversely affect the performance of large irrigation schemes.

Second, despite cautions by Playán and Mateos (2006),[6] modernisation is perhaps too frequently seen in narrow terms as some combination of the upgrading of upgraded canal irrigation systems to

[5] Wade and Chambers (1980), Chambers (1988) and others argued that an outcome of the split between main canal system managed by the irrigation agency and tertiary distribution managed by farmers is that each party fails to take responsibility for the impact of their actions on the other. Farmers end up having a low stake in main system management and the apex organisation has little voice in matters 'below the outlet'.

[6] On page 106, they wrote "modernisation is understood as a fundamental transformation of the management of irrigation water resources aiming to improve the utilisation of resources and the service provided to the farmers" and "combines changes in rules and institutional structures, water delivery services, farmers' irrigation scheduling, technical and managerial upgrading and advisory and training services, all in addition to the introduction of modern equipment, structures and technologies."

piped systems; the employment of more computerisation and sensors; and, too frequently, the lining of canals (Kijne, 2003). Concentrating solely on hardware modernisation runs the risk that a) formal and expensive engineering procedures steer the rehabilitation process and b) new technologies do not match the social and institutional practices and farmer knowledges already in place.

Thus with regard to existing policies, our concerns are fivefold: (i) donors and governments too often still use blueprints from the 1980s for canal rehabilitation and PIM; (ii) there is inadequate investment in necessary parallel interventions such as farmer-leadership training and inadequate inclusion of the private sector which might otherwise have sustained these investments; (iii) although some irrigation agency reforms were conducted these have not been sufficiently transformative (Suhardiman and Giordano, 2014); (iv) there is insufficient evidence of analyses of lessons learned; (v) policies for large irrigation systems have been hampered by desires for them to be 'small' in ethos. Put another way, no 'single silver bullet' policy or sets of interventions readily applicable to these systems exist (Turral et al., 2010; Easter, 2000). Indeed, one must ask whether investments in large-scale systems have led to the necessary durable upturn in irrigation performance (Inocencio et al., 2007). Drawing on these concerns and the two topics discussed in this sub-section, we argue that a much more comprehensive farmer-centred approach to large-scale systems is required.

The prosaic image of irrigation as a technology and activity

Another overarching deficiency is more difficult to pin down; one that we briefly describe here and then attempt to refute. Put simply, the science and policy narrative for irrigation is often too prosaic and mundane. In other words, the 'case for irrigation' (and 'irrigators') regularly fails to adequately capture the complex challenges, dynamics and benefits of irrigation systems and the varied roles of the people that are part of these systems. Common narratives purport that irrigation is 'only' a technical input to crop production (like seeds or agrochemicals) or a component part of rural infrastructure (like roads or electrification). A typical example is given by Godfray et al. (2010: 813 and 815) in referring to irrigation alongside other inputs such as "fertiliser, machinery, crop-protection products, and soil-conservation measures".

Similar downplaying of roles and responsibilities applies to irrigators and gatekeepers; and yet these two actors are collectively responsible for the diversion and distribution of about 5 cubic kilometres of water every day.[7] Framed differently, irrigators and gatekeepers (Van der Zaag and Rap, 2012) should be seen as very significant water managers; "Water users are key players in the game, not an audience" (Waheb, 2014).

The problem faced in countering the perspective of irrigation as 'only an input' is that this interpretation is true when considering irrigation at the plant and field-plot scale. Furthermore, watering of crops is a tremendous challenge in its own right as evidenced by the many journal articles devoted to irrigation agronomy or in-field design (e.g. Geerts et al., 2010) and which merits ongoing research. Irrigation is undeniably the provision of water to the crop and field. And an irrigator, responsible for say 2 ha, is easily characterised as a minor sink of evapotranspiration perhaps not much different to a rain-fed farmer or even a domestic consumer.

However, the size and hierarchical properties of large-scale irrigation systems require a cognitive step-change. Rather than viewing irrigation as a 'green revolution' crop input as Godfray et al. (2010) and Licker et al. (2010) do, it is more useful to treat a large irrigation scheme as a distinctive socio-technological production system within a particular ecosystem made up of multiple component parts and players and with far-reaching impacts on its surrounds. In other words, irrigation systems are

[7] Assumption: The global LSIS area of 130 Mha withdraws 1400 mm of gross water (and consumes 1025 mm of net water) over 365 days. In comparison, the annual withdrawal for global irrigation in LSIS is about 3.5 times that of the Mississippi River's average annual discharge. Actual daily and monthly amounts differ considerably due to seasonality.

entities that inhabit and shape their environs. Furthermore, LSIS managers are dealing with wicked problems different from commonplace framings of farm productivity. Conventional linear theories of change need to be complemented with iterative, multi-level and adaptive solutions (Johnson et al., 2014; Meinke et al., 2009). This vision is much more in keeping with interdisciplinary research promoted by the International Water Management Institute (IWMI) and Wageningen/UNESCO-IHE Universities (e.g. van den Dries, 2002; Mollinga, 2003) amongst others.

Persuading the many actors working in national finance ministries and ODA (official development assistance) that irrigation represents a complex socio-technological system with high rewards is a communication challenge. Yet these complexities must shape the way irrigation policy is formulated. It would be counterproductive to craft an elementary framework of irrigation characteristics and objectives as this would provide insufficient guidance for policy and actions.

LONG-TERM AIMS: GENERATING RIVER BASIN AND GLOBAL GOODS FROM LSIS

We now examine the second element of the theory of change namely the objectives that large-scale irrigation systems should seek to achieve. These are presented as a set of global and river-basin goods. We do not present these objectives in detail or beyond an initial set of illustrative calculations. Not only is space limited, but precise target-setting is more appropriately the purview of individual nations, basins and irrigation systems at a given time. To assist this scenario planning and target-setting, we envisage a parallel research agenda which is one of the assumptions presented in the ToC below.

Water allocation and river basin management

As a result of considerable water withdrawals and depletion, large areas of irrigation influence the water governance of host river basins and constrain the allocation of water to other sectors. The 130 Mha of global LSIS account for a mean daily depletion of about 3.65 km^3 (utilising a 365-day year) whereas the total urban, industrial and domestic depletion is usually less than a tenth of this. Irrigation therefore accounts for about 70-85% of freshwater depletion in many semiarid and arid river basins (CAWMA, 2007). In addition, where groundwater reserves are under threat, irrigation often drives the mining of aquifers (de Fraiture and Wichelns, 2010).

While the scale of LSIS water depletion is largely a function of beneficial productive evapotranspiration, there is widespread perception that irrigation 'wastes' significant amounts of water that might otherwise be used to improve irrigation timing, or extend irrigated agricultural lands, or be reallocated to meet environmental, urban, industrial or energy demands. Although there are significant misunderstandings about the science of water waste and savings (often wasted water is not 'lost' as it is collected by downstream users or within irrigation systems), most scientists agree that productivity can be significantly boosted by using water in a more careful and timely manner (Molden et al., 2010; Lankford, 2012) and that there is room to improve performance with benefits for both raising crop production and saving water (de Fraiture and Wichelns, 2010; CAWMA, 2007).

While detailed evidence from specific schemes is often not generalisable due to a lack of robust research on the hydrology of irrigation systems, it is possible to draw up an illustration about how much a 10% reduction of total irrigation consumption (beneficial and non-beneficial) of 1025 mm annually would offer for water redistribution to targeted destinations. From these values we estimate realisable 'savings' of about 100 mm depth/130 M ha.[8] This volume is 130 km^3 which for ease of understanding equates to a supply of about 50 litres/day for each person of the world's population of 7.4 billion.

[8] We first assume large-scale systems differ from small-scale systems in experiencing a greater dependability of supply from larger rivers and aquifers. This global figure of 1025 mm arrives from 1.5 irrigating seasons each of 650 mm crop water requirement; a single annual wetting up irrigation dose of 150 mm; a non-beneficial non-recovered fraction of 250 mm; and a

Global food security

The substantive distinction between small and large-scale systems relates to the latter's position in being able to produce very large amounts of food and industrial crops such as rice, sugar cane and cotton using gravity distribution of water. The position of irrigation for food security has been recognised for many years; for example, Le Moigne (1992) argued that the combination of new cereal technologies and controlled water helped to avert widespread famine during the second half of the 20th century.

Of the many ways in which irrigation and global food security can be linked, we focus on one broadacre grain crop, namely rice. Rice, a key carbohydrate vital to global food security (Khush, 2003) is grown using different forms of field water control (a mix of irrigation, levelled fields and drained water from rainfall). Just six nations where rice is a daily staple account for about 45% of the world's population.[9] It is no coincidence that in these countries large-scale irrigation accounts for approximately 67% of the total area under irrigation.

We use rice as a calorie calculus to reveal the extent to which large-scale irrigation contributes global food security and could do so in the future with incremental yield increases. By making certain assumptions,[10] the production of an extra tonne of rice on 50% of 115 Mha under LSIS generates about twice the daily calorie need (pegged at 2500 cal/day) of the current global population of 7.4 billion. This computation underpins the argument that better irrigation performance would very significantly help meet future food requirements while water resources are simultaneously under pressure due to climate change and rising demand from other users (Hanjra and Qureshi, 2010).

Water-energy and river basin management

Large-scale irrigation using gravity to distribute water plays a pivotal role in mitigating carbon emissions from energy generation and usage. Well-managed LSIS are an incentive to prevent conversion of systems from open-canal distribution to pumped systems for sprinkler or drip irrigation. This mitigates the trend of lifting groundwater to be fed into canals and fields, recorded by Kuper et al. (2012), as a response to farmer perceptions regarding the uncertainty of volumes and timings of canal supplies, despite the additional pumping costs involved (see also Foster and Shah, 2012).

