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Irrigating Zimbabwe after Land Reform: The Potential of Farmer-Led Systems

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ABSTRACT: Farmer-led irrigation is far more extensive in Zimbabwe than realised by planners and policymakers. This paper explores the pattern of farmer-led irrigation in neighbouring post-land reform smallholder resettlement sites in Zimbabwe's Masvingo district. Across 49 farmer-led cases, 41.3 hectares of irrigated land was identified, representing two per cent of the total land area. A combination of surveys and in-depth interviews explored uses of different water extraction and distribution technologies, alongside patterns of production, marketing, processing and labour use. In-depth case studies examined the socio-technical practices involved. Based on these data, a simple typology is proposed, differentiating homestead irrigators from aspiring and commercial irrigators. The typology is linked to patterns of investment, accumulation and social differentiation across the sites. The results are contrasted with a formal irrigation scheme and a group garden in the same area. Farmer-led irrigation is more extensive but also more differentiated, suggesting a new dynamic of agrarian change. As Zimbabwe seeks to boost agricultural production following land reform, the paper argues that farmer-led irrigation offers a complementary way forward to the current emphasis on formal schemes, although challenges of water access, environmental management and equity are highlighted.

KEYWORDS: Farmer-led irrigation, land reform, water control, sociotechnical system, Zimbabwe

INTRODUCTION

Water control is often central to successful agriculture, but how should this be done, through what technologies, financing, institutions and governance regimes? The standard answer in Zimbabwe has been the construction of engineered irrigation schemes, yet this paper argues that farmer-led irrigation, with more flexible, adaptive socio-technical arrangements, is highly significant but much less recognised (cf. Woodhouse et al., 2017; Beekman et al., 2014; Nkoka et al., 2014; Bolding et al., 1996).

Following Woodhouse et al. (2017: 13), farmer-led irrigation development is seen as "a process where farmers assume a driving role in improving their water-use for agriculture by bringing about changes in knowledge production, technology use, investment patterns and market linkages, and the governance of land and water". In other words, irrigation development is the process by which socio-technical assemblages are constructed, involving multiple components – water, land, labour, technology and markets. These are linked to social knowledge and skills, in order to improve water control and agricultural production. The form such assemblages take will depend on access to a range of material and other resources, and in any setting these conditions will vary by wealth, gender, age and other dimensions.

Different assemblages therefore emerge over time, depending on ecological, social and economic conditions, with resulting differentiation between irrigators. Some are able to invest and accumulate as a result of irrigated production, while others cannot expand or intensify production. Patterns of class formation emerge, linking farmer-led irrigation to dynamic processes of agrarian change (cf. Bernstein, 2010). Such processes are, this paper argues, quite different from those associated with standardised irrigation schemes or group gardens,[1] suggesting important implications for policy in the post-land reform setting.

Zimbabwe's land reform of 2000 resulted in the redistribution of around eight million hectares, previously occupied by around 4500 large-scale, white-owned commercial farms. This resulted initially in the establishment of approximately 146,000 smallholder farms (designated A1 schemes) and 16,000 medium-scale farms (designated A2) (Scoones et al., 2010