To calculate the tonnes of carbon emissions avoided by remaining with gravity, we make the following six assumptions: (i) a zero energy budget for gravity water sourced from a river;[11] (ii) changes in technology apply to an exemplar area of 13 Mha (approximately 10% of the global area under LSIS); (iii) switches to pumped and pressurised systems are assumed to take place with a ratio of groundwater to drip to sprinkler of 60: 20: 20; (iv) the pumping head (or lift) for groundwater, drip and sprinkler is 15 metres (m), 24 m and 60 m, respectively; (v) an annual irrigation dose of 1400 mm (see footnote #8),

contribution from rainfall of 350 mm. In this paper, we assume a recovered fraction of 375 mm. Thus; [Net irrigation depletion of 1025 mm = (1.5 x 650)+150+250–350] and [Gross irrigation withdrawal of 1400 mm = (1.5 x 650)+150+250+375–350]. While a reduction in beneficial evaporation can lead to a loss in production, this is potentially compensated for by better coordination of inputs and timing of irrigation often seen when deficit irrigation scheduling is employed.

[9] The six nations are China, India, Pakistan, Indonesia, Bangladesh and the Philippines.

[10] Assumptions: 1) 50% of 115 million hectares is devoted to rice; 2) Allowance for 60% losses converting field rice to table rice (Oerke and Dehne, 2004); 3) Average daily calorie intake set high at 2500 (though women need less); 4) Global calories for 7.4 billion people = 18,500 billion calories; 4) The energy content of table rice is about 110 calories per 100 g (or 1.1 million calories per tonne of rice/ha); 5) Total table rice calories generated by an extra tonne of field rice grown on 57.5 million ha = 3.83×10^{13} or approximately two times that required by the global population.

[11] Life cycle calculations of embedded energy in irrigation hardware are discounted for these comparisons. In addition we appreciate that a current baseline might already include a percentage of gravity systems that involve water pumped from rivers and aquifers. Thus more accurately we are calculating an avoidance of additional carbon generated to lift more water or pressurise water delivery to fields and farms than is currently applied to the exemplar area of 13 Mha.

requiring approximately 3600 hours of pumping over the whole year; (vi) the energy to carbon conversion is based on diesel being the source of energy.[12] Results can be presented in different ways. For example, pumped groundwater, drip and sprinkler 'cost' 1.5, 2.0 and 4.5 tonnes of CO_2/ha of irrigated land respectively. Also, these values give a weighted average carbon dioxide footprint of water consumption of 0.19 kg CO_2/m^3 of water which means that converting 13 Mha from gravity to pumped/pressurised distribution would generate emissions of 35 million tonnes of CO_2. Putting this into perspective, 35 Mt of CO_2 would 'cost' approximately 6.14% of the UK's total annual emissions or sit between the emissions of Ecuador and Azerbaijan, ranked 76th and 77th, respectively, in the world (Olivier et al., 2014). In brief, these calculations of energy avoided show the part that gravity distribution of water plays in the nexus of food, energy and water (Mukherji and Shah, 2012).

Financial performance

Large-scale irrigation systems present a paradox for decision-makers and scientists. While the value of crop production (as an expression of turnover or revenue) generated from these systems is significant, this has not translated into financial autonomy or sustainable performance independent of recurring investments by governments and donors (Malik et al., 2014). Irrigation agencies, water user associations and other stakeholders seem unable or unwilling to create realistic operating budgets to pay for recurrent management costs let alone create a capital budget for major repairs and system upgrading.

A simple calculation shows how large the financial value of production of an individual rice irrigation system of 100,000 ha can be. Assuming an average yield of rice at 4.0 t/ha and a global price of 475 US$/tonne, 100,000 ha generate a crop valued at 1900 US$/ha or a total of 190 million dollars.[13] A revenue of 190 US$ million is about four times the size of a small and medium enterprise (SME) as defined by the European Commission (EC, 2005). Yet LSIS are not given the same political and economic treatment as SMEs (Blackburn and Schaper, 2012).

Moving to the global scale we can now calculate the value of the 130 Mha of global LSIS undergoing an improvement process. By assuming slightly higher average annual revenues for mixed cropping of US$2580/ha,[14] the primary production value of 130 Mha LSIS globally is estimated as US$ 355 billion. This places LSIS equivalent to the world's sixth largest company ranked by revenue on the Forbes Global 2000 list for May 2014 (above Volkswagen Group, Toyota and PetroChina but below BP[15]). Moderately higher crop yields (and prices) would generate even more favourable financial comparisons.

Our point in making these comparisons is not to suggest that LSIS should be seen as institutionally or financially equivalent to private companies. Instead LSIS should be seen as significant national assets exhibiting a strategic economic status of an equivalent value to that of large companies domiciled in those countries. However, as we argue in the conclusion below, there is a very substantial gap in terms of how irrigation systems are treated by host countries and their development partners.

[12] Values for irrigation CO_2 vary due to assumptions made. For example Rothausen and Conway (2011) report 0.6 kg CO_2/m^3 of water or three times higher than the calculation above.

[13] For the same 100,000 ha area, every extra 0.5 tonne of rice increase generates an approximate revenue of US$24 million. We accept that yield and price variances may be significant.

[14] We assume a 70:15:15 crop mix of rice, sugar cane and 'other cash crop' (e.g. fruits and vegetables), respectively, using each creating a revenue of 2185, 3000 and 4025 US$/ha, respectively.

[15] If compared to the GDP of countries, this value would put LSIS below Colombia and above South Africa, countries ranked 32nd and 33rd in the world (World Bank data on GDP updated 16 December 2015). Note that comparing GDP, turnover and revenue depend on how they are defined and calculated.

A GLOBAL IRRIGATION COMPACT TO REVITALISE LARGE-SCALE IRRIGATION SYSTEMS

In this section of the paper we introduce the third element of a ToC which is the policy for transformational change. To go beyond current 'business-as-usual' interventions towards a focus on improved irrigation performance, it is essential to stimulate new debate on national and global irrigation policies. We believe our distinctive policy formulation, namely a 'global irrigation compact' (GIC) achieves that aim.

Referring to the OED definition of 'compact'[16], 'mutuality' is the critical component[17] as this requires stakeholders to recognise; i) that responsibility for raising LSIS performance sits with water users, irrigators and gatekeepers as much as with officers of irrigation departments, the private sector, government agencies and development partners; ii) that good water management at the field level (below the outlet) and within the main canal system is mutually beneficial and reinforcing; iii) that irrigation systems are mutually interconnected with their host river basins and other water-using neighbours such as wetlands and urban areas. Therefore, the compact aims to support innovative partnerships to deliver effectual mutuality which we believe will be key to future success in revitalising LSIS. Our proposed wording for the global irrigation compact is:

> *Large-scale irrigation systems (LSIS) underpin significant local to global benefits including ecosystem services, economic growth, food and water security, and livelihoods for irrigators and associated communities. Therefore, farmers and community leaders, government agencies, NGOs, private-sector entities and development partners commit to mutually create new leadership, partnership, ownership and learning arrangements that enable irrigation schemes and their farmers to establish self-sustaining, cost-effective, business-like, progressive, technologically literate and adaptive management of LSIS uniquely designed for the improvement of each scheme. These actions aim to deliver greater land, water, labour and financial productivity and equity accompanied by enhanced and transparent social, sectoral, energy and ecosystems accountability. In turn, irrigators, water managers and engineers aspire to manage land, water and energy better with each passing year. Resource savings are tracked, transferred to, and where relevant, compensated for by specified parties and sectors. Progress unlocks further resources and incentives.*

The first sentence of the compact was discussed in the previous section on long-term aims. The following sections analyse and explain the remainder of the compact.

An enabling environment

The proposed compact identifies the need for an environment that is conducive to a new round of high impact investments leading to sustainable improvements in LSIS performance. The second sentence of the compact begins by defining (non-exhaustively) the 'who is to be involved' in creating this environment, also recognising that a broad spectrum of stakeholders have their contributions to make: *Therefore, farmers and community leaders, government agencies, NGOs, private-sector entities and development partners commit...".*

In view of increasingly constrained public (government and development) financial allocations to the irrigation sector, it is expected that the private sector, NGOs and charities, plus irrigating communities themselves will have to be mobilised to financially support irrigation systems, especially via the value chain. Getting the institutional and ownership structures right will be critical to incentivising the private and charitable sectors to become more engaged with LSIS and that farmers, as a representation of

[16] The Oxford English Dictionary defines a 'compact' as "A covenant or contract made between two or more persons or parties; a mutual agreement or understanding; 'a mutual and settled appointment between two or more, to do or to forbear something'" (OED, 2014).

[17] In keeping with thinking by British industrialists on how the UK Government might revitalize manufacturing that is simultaneously socially responsible (BBC, 2014).

'private sector' involvement, will be vital agents of change in LSIS. In addition the private sector, perhaps commissioned by irrigators, could also take a more central role in managing systems.

The second sentence continues; "*to mutually create new leadership, partnership, ownership and learning arrangements that enable irrigation schemes and their farmers…*". Here the compact contains the desire to create an environment that will transform the many factors that shape irrigation performance and productivity. This will involve, inter alia:

- *Recognition and reward of leaders*. Leadership will be vital to success and must be fostered among all actors at all levels particularly within the apex irrigation office (AIO). The new approach recognises that irrigators are clients who commission services from the AIO and its contracted partners. Moreover, success will also depend on how local leadership organisations such as NGOs and water user associations work with their community members.
- *Developing partnerships*. Enhanced levels of mutuality will define the GIC. Farmers must see themselves as answering a number of mutually reinforcing obligations and bonds; to each other; to the AIO; to regulatory and advisory personnel; and to other water-using neighbours within their river basin. These new partnerships should help counter the current dominating relationship between an irrigation scheme and its public/government irrigation agency.
- *Clarity and agreement about the ownership of LSIS infrastructure*. Determining the ownership and tenure of each irrigation system will be foundational to improved performance. Although irrigation management transfer (IMT) has gone some way in the partial handover of systems to farmers, more can be done in terms of rethinking property rights and creating 'shareholder' values and entities where the full range of infrastructure, hardware and software is owned by farmers and, possibly, by other actors such as private operating companies. Just as small and medium enterprises (SMEs) can be owned by employees and/or other shareholders, irrigation systems should consider more business-like agreements regarding the ownership of systems and of the ongoing services and physical upgrades expected by farmers.
- *Adaptive learning and management*. Knowledge and learning will be a critical part of the new approach to LSIS. System management should not only deal with day-to-day operations but also be engaged in development trajectories that will require significant amendments such as reform of land- and water-tenure arrangements, cap-and-trade reductions in water allocations, and changes to water distribution when irrigated land is either lost to other uses or when new lands are brought into command. To address these changes will require a greater degree of adaptive learning together with an ethos of stewardship of water, land and biodiversity within LSIS command areas. In addition, recognition of the goods and services provided by irrigation beyond the physical boundaries of LSIS should be part of this approach.

However, a risk or paradox operates here; the compact must not result in the creation of a new self-serving bureaucracy. This danger must not be underestimated. The risk is that a new wave of investments in irrigation will be channelled through unreformed organisations to sustain the status quo. The puzzle is how to reform or replace existing institutions to create the necessary business-like approach to support the executive functions of the AIO that will facilitate higher levels of performance of the LSIS. (As indicated below, one answer to this question is to seek out volunteer systems willing to trial the changes implied by the global irrigation compact).

Pathways of system improvement

Returning to the central concept in the description of an enabling environment for irrigation services, the compact continues; "*to establish self-sustaining, cost-effective, business-like, progressive, technologically literate and adaptive management of LSIS uniquely designed for the improvement of each scheme*".

This phrase spells out the key qualifiers for the pathway of system improvement; the sum aim of which is 'sustainability'. This means moving away from a 'build-neglect-rebuild' (BNR) cycle to a 'build-serve-earn-maintain-grow' (BSEMG) upward-curving trend (see also Burt, 2013). Over the past 60 years, governments and their development partners have invested heavily in the creation of LSIS; and too frequently have had to invest further within a relatively few years to rebuild infrastructure. With increasingly constrained development budgets the BNR cycle cannot continue. As a goal, LSIS should aim towards becoming self-sustaining – although we acknowledge that additional government subsidies (e.g. via no-cost infrastructure rehabilitation, crop price support and subsidised land and water prices) drawn from tax revenue are likely to be needed. In most systems, we can be confident that farmers will want to see reforms in the irrigation operating agencies such that they become more "cost-effective and business-like" in their dealings with farmers. Even for protective irrigation systems where farmers may prefer the current low-equilibrium systems with few irrigations, and where the State continues to subsidise O&M, there is an increasing pressure for improved knowledge, accountability and performance within closing river basins. In summary, the trend is towards the need for a new cadre of adaptive socio-technologically literate managers. This will almost certainly mean reform of the incumbent irrigation agency and given this will not be easy, a large measure of far-sighted and strongly supported leadership will be required.

The global irrigation compact will have cost implications because it seeks to discard the current efficient donor model predicated on a 'patronage-with-participation' blueprint of spending via irrigation agencies. Instead the compact embodies the 'contingency hypothesis' (Shah et al., 2012) applied to irrigation systems where the particular mix of leadership, ownership, bylaws, membership, penalties and rewards is contingent upon on an irrigation system's internal and external circumstances. Similarly, for its effect on system behaviour, the physical design (canals, gates, storage, etc.) of each system is also treated uniquely.

The term '*cost-effective*' means that costs must be kept to an agreed level per ha.[18] This economic target for rehabilitation or modernisation also underwrites how the compact will be delivered using a mix of farmer, artisanal and engineer skills, with design improvements selected for their cost-effectiveness and acceptance by irrigators drawn from throughout the system. Also investments and payments should address farmers' wishes to keep recurrent costs effective so that the AIO is reasonably staffed and responsive to farmers' concerns.

The term '*business-like*' in the compact is significant. It signals that irrigation systems need to be financially accountable to their owners and farmers and thus be oriented as quasi-business or full business operations. Nonetheless, the term 'business-like' rather than 'business' also recognises that there is no preferred ideology at work; this compact does not demand that large-scale systems become private companies or that water is fully priced or that scheduling services become remunerated. In addition, 'business-like' captures the recommendation that management procedures found in businesses (e.g. SMEs) such as audits (Shah et al., 2012), asset management (Burton and Hall, 1999; Kustiani and Scott, 2012) and personnel training become accepted practice.

The word '*progressive'* in the compact implies 'developing by stages' using adaptive management strategies. This means gains and lessons are locked in and employed to move to the next improvement. By moving progressively, the compact aims to move away from 'big-bang' rehabilitation followed by a decline. Gradual progress also allows the recursive and mutual elements of the compact to be nurtured – for example, on how farmers are asked to contribute via financial levies, attend meetings and discuss

[18] A budget of US$3-5000/ha is half the average donor costs of about US$10,000/ha recorded in sub-Saharan Africa (data collected by DANIDA in Tanzania from 1999 to 2002). Also see Inocencio et al., 2007. In the 1990s, IWMI termed this cost-effective approach as 'pragmatic' (Merrey, 1997).

their ideas for using water more sparingly. 'Progressive' is also about multi-variable performance and basin accountability captured in the final sentence of the compact (see below).

The qualifier '*technologically literate*' determines how the system managers and water users develop and improve water distribution technologies. This aspect perhaps represents one of the greatest risks to endeavours to improve LSIS performance; namely, the spending of new financial resources on 'normal' system hardware (such as canal lining and control gates) rather than to first understand how the system behaves and what is required to provide irrigators with better water services that suit the system (Renault et al., 2007). Nevertheless, recent advances in telemetry, mobile telephony and mobile and cloud-based computing offer significant new opportunities to revisit the so-far disappointing track record of computers in scheduling and controlling of canal water distribution.

Outcomes and measures

The compact introduces the performance objectives of the proposed interventions as: "*These actions aim to deliver greater land, water, labour and financial productivity and equity accompanied by enhanced and transparent social, sectoral, energy and ecosystems accountability*". We explored some of these above as global outcomes. However, the compact recognises there are other important accountabilities, especially with respect to energy use and water allocation to ecosystems, urban areas and other sectors. A few salient points regarding these are now made.

An era of service-oriented management of large-scale irrigation systems treated as business-like assets sitting within a closing river basin could see financial recording and auditing becoming central to their management. Such transformations are goals long sought by institutions such as the Asian Development Bank (ADB) and the World Bank. This would go a long way to reinforcing the sense that LSIS managers were purposively targeting water and canal services for farmers rather than creating rent-seeking opportunities for themselves. One could envisage a suite of financial and other accounts generated on a regular basis. Being able to benchmark and compare irrigation systems within a country and across countries (Malano et al., 2004) would also give irrigators and regulators the evidence to evaluate and, if necessary, disqualify service providers.

The technical monitoring of efficiency and productivity within each LSIS will need to be locally defined and carefully tailored to the system's and users' needs. While knowledge of the irrigation system is required to better manage it, the risk is that monitoring orthodoxies will be imposed on system users. Thus we distinguish between responding to farmers' and/or operator's concerns 'who wish to know what is going on and how to do better' against a prior assumption that measurement is necessary. Although charging for water services (or water) in proportion to the amount of water withdrawn may be an eventual outcome of performance improvements, the immediate goal is to improve trust and communication regarding mutual obligations. Also we make a distinction between monitoring for day-to-day operational needs and the more detailed measurements required for research to accelerate change.

In other words, we distinguish between the following kinds of data: (i) data for the sake of the farmers who may want to record what they were entitled to; (ii) data for system operators who want to know what is happening and how to adjust the system to provide the required services; (iii) data for bureaucrats and statisticians who want to report on high-level and national performance; and (iv) data for researchers who wish to relate system dynamics to management decisions or advise stakeholders on different schools of thought regarding measurement and monitoring. The corollary of dividing monitoring in this way is to understand the risks and opportunities associated with data collection; for example that informal farmer monitoring of performance (e.g. the time it takes to complete a field) can sit comfortably alongside formal hydrological monitoring.

In addition, monitoring of social trends may also help deliver the global irrigation compact. For example, accelerating rural to urban migration and increasing off-farm opportunities are driving rapid change in many irrigated areas of Asia (Deshingkar, 2006; Mukherji et al., 2009; Fishman et al., 2013; Bell and Charles-Edwards, 2013). The impacts of these trends on agricultural systems and communities could be analysed and where appropriate responded to.

The proposed compact explicitly promotes irrigation systems as responsible partners alongside other sectors within basins and aquifers. Meeting these responsibilities means system owners will have to account for trends in water abstraction and consumption to enable allocations for societal, economic and ecological flows, or to quantify interactions between water, land and energy use in response to growing demands for these resources by environmental, urban, industrial and energy sectors. In particular, system audits should include assessment of whether ecosystem services are enhanced or diminished by irrigation systems (Bommarco et al., 2013). Performance measurement can also assess carbon sequestration within the context of these systems as well as energy efficiencies and externalities.

However, we note the first words of this part of the compact; "*These actions aim to deliver…*". The use of the word 'deliver' invokes the question of who will monitor irrigation systems and their multiple characteristics and impacts. While the superficial answer might be that an array of stakeholders contribute to this, the undoubted challenges of monitoring, measurement and auditing reinforce the need for a targets-driven professionalised service that sits at the heart of an irrigation system that, in turn, employs a mix of instruments to deliver canal system management, better water scheduling and in-field distribution. This service (either working within or alongside the AIO) will need special attention if this new approach to irrigation governance is to succeed.

In summary, the global irrigation compact foresees the evolution, over time, of a hybrid of informal and formal auditing to assess food, water, land, energy and environmental goods and services, as well as measures of social, economic and financial performance.

Closing the circle: Rewards for better water management

The final three sentences of the compact deal with the incentives to improve performance, summarised as: "*In turn irrigators, water managers and engineers, aspire to manage land, water and energy better with each passing year. Resource savings are tracked, transferred to, and where relevant, compensated for by, specified parties and sectors. Progress unlocks further resources and incentives*".

With this ending, the compact closes the circle by requiring that land and water are demonstrably better managed as time moves on. An important element of self-sustaining mutuality arises when farmers and operators are given the responsibility of, and are rewarded for, managing water in ways that make tangible water savings at different scales that unlock and free-up resources.

The words '*each passing year*' and '*progress*' invoke another policy paradox. The compact simultaneously envisages bold changes to large irrigation systems and at the same time recommends a steady cycle of learning. Despite profound shifts in governance, there is a strong theme of incremental change that learns from progress within each cycle.

These final sentences of the compact return to the hotly debated topic of measuring performance within the context of water saving and potential reallocation of water (either within the system or to other users in the basin). Although measurement and monitoring will be difficult and should not be specified for all systems, some collective understanding of a cycle of improvement must be agreed between irrigators and service providers. This means that the recording and tracking of water may be required to determine whether indeed savings are there to be made (Batchelor et al., 2014; Lankford, 2013; Perry, 2007). Theoretically, losses-as-water-savings represent opportunities for irrigation systems to become more accountable to themselves and their immediate and distant neighbours. In particular, tracking gains to environmental flows would build evidence that large-scale systems can play a part in sustaining ecosystem services.

The final sentence of the compact points to the complex topic regarding the rewards and incentives offered to farmers and the apex irrigation office for achieving results. This might take place in two ways; first, via support from donors and governments in the form of results-based financing.[19] Second, specific deliverables are rewarded, e.g. capping water consumption and releasing water to other sectors (Cortignani and Severini, 2011). It is possible that directly compensating irrigation systems for reducing water consumption and minimising waste-induced delays of water moving through drainage networks (which can alter the shape of river hydrographs) might help finance budget deficits to cover O&M costs. There is little track record here that might guide practice and thus this topic represents an area for innovation and research.

KEY ASSUMPTIONS

The final element of a theory of change covers the assumptions that if met can assist the process of change. Some assumptions are closely connected to the policy process and arguably are part of it, while others are more or less immediately actionable or tangible. For example, leadership by global irrigation organisations can be modified but global food prices that dictate the profitability of irrigated agriculture are not so easily influenced.

We describe these key assumptions briefly and acknowledge that, in implementing the compact and dealing with these assumptions, stakeholders will be confronted with many foreseen and unforeseen challenges. We recognise that while the ToC sets the broad framework, individual schemes will interpret the changes needed.

Organisational leadership roles

We now consider how different organisations could provide leadership to catalyse the compact.

Initiating and executing the compact

Not included in the text of the compact are important details covering how it might be initiated and executed. The irrigation and development community will need to discuss many more principles, modalities and cross-checks than are contained in this paper. Major global organisations will need to play key roles in convening a global and national consultative process, perhaps along the lines of the World Commission on Dams (WCD, 2000) to guide the implementation of the new compact.

Reviving a global culture towards revitalising large-scale irrigation

Cultivating a global appetite for further investment in large-scale irrigation will help establish a consensus towards the objectives and processes associated with the ToC. Parts of this consensus are already in place. For example IWMI and the CGIAR Program on Water, Land and Ecosystems (WLE) have recognised the importance of revitalising both large- and small-scale irrigation. The World Bank is also reengaging with irrigation (World Bank, 2006) as are other development partners such as the Asian Development Bank (ADB, 2012). While these are important initiatives, there is scope for stronger coordination between organisations, and to bring in other players including professional bodies such as the International Commission for Irrigation and Drainage (ICID) and bilateral development partners.

Irrigation agency reform

The central role of government and parastatal agencies in shaping the culture of irrigation services is significant (Suhardiman and Giordano, 2014; Faures et al., 2007). Furthermore, international agencies

[19] Reflecting developments in the education and health sectors (e.g. Meessen et al., 2011).

such as IWMI, divisions of the UN (e.g. FAO), and the multilateral development banks can assist in setting the pace and degree of reform. While it is not possible to itemise how change might be scheduled, a mix of strategies (e.g. building on those given by Mukherji et al., 2009) is envisaged. Issues include: (a) Redistributing the functions, services and personnel from central irrigation agencies to local irrigation system offices; (b) Creating CEO-type leadership positions where pay and terms are aligned with the performance of the irrigation system and the satisfaction of irrigators rather than that of the public agency; (c) Getting irrigation officers to respond to external motivations and more business-like incentives (e.g. shares in a shareholder agreement, visiting other irrigation systems); (d) Reforming irrigation agencies to provide regulatory oversight on new farmer-led organisations; (e) Delivering additional training for irrigation officers and engineers so that legal, financial, regulatory and planning functions are better understood and utilised; (f) Realigning the status of gatekeepers so that they become rewarded by the system as a whole rather than in response to pressure from individual irrigators; (g) Increasing support to NGOs working with irrigators; (h) Reinvigorating postgraduate training in irrigation and irrigated agriculture; (i) Establishing a legal framework for large-scale irrigation within each country that documents both formal and customary law; (j) Updating the embedded principles of irrigation design, planning and operation that currently sustain possibly outmoded engineering practices (see Lankford, 2004) to embrace the wider objectives of ecosystems and other societal objectives.

Empowering farmers; legal frameworks and tenure

In parallel with the restructuring of national/public irrigation agencies, it is assumed that governments will empower farmers to more forcefully drive reform of these agencies plus apex irrigation offices and their own water user associations. Change might entail relatively easy initiatives such as; participatory assessments to determine how farmers consider issues such as irrigation service standards, payments and penalties; the selection and training of leaders within water user groups; and the provision of technical training beyond purely crop, land and water topics. But empowering farmers will also depend on; (a) trust linked to a transparent and secure land, water, service and infrastructure tenure (Hodgson, 2016); and (b) how participation is supported by government agencies in turn undergoing reform. Most likely these two factors will require the resolution of substantive legal issues that determine the constitutional power of irrigators within a revitalised irrigation sector.

Reform of 'basin to LSIS to urban water' linkages

One of the most substantial pressures on irrigation managers to improve performance will be the increasing value of water influenced by a) physical scarcity driven by climate and weather, and b) artificial scarcity driven by the demand for water from other sectors (Scott et al., 2007; Molle and Berkoff, 2009). Both forms of water scarcities create room for policy formulation; how should irrigation systems and their host basins confront scarcity to drive productivity and efficiency gains (Loeve et al., 2007). We believe reform of river basin institutions and adoption of appropriate strategies to manage water allocation between sectors could help push constituent irrigation systems to higher performance. For example, a 'cap-trade' approach to water in these large systems should result in significant shifts in behaviour. Furthermore, creating stronger partnerships between urban conurbations and large irrigation systems might also prove fruitful.

Improving irrigation infrastructure

Although each large-scale irrigation system is unique in terms of its natural endowment, institutions and technologies, stakeholders involved in revitalising the sector will need to draw upon a common framework to introduce and tailor technical system improvements. One such template for this framework to draw upon is the MASSCOTE approach (Renault et al., 2007).

Mobilising global leadership in the change process

The above examples cover 'topics' that organisations can address (e.g. the role of irrigation water rights in accommodating scarcity and change). However, there are two additional interrelated questions. First, who will lead the multilevel leadership process, first, at the global level and then, subsequently, at the country and system level? Second, how might global and national organisations rapidly, optimally and strategically bring about change when constrained by limited funds and personnel? Rephrasing this second question; how can the organisations involved in irrigation reform be more effective? One answer is generic and not necessarily convincing; 'Organisations will do what they can'.

But to answer both questions provocatively, three examples using IWMI are given.[20] One example is for IWMI to partner with ('adopt') and directly influence the management of, say, five to ten volunteer large irrigation systems in different parts of the world. Through the act of volunteering, irrigators and support networks (e.g. irrigation agencies also willing to change) plausibly demonstrate high levels of preparedness to adopt new forms of irrigation governance. This approach would also mobilise global expertise to test new practices to generate lessons to be applied elsewhere. A second example would involve IWMI (and others) creating an 'irrigator change unit' that could link up a global network of water user associations (e.g. 100 in the first instance) to animate farmers to demand new partnerships and improved water services. Third, IWMI could lead a consortium of interested parties (e.g. irrigation agencies, farmers, FAO, ICID, universities, NGOs, etc) to drive change in irrigated agriculture as defined by the compact.

A research programme to support theory of change

Revitalising irrigation will require research to support new organisations and management systems. However, a review of current financing for irrigation research suggests a considerable gap between the importance of irrigated agriculture to food and water security and the level of research investments. This conclusion applies to organisations such as the UK Research Councils, DFID, the European Commission, the World Bank, the Gates Foundation and many more. Where studies of agricultural water are being funded their scope tends to focus on small-scale producers. Successful revitalisation of irrigation will require renewed efforts to provide recommendations for irrigation service delivery in the context of climate change, evolving social and demographic transitions and broader performance objectives including the maintenance of ecosystem services. There is insufficient space to detail research topics but one example includes studies on how irrigators, irrigation agencies and the private sector might work together within an executive apex irrigation office to adopt a more business-like approach to the management of large schemes.

Capacity building; university and professional training

The irrigation compact infers there will be an increased need for capacity development and training to support transformational change in the sector. Unfortunately we find that, unlike 15-20 years ago, no single institution now offers dedicated postgraduate irrigation training. This decline has mirrored the shrinking market in the number and status of irrigation jobs (universities close down courses that are no longer economically viable). So, while there are universities and degrees that address irrigation engineering or wider water degrees that have a single module on irrigation, nothing tackles all the social, economic and technical dimensions of irrigation to the required depth and in a multidisciplinary

[20] To further illustrate this point; there is no irrigation equivalent of WaterAid, the British charity that works internationally to deliver solutions in water and sanitation (although there are some national irrigation organisations). Of all the global institutions working on gravity irrigation, the International Water Management Institute (IWMI) has the best irrigation research capacity but currently is not configured to provide co-management services. There is a precedent however; in 1989, IWMI (then IIMI) partnered with the Irrigation Department of Sri Lanka to support the Kirindi Oya and Uda Walawe Projects.

and interdisciplinary manner. Perhaps the closest to what is required is found at the universities of Wageningen and UNESCO-IHE, but their teaching of irrigation has diminished especially on the design and management of large-scale systems.

Furthermore, a sample of professional irrigation training courses on the web finds that nearly all training is technology-oriented (towards drip and sprinkler) and is provided by companies that own or sell the technology. None of these deal with large-scale irrigation systems. This observation reinforces the concern that, currently, the global provision of either short or longer courses on irrigation is not well placed to serve the sector.

The notion that 'civil engineers' rather than irrigation engineers can fill this gap in skills and turn their hands to irrigation when required is to underplay the multiple influences on irrigation. On the contrary, our analysis is that many disciplines support large-scale irrigation. In particular, engineers need to be familiar with the history of and debate over water control problems inferred by the design-management interactions literature (e.g. Bos, 1987; Bolding et al., 1995; Horst, 1998) which is beyond the curriculum content of canal hydraulics.

Other assumptions

We finish this element of the ToC with a set of assumptions regarding 'political economy' factors that will influence the success of a change programme. Inter alia, we assume (a) that prices and income for produce grown on irrigation systems are sufficiently remunerative to assist in the funding of the change process; (b) that the scarcity and value of water and, where relevant, the price of water in river basins, will underpin water efficiency and productivity gains in irrigation systems; (c) that large-scale irrigation systems are seen as strategic assets by host nations triggering high-level political support for transformational change; (d) that the private sector will view large irrigation systems as requiring collaborative stewardship-type engagement[21]; and (e) that irrigation agency reform is viewed as an economic necessity by donors, governments and other stakeholder organisations.

CONCLUSIONS

Recognising the 'systems' nature of large-scale irrigation systems and their influences on ecosystem services, food, water, land, energy and livelihoods, a global irrigation compact to revitalise their governance, management and performance has been proposed. The compact emphasises new leadership, partnership and ownership arrangements for LSIS. The idea of a compact (or covenant) aims to stimulate a penetrating and transformative discussion on the future of large-scale irrigation systems. This discussion and any ensuing policy prescriptions must accommodate and navigate the puzzles and paradoxes that lie in wait. For example, while the principle of the GIC may appear to be private-sector oriented and to frame irrigation as a business,[22] the proposed compact embraces the empowerment and involvement of irrigators to a far greater extent than current Participatory Irrigation Management (PIM) efforts.

The compact thus assumes that public or public-private LSIS agencies must become more directly responsive to irrigators. This is a prerequisite identified by Mukherji et al. (2012) and a key factor thought to explain increases in irrigation in Madhya Pradesh, India (Shah and Kela, 2015). Similarly, while striving for greater technical and social literacy amongst engineers and farmers, new programmes must be careful not to recreate conditions where the irrigation technicians and engineers capture the deliberative process (Blake, 2013). Furthermore, although requiring donors and government

[21] In keeping with ongoing progress in private sector and corporate water stewardship (Hepworth and Orr, 2013; WWF, 2013).

[22] Also reflecting developments in water and sanitation (Snel, 2014; Mulumba et al., 2014).

investments to kick-start the process, it is the irrigators who must propel, sustain and respond to the proposed changes in LSIS management. Irrigators will be particularly critical in the face of inertia to change from entrenched irrigation agencies. Irrigators will have to see themselves (and be seen by society) as 'responsible water citizens', a point emphasised by the mutuality element of the compact.

The global-to-local span of the compact is another puzzle to be solved. While the compact is sector-wide and global in scope, the unique characteristics of individual irrigation systems must be addressed. A new emphasis on LSIS must incorporate a general framework of improvement while allowing each irrigation system to find and interpret its own identity.

Invoking the 'perfect storm' metaphor of Sir John Beddington (BBC, 2009), large-scale irrigation can be considered more imaginatively. While this might be seen as overt bias by the irrigation-minded authors of this paper, large-scale irrigation can be thought of as being 'in the eye of the perfect storm'. The eye of the storm signals both the locus that irrigation possesses in helping to resolve the global food concerns as well as, ironically, the dead-calm that LSIS finds itself in. Thus, we explicitly position large-scale irrigation in the centre of food production for those nations where irrigation is commonplace and in the centre of global food security where important agricultural commodities such as wheat, rice, sugarcane and maize are situated. In this sense, 115/130 Mha of irrigated land represent immense 'calorific batteries' for the world's growing population. Furthermore, Beddington's storm is about land and water shortages and energy constraints in a climate-changing and carbon-sensitive world. These latter dynamics mean that large-scale irrigation is not neutral in this calculus. Via sizeable water depletion, LSIS add to climate strains on the hydrology of rivers and aquifers with consequences for the 'allocability' as well as availability of water to share between competing sectors including ecosystem services. In addition, LSIS are at the sharp end of ill-considered policies to improve efficiency via sprinkler and drip with negative consequences for carbon emissions (Rodriguez-Diaz et al., 2011). In summary, getting gravity systems to properly account for their water, land and energy and to potentially cap and reduce these are objectives central to the storm and storm-eye analogy.

To be clear about future policy directions, there are three main pathways that now lie before governments, donors and investors. These are; (i) to largely ignore large-scale irrigation which is arguably a version of 'business-as-usual'; (ii) to increase expenditure on reforming LSIS but via 'business-as-usual' modalities such as 'patronage-with-participation' (which may minimally alter performance); and (iii) to increase investment and/or change investment types in LSIS along with innovative reform. The theory of change, expressed as a global irrigation compact, in this paper recognises the need for increased emphasis on sharing the resources, knowledges, problems, risks and benefits by and between many more types of stakeholders, especially irrigators. Echoing Burt (2013), this is a high-stakes, high-reward policy that not only builds on but also questions decades of historical effort and sunk-capital. Although we do not wish to underplay the challenge of addressing large-scale irrigation systems and the agencies that shield them, we equally point to the rewards that could flow from new interventions in terms of food, energy conservation, urban water supply, biodiversity and ecosystem services. The real risk (with predictable disappointing outcomes) would be to adopt either of the first two of the pathways and to spend at the same rate as in the last 20 years using the same procedures and programmes. A game-changing shift is required (Bird, 2014). Soberly, this might require a 10-15 year horizon of change. Yet this commitment would put irrigation on a more secure footing to face and help solve projected acute global challenges in the period 2020 to 2050 (FAO, 2009).

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REFERENCES

ADB (Asian Development Bank). 2012. *Water Operational Plan 2011-2020, No RPT124287*, ADB Reports. Manila: Asian Development Bank.

Aldaya, M.M.; Muñoz, G. and Hoekstra, A.Y. 2010. *Water footprint of cotton, wheat and rice production in Central Asia.* Research Report Series No. 41. Delft, The Netherlands: UNESCO-IHE Institute for Water Education.

Batchelor, C.; Reddy, V.R.; Linstead, C.; Dhar, M.; Roy, S. and May, R. 2014. Do water-saving technologies improve environmental flows? *Journal of Hydrology* 518(A): 140-149.

BBC (British Broadcasting Corporation). 2009. *Averting a perfect storm of shortages.* http://news.bbc.co.uk/1/hi/8213884.stm (Accessed 2nd August 2014)

BBC. 2014. *Radio 4 and viewpoint: Should there be a business covenant?* www.bbc.co.uk/news/business-28351459 (Accessed 5th August 2014)

Bell, M. and Charles-Edwards, E. 2013. *Cross-national comparisons of internal migration: An update of global patterns and trends.* Technical Paper No. 2013/1. New York: Population Division, United Nations Department of Economic and Social Affairs.

Bernier, Q. and Meinzen-Dick, R.S. 2015. *Public private partnerships for irrigation: Expanding access or increasing inequality.* Washington, DC: International Food Policy Research Institute (IFPRI).

Bird, J.D. 2014. *Game changers for irrigated agriculture – Do the right incentives exist?* In International Commission on Irrigation and Drainage (ICID). First World Irrigation Forum, Mardin, Turkey, 28 September – 3 October 2013. Summary report, pp. 17-18.

Birendra, K.C.; Schultz, B. and Prasad, K. 2010. Water management to meet present and future food demand. *Irrigation and Drainage* 60(3): 348-359.

Blackburn, R.A. and Schaper, M.T. 2012. *Government, SMEs and entrepreneurship development: Policy, practice and challenges.* Surrey, UK: Gower Publishing Ltd (Ashgate).

Blake, D.J.H. 2013. Irrigationalism – The politics and ideology of irrigation development in the Nam Songkhram Basin, Northeast Thailand. PhD thesis, University of East Anglia.

Bolding, A.; Mollinga, P.P. and van Straaten, K. 1995. Modules for modernization: Colonial irrigation in India and the technological dimension of agrarian change. *The Journal of Development Studies* 31(6): 805-844.

Bommarco, R.; Kleijn, D. and Potts, S.G. 2013. Ecological intensification: Harnessing ecosystem services for food security. *Trends in Ecology & Evolution* 28(4): 230-238.

Bos, M.G. 1987. Water management aspects of irrigation system design. In Irrigation design for management Asian regional symposium, Volume II, Discussions and Special Lectures, Kandy, Sri Lanka, 16-18 February 1987. Wallingford, UK: Hydraulics Research, pp. 67-76.

Bottrall, A. 1985. *Managing large irrigation schemes: A problem of political economy, Agricultural Administration Unit.* Occasional Paper No. 5. London, UK: Overseas Development Institute.

Brooks, N.; Aure, E. and Whiteside, M. 2014. Final Report. Assessing the impact of ICF programmes on household and community resilience to climate variability and climate change, Hemel Hempstead: Evidence on Demand.

Bruns, B. 2013. Bureaucratic bricolage and adaptive co-management in Indonesian irrigation. In Wagner, J. (Ed), *The social life of water in a time of crisis,* pp. 255-277. New York: Berghahn Books.

Burt, C.M. 2013. The irrigation sector shift from construction to modernization: What is required for success? *Irrigation and Drainage* 62(3): 247-254.

Burton, M.A. and Hall, R.P. 1999. Asset management for irrigation systems – Addressing the issue of serviceability. *Irrigation and Drainage Systems* 13(2): 145-163.

CAWMA (Comprehensive Assessment of Water Management in Agriculture). 2007. *Water for food, water for life: Comprehensive Assessment of Water Management in Agriculture* (CAWMA). London: Earthscan; Colombo: International Water Management Institute.

Chambers, R. 1988. *Managing canal irrigation. Practical analysis from South Asia*. Wye Studies in Agricultural and Rural Development. Cambridge, UK: Cambridge University Press.

Cortignani, R. and Severini, S. 2011. An extended PMP model to analyse farmers' adoption of deficit irrigation under environmental payments. *Spanish Journal of Agricultural Research* 9(4): 1035-1046.

Crossman, N.D.; Connor, J.D.; Bryan, B.A.; Summers, D.M. and Ginnivan, J. 2010. Reconfiguring an irrigation landscape to improve provision of ecosystem services. *Ecological Economics* 69(5): 1031-1042.

de Fraiture, C. and Wichelns, D. 2010. Satisfying future water demands for agriculture. *Agricultural Water Management* 97(4): 502-511.

de Fraiture, C.; Molden, D. and Wichelns, D. 2010. Investing in water for food, ecosystems, and livelihoods: An overview of the comprehensive assessment of water management in agriculture. *Agricultural Water Management* 97(4): 495-501.

Deshingkar, P. 2006. *Internal migration, poverty and development in Asia.* ODI Briefing Paper and Paper for Session 3: Realising the Potential for Poverty Reduction, Parallel Group 3A: Topic Paper 2. www.asia2015conference.org

Easter, K.W. 1993. Economic failure plagues developing countries' public irrigation: An assurance problem. *Water Resources Research* 29(7): 1913-1922.

Easter, K.W. 2000. Asia's irrigation management in transition: A paradigm shift faces high transaction costs. *Review of Agricultural Economics* 22(2): 370-388.

EC (European Commission). 2005. *The new SME definition. User guide and model declaration.* European Commission (EC): Enterprise and Industry Publications.

FAO (Food and Agriculture Organization of the United Nations). 2009. *Global agriculture towards 2050. How to feed the world in 2050*. High Level Expert Forum, Rome 12-13 October 2009. 9. Issues Paper HLEF2050. Rome: Food and Agriculture Organization of the United Nations.

Faures, J.-M. and Mukherji, A. 2009. *Trends and drivers of Asian irrigation*. Report submitted to Asian Development Bank, October 2009.

Faures, J.-M.; Svendsen, M.; Turral, H.; Berkoff, J.; Bhattarai, M.; Caliz, A.M.; Dargouth S.; Doukkali, M.R.; El-Kady, M.; Facon, T.; Gopalakrishnan, M.; Groenfeldt, D.; Hoanh, C.T.; Hussain, I.; Jamin, J.-Y.; Konradsen, F.; Leon, A.; Meinzen-Dick, R.; Miller, K.; Mirza, M.; Ringler, C.; Schipper, L.; Senzanje, A.; Tadesse, G.; Tharme, R.; van Hofwegen, P.; Wahaj, R.; Varela-Ortega, C.; Yoder, R. and Zhanyi, G. 2007. Reinventing irrigation. In Molden, D. (Ed). *Water for food, water for life: A Comprehensive Assessment of Water Management in Agriculture,* pp. 353-394*.* London, UK: Earthscan; Colombo, Sri Lanka: IWMI.

Fishman, R.; Jain, M. and Kishore, A. 2013. Patterns of migration, water scarcity and caste in rural Northern Gujarat. Working Paper. London: International Growth Centre, IGC India Country Program.

Foster, S. and Shah, T. 2012. *Groundwater resources and irrigated agriculture: Making a beneficial relation more sustainable.* Stockholm, Sweden: Global Water Partnership (GWP) Secretariat (GWP Perspectives Paper 4).

G8. 2009. "L'Aquila" *joint statement on global food security.* L'Aquila Food Security Initiative (AFSI), L'Aquila July 2009. www.g8italia2009.it/static/G8_Allegato/LAquila_Joint_Statement_on_Global_Food_Security%5B1%5D,0.pdf (accessed 21 January 2015)

Geerts, S.; Raes, D. and Garcia, M. 2010. Using AquaCrop to derive deficit irrigation schedules. *Agricultural Water Management* 98(1): 213-216.

Godfray, H.C.J.; Beddington, J.R.; Crute, I.R.; Haddad, L.; Lawrence, D.; Muir, J.F.; Pretty, J.; Robinson, S.; Thomas, S.M. and Toulmin, C. 2010. Food security: The challenge of feeding 9 billion people. *Science* 327(5967): 812-818.

Gorantiwar, S.D. and Smout, I.K. 2005. Performance assessment of irrigation water management of heterogeneous irrigation schemes: 1. A framework for evaluation. *Irrigation and Drainage Systems* 19(1): 1-36.

Gordon, L.J.; Finlayson, C.M. and Falkenmark, M. 2010. Managing water in agriculture for food production and other ecosystem services. *Agricultural Water Management* 97(4): 512-519.

Hanjra, M.A.; Ferede, T. and Gutta, D.G. 2009. Reducing poverty in sub-Saharan Africa through investments in water and other priorities. *Agricultural Water Management* 96(7): 1062-1070.

Hanjra, M.A. and Qureshi, M.E. 2010. Global water crisis and future food security in an era of climate change. *Food Policy* 35(5): 365-377.

Hellegers, P.; Zilberman, D.; Steduto, P. and McCornick, P. 2008. Interactions between water, energy, food and environment: Evolving perspectives and policy issues. *Water Policy* 10(S1): 1-10.

Hepworth, N. and Orr. S. 2013. Corporate Water Stewardship: Exploring Private Sector Engagement in Water Security. In Lankford, B.A.; Bakker, K.; Zeitoun, M. and D Conway (Eds), *Water security: Principles, perspectives and practices*, pp 220-238. London: Earthscan Publications.

Hodgson, S. 2016. *Exploring the concept of water tenure*. A Discussion Paper for FAO. Rome: Food and Agriculture Organisation.

Horst, L. 1998. *The dilemmas of water division, considerations and criteria for irrigation system design.* Colombo: International Water Management Institute.

Hussain, I. and Hanjra, M.A. 2004. Irrigation and poverty alleviation: Review of the empirical evidence. *Irrigation and Drainage* 53(1): 1-15.

Inocencio, A.; Kikuchi, M.; Tonosaki, M.; Maruyama, A.; Merrey, D.; Sally, H. and de Jong, I. 2007. *Costs and performance of irrigation projects: A comparison of Sub-Saharan Africa and other developing regions.* IWMI Research Report No. 109. Colombo, Sri Lanka: International Water Management Institute (IWMI).

Johnson, N.; Swallow, B. and Meinzen-Dick, R. 2014. Research on institutions for agricultural water management under the CGIAR Challenge Program on Water and Food. In Harrington, L.W. and Fisher, M.J. (Eds), *Water scarcity, livelihoods and food security: Research and innovation for development,* pp. 125-155. Earthscan Studies in Water Resource Management. Wallingford: Earthscan.

Khush, G. 2003. Productivity Improvements in rice. *Nutrition Reviews* 61(6 Pt2): S114-S116.

Kijne, J.W. 2003. *Unlocking the water potential of agriculture.* Rome: Food and Agriculture Organisation (FAO).

Klugman, B. 2011. Effective social justice advocacy: A theory-of-change framework for assessing progress. *Reproductive health matters* 19(38): 146-162.

Kuper, M.; Hammani, A.; Chohin, A.; Garin, P. and Saaf, M. 2012. When groundwater takes over: Linking 40 years of agricultural and groundwater dynamics in a large-scale irrigation scheme in Morocco. *Irrigation and Drainage* 61(1): 45-53.

Kustiani, I. and Scott, D. 2012. Developing an asset management plan for a sustainable future Indonesia irrigation systems. *WIT Transactions on Ecology and the Environment* 168: 323-337.

Lankford, B.A. 2012. Fictions, fractions, factorials, fractures and fractals; on the framing of irrigation efficiency. *Agricultural Water Management* 108: 27-38.

Lankford, B.A. 2013. *Resource efficiency complexity and the commons: The paracommons and paradoxes of natural resource losses, wastes and wastages*. Abingdon: Earthscan Publications.

Lankford, B.A. 2004. Resource-centred thinking in river basins: Should we revoke the crop water approach to irrigation planning? *Agricultural Water Management* 68(1): 33-46

Le Moigne, G.; Barghouti, S. and Garbus, L. (Eds). 1992. *Developing and improving irrigation and drainage systems.* World Bank Technical Paper No. 178. Washington, DC: World Bank.

Lees, S.H. 1986. Coping with bureaucracy: Survival strategies in irrigated agriculture. *American Anthropologist* 88(3): 610-622.

Licker, R.; Johnston, M.; Foley, J.A.; Barford, C.; Kucharik, C.J.; Monfreda, C.; et al., 2010. Mind the gap: How do climate and agricultural management explain the 'yield gap' of croplands around the world? *Global Ecology and Biogeography* 19(6): 769-782.

Loeve, R.; Dong, B.; Hong, L.; Chen, C.D.; Zhang, S. and Barker, R. 2007. Transferring water from irrigation to higher valued uses: A case study of the Zhanghe irrigation system in China. *Paddy and Water Environment* 5(4): 263-269.

Malano, H.; Burton, M. and Makin, I. 2004. Benchmarking performance in the irrigation and drainage sector: A tool for change. In Special Issue – Benchmarking in the Irrigation and Drainage Sector. *Irrigation and Drainage* 53(2): 119-134

Malik, R.P.S.; Prathapar, S.A. and Marwah, M. 2014. *Revitalizing canal irrigation: Towards improving cost recovery.* IWMI Working Paper No. 160. Colombo, Sri Lanka: International Water Management Institute (IWMI).

Maystadt, J.F.; Trinh Tanh, J.F. and Breisinger, C. 2012. *Does food security matter for transition in Arab countries?* IFPRI Discussion Paper No. 1196. Washington, DC: International Food Policy Research Institute.

Meessen, B.; Soucat, A. and Sekabaraga, C. 2011. Performance-based financing: Just a donor fad or a catalyst towards comprehensive health-care reform? *Bulletin of the World Health Organization* 89(2): 153-156.

Meinke, H.; Howden, S.M.; Struik, P.C.; Nelson, R.; Rodriguez, D. and Chapman, S.C. 2009. Adaptation science for agriculture and natural resource management – Urgency and theoretical basis. *Current Opinion in Environmental Sustainability* 1(1): 69-76.

Meinzen-Dick, R. 2007. Beyond panaceas in water institutions. *Proceedings of the National Academy of Sciences* 104(39): 15200-15205.

Merrey, D.J.; Meinzen-Dick, R.; Mollinga, P.P.; Karar, E.; Huppert, W.; Rees, J.; Vera, J.; Wegerich, K. and van der Zaag, P. 2007. Policy and institutional reform: The art of the possible. In Molden, D. (Ed), *Water for food, water for life: A Comprehensive Assessment of Water Management in Agriculture,* pp. 193-231. London, UK: Earthscan; Colombo, Sri Lanka: IWMI.

Merrey, D.J. 1997. *Expanding the frontiers of irrigation management research: Results of research and development at the International Irrigation Management Institute, 1985 to 1997.* www.iwmi.cgiar.org/Research_Impacts/Impact_Assessment/PDFs/01.pdf

Molden, D.; Oweis, T.; Steduto, P.; Bindraban, P.; Hanjra, M.A. and Kijne, J. 2010. Improving agricultural water productivity: Between optimism and caution. *Agricultural Water Management* 97(4): 528-535.

Molle, F. and Berkoff, J. 2009. Cities vs. agriculture: A review of intersectoral water re-allocation. *Natural Resources Forum* 33(1): 6-18.

Molle, F.; Mollinga, P.P. and Wester, P. 2009. Hydraulic bureaucracies and the hydraulic mission: Flows of water, flows of power. *Water Alternatives* 2(3): 328-349

Mollinga, P.P. 2003. *On the waterfront: Water distribution, technology and agrarian change in a South Indian canal irrigation system*. Hyderabad: Orient Blackswan.

Mukherji, A. and Shah, T. 2012. *A review of international experience in managing energy irrigation nexus.* Colombo, Sri Lanka: IWMI-Tata Water Policy Research Highlight No. 34.

Mukherji, A.; Facon, T.; de Fraiture, C.; Molden, D. and Chartres, C. 2012. Growing more food with less water: How can revitalizing Asia's irrigation help? *Water Policy* 14(3): 430-446.

Mukherji, A.; Facon, T.; Burke, J.; de Fraiture, C.; Faures, J.-M.; Fuleki, B.; Giordano, M.; Molden, D. and Shah, T. 2009. *Revitalizing Asia's irrigation: To sustainably meet tomorrow's food needs.* Colombo, Sri Lanka: International Water Management Institute (IWMI); Rome, Italy: FAO.

Mulumba, J.N.; Nothomb, C.; Potter, A. and Snel, M. 2014. Striking the balance: What is the role of the public sector in sanitation as a service and as a business? *Waterlines* 33(2): 195-210.

Ober, H. 2012. *CARE International UK Peacebuilding with Impact: Defining theories of change,* London: CARE International UK.

OED (Oxford English Dictionary). 2014. Oxford English Dictionary on-line edition. www.oed.com

Oerke, E.C. and Dehne, H.W. 2004. Safeguarding production – Losses in major crops and the role of crop protection. *Crop Protection* 23(4): 275-285.

Olivier, J.G.J.; Janssens-Maenhout, G.; Muntean, M. and Peters, J.A.H.W. 2014. *Trends in global CO2 emissions: 2014 Report.* PBL Netherlands Environmental Assessment Agency, The Hague; European Commission, Joint Research Centre (JRC), Institute for Environment and Sustainability (IES). http://edgar.jrc.ec.europa.eu/news_docs/pbl-2014-trends-in-global-co2-emissions-2014-report-93171.pdf

Ostrom, E. 1990. *Governing the commons: The evolution of institutions for collective action.* Cambridge: Cambridge University Press.

Ostrom, E. 1992. *Crafting institutions for self-governing irrigation systems*. San Francisco: ICS Press.

Perry, C. 2007. Efficient irrigation; inefficient communication; flawed recommendations. *Irrigation and Drainage* 56(4): 367-378.

Playán, E. and Mateos, L. 2006. Modernization and optimization of irrigation systems to increase water productivity. *Agricultural Water Management* 80(1-3): 100-116.

Plusquellec, H.; Burt, C. and Wolter, H.W. 1994. *Modern water control in irrigation. Concepts, issues, and applications.* World Bank Technical Paper No. 246. Irrigation and Drainage Series. Washington, DC, USA: World Bank.

Rao, P.S. and Sundar, A. 1986. *Managing main system water distribution.* IIMI Management Brief, June 1986, No. 1. Sri Lanka: The International Irrigation Management Institute.

Renault, D.; Facon, T. and Wahaj, R. 2007. *Modernizing irrigation management – The MASSCOTE approach.* Rome: Food and Agriculture Organisation of the United Nations.

Repetto, R.C. 1986. *Skimming the water: Rent-seeking and the performance of public irrigation systems.* Washington, DC: World Resources Institute.

Rockström, J.; Karlberg, L.; Wani, S.P.; Barron, J.; Hatibu, N.; Oweis, T.; Bruggeman, A.; Farahani, J. and Qiang, Z. 2010. Managing water in rainfed agriculture – The need for a paradigm shift. *Agricultural Water Management* 97(4): 543-550.

Rodriguez-Díaz, J.A.; Pérez-Urrestarazu, L.; Camacho-Poyato, E. and Montesinos, P. 2011. The paradox of irrigation scheme modernization: More efficient water use linked to higher energy demand. *Spanish Journal of Agricultural Research* 9(4): 1000-1008.

Rosegrant, M.W.; Ringler, C. and Zhu, T. 2009. Water for agriculture: Maintaining food security under growing scarcity. *Annual Review of Environment and Resources* 34(1): 205-222.

Rothausen, S.G.S.A. and Conway, D. 2011. Greenhouse-gas emissions from energy use in the water sector. *Nature Climate Change* 1(4): 210-219.

Schuetz, T.; Förch, W. and Thornton, P. 2014. *Revised CCAFS Theory Of Change Facilitation Guide.* CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). https://cgspace.cgiar.org/handle/10568/56873

Schultz, B.; Tardieu, H. and Vidal, A. 2009. Role of water management for global food production and poverty alleviation. *Irrigation and Drainage* 58(1): S3-S21.

Scott, C.A.; Flores-López, F. and Gastélum, J.R. 2007. Appropriation of Río San Juan water by Monterrey city, Mexico: Implications for agriculture and basin water sharing. *Paddy and Water Environment* 5(4): 253-262.

Shah, T. 2010. *Past, present and the future of canal irrigation in India.* www.rimisp.org/wp-content/uploads/2010/05/Paper_Tushaar_Shah-4.pdf (accessed 15 February 2015)

Shah, T. 2009. *Taming the anarchy: Groundwater governance in South Asia.* A co-publication with the International Water Management Institute (IWMI). Washington, DC: RFF Press.

Shah, T. and Kela, P. 2015. MP Lessons for Bumper Agricultural Growth. Tuesday 19 May 2015. Financial Express, India.

Shah, T.; Anwar, A.; Amarasinghe, U.; Hoanh, C.T.; Mohan, J.; Molle, F.; Mukherji, A.; Prathapar, S.A.; Suhardiman, D.; Qureshi, A.S. and Wegerich, K. 2012. *Canal irrigation conundrum: Applying contingency theory to irrigation system management in India*. Colombo, Sri Lanka: IWMI-Tata Water Policy Research Highlight No. 25.

Shivakoti, G.P.; Vermillion, D.L.; Lam, W.F.; Ostrom, E.; Pradhan, U. and Yoder, R. (Eds). 2005. *Asian irrigation in transition: Responding to challenges.* New Delhi: SAGE Publications.

Shivakoti, G.P. 2003. Facilitating policies for improved governance and management of Asian irrigation systems. Paper presented at a colloquium at the Workshop in Political Theory and Policy Analysis, Indiana University, USA, September 22, 2003.

Snel, M. 2014. Guest editorial: Sanitation as a business. *Waterlines* 33(3): 193-194.

Suhardiman, D. and Giordano, M. 2014. Is there an alternative for irrigation reform? *World Development* 57: 91-100.

Theisohn, T. and Lopes, C. 2003. *Ownership leadership and transformation: Can we do better for capacity development*. Abingdon: Earthscan.

Tookey, D.L. 2007. The environment, security and regional cooperation in Central Asia. *Communist and Post-Communist Studies* 40(2): 191-208.

Tsur, Y.; Roe, T.; Doukkali, R. and Dinar, A. 2004. *Pricing irrigation water: Principles and cases from developing countries.* Washington, DC: RFF Press. Republished in 2010 by Routledge.

Turral, H.; Svendsen, M. and Faures, J.-M. 2010. Investing in irrigation: Reviewing the past and looking to the future. *Agricultural Water Management* 97(4): 551-560.

UN (United Nations). 2015. Transforming our world: The 2030 agenda for sustainable development. A/Res/70/1, United Nations. New York. https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf (accessed 17 December 2015)

Underhill, H.W. 1990. *Small-scale irrigation in the context of rural development*. Cranfield: Cranfield Press.

van den Dries, A.L.J. 2002. *The art of irrigation. The development, stagnation, and redesign of farmer-managed irrigation systems in Northern Portugal*. PhD thesis, Wageningen University. http://edepot.wur.nl/121330

van der Zaag, P. and Rap, E. 2012. The pivotal role of canal operators in irrigation schemes: The case of the Canalero. *Irrigation and Drainage* 61(4): 436-448.

Vermillion, D.L. 1997. *Impacts of irrigation management transfer: A review of the evidence.* Research Report No. 11. Colombo, Sri Lanka: International Irrigation Management Institute.

Vermillion, D.L. 2005. Irrigation sector reform in Asia: From 'participation with patronage' to 'empowerment with accountability'. In Shivakoti, G.P.; Vermillion, D.L.; Lam, W.F.; Ostrom, E.; Pradhan, U. and Yoder, R. (Eds), *Asian irrigation in transition: Responding to challenges,* pp. 409-436. New Delhi: SAGE Publications.

Vogel, I. 2012. *Review of the use of 'Theory of Change' in international development*. DFID Research Paper. London: Department for International Development.

Wade, R. 1988. *Village Republics: Economic conditions for collective action in South India.* Cambridge: Cambridge University Press.

Wade, R. and Chambers, R. 1980. Managing the main system: Canal irrigation's blind spot. *Economic and Political Weekly* 15(39): 107-A112.

Waheb, A. 2014. In International Commission on Irrigation and Drainage (ICID). First World Irrigation Forum, Mardin, Turkey, 28 September – 3 October 2013. Summary report.

WCD (World Commission on Dams). 2000. *Dams and development: A new framework for decision making*. World Commission on Dams. London: Earthscan Publications Ltd.

Wisser, D.; Fekete, B.M.; Vörösmarty, C.J. and Schumann, A.H. 2010. Reconstructing 20th century global hydrography: A contribution to the Global Terrestrial Network-Hydrology (GTN-H). *Hydrologic Earth System Sciences* 14(1): 1-24.

World Bank. 2006. *Reengaging in agricultural water management: Challenges and options.* Directions in Development. Washington, DC: World Bank.

WWF, 2013. *Water Stewardship. Perspectives on business risks and responses to water challenges*. WWF Brief 2013. Gland: World Wide Fund for Nature.

APPENDIX 1. ESTIMATIONS OF LARGE-SCALE IRRIGATED AREAS IN DEVELOPING/TRANSITIONAL COUNTRIES (SEE FOOTNOTES).

Region and Country	Total irrig. area, '000 ha	Proportion %	Area LSIS, '000 ha	Source material where possible to determine proportion (%) or LSIS area directly.
South and SE ASIA				
Afghanistan	3,208	10	321	www.areu.org.af/Uploads/EditionPdfs/811E-Typology%20of%20Irrigation%20Systems.pdf
Bangladesh	5,264	10	526	www.fao.org/nr/water/espim/country/index.stm
Cambodia	354	35	124	www.fao.org/nr/water/aquastat/countries_regions/cambodia/index.stm
China	68,126	44	29,975	Estimated proportion from 1993 data on proportions
India	66,700	35	23,345	FAO information estimated at 35% = 23 Mha. Other estimates at 17 Mha.
Indonesia	6,722	85	5,714	http://publications.iwmi.org/pdf/H028872.pdf
Iran	9,413	10	941	Area > 50 ha, www.fao.org/docrep/w4356e/w4356e0d.htm
Iraq	3,525	20	705	Estimated (a cautious low estimate).
Japan	2,474	7.4	183	From ICID Japan secretariat, by email
Korea	772	62.0	479	www.fao.org/docrep/005/ac623e/ac623e0j.htm
Laos	310	3	9	http://publications.iwmi.org/pdf/H015463.pdf
Malaysia	380	60	228	www.fao.org/nr/water/espim/country/malaysia/index.stm
Myanmar	2,292	28	642	www.fao.org/nr/water/espim/country/myanmar/index.stm (weirs + dams)
Nepal	1,313	25	328	www.fao.org/nr/water/espim/country/nepal/index.stm
North Korea	1,460	75	1,095	Estimated; socialist central control government
Pakistan	20,200	85	17,170	Estimated proportion from 1990 data on proportions
Philippines	1,571	40	628	www.fao.org/nr/water/espim/country/philippines/index.stm
Sri Lanka	570	65	371	www.fao.org/nr/water/espim/country/sri_lanka/index.stm
Thailand	6,415	75	4,811	www.fao.org/nr/water/espim/country/thailand/index.stm
Viet Nam	4,600	60	2,760	www.fao.org/nr/water/espim/country/viet_nam/index.stm
Totals/weighted average	205,669	44	90,356	

CENTRAL ASIA				
Azerbaijan	1,424	99	1,410	www.fao.org/docrep/w6240e/w6240e07.htm
Kazakhstan	2,066	91	1,880	www.fao.org/docrep/w6240e/w6240e11.htm
Kyrgyzstan	1,023	80	818	www.fao.org/docrep/w4356e/w4356e0h.htm
Tajikistan	742	90	668	www.fao.org/docrep/w4356e/w4356e0u.htm
Turkmenistan	1,995	90	1,796	Estimated www.eoearth.org/view/article/157004/
Uzbekistan	4,215	90	3,794	Extrapolated from other ex-soviet countries
Totals/weighted average	11,465	90	10,365	
LATIN AMERICA				
Argentina	2,357	70	1,650	www.idrc.ca/Documents/106298-Energy-exploration-report-Argentina.pdf
Brazil	5,400	6	324	www.fao.org/nr/water/aquastat/countries_regions/brazil/index.stm
Chile	1,110	40	444	Conservative estimate by authors
Mexico	6,500	55	3,575	Ochoa and Garces-Restrepo (2007)
Peru	2,530	25	633	Conservative estimate by authors
Venezuela	1,055	15	158	Conservative estimate by authors
Totals/weighted average	18,952	36	6,784	
SUB-SAHARAN AFRICA				
Ethiopia	290	20	58	Estimate from this www.fao.org/docrep/v8260b/V8260B0s.htm
Kenya	103	39	40	Estimated by authors
Madagascar	1,086	15	163	Conservative estimate by authors
Mali	371	35	130	ftp://ftp.fao.org/agl/aglw/docs/Aquastat_Dams_Africa_070524.pdf
Mozambique	118	43	50	ftp://ftp.fao.org/agl/aglw/docs/Aquastat_Dams_Africa_070524.pdf
Nigeria	293	15	44	Conservative estimate by authors
South Africa	1,601	10	160	Conservative estimate by authors
Swaziland	50	90	45	Author's experience in this country
Tanzania	130	12	15	Author's experience in this country

Zimbabwe	174	15	26	Conservative estimate by authors
Totals/weighted average	4,216	17	731	
MENA				
Algeria	570	26	150	ftp://ftp.fao.org/agl/aglw/docs/Aquastat_Dams_Africa_070524.pdf
Egypt	3,650	77	2,811	ftp://ftp.fao.org/agl/aglw/docs/Aquastat_Dams_Africa_070524.pdf
Libya	470	9	40	ftp://ftp.fao.org/agl/aglw/docs/Aquastat_Dams_Africa_070524.pdf
Morocco	1,458	40	583	ftp://ftp.fao.org/agl/aglw/docs/Aquastat_Dams_Africa_070524.pdf
Syria	1,399	33	462	www.fao.org/docrep/w4356e/w4356e0t.HTM
Sudan	1,890	55	1,040	Estimated from Gezira plus others as a fraction of total
Turkey	5,215	33	1,721	ftp://ftp.fao.org/agl/aglw/imt/CSTurkey.pdf
Totals/weighted average	14,652	46	6,806	
Total in area in '000 ha	254,954		115,042	
Total area in ha			115,041,802	
Average % for LSIS		45.1		

Source: Authors, from FAO Aquastat and various materials.[23]

[23] There are many assumptions and error terms regarding the total area under irrigation and proportion of area under LSIS. Many estimates are taken from analyses going back to the 1990s. The table does not include Australia, USA/Canada, Caribbean countries, Europe and the Russian Federation. It also does not report the many countries with small irrigated areas. This calculation reveals that approximately 45% of the world's irrigation in developing/transitional countries can be described as large-scale. It is estimated that 90-95% of large-scale systems will be gravity/canal-fed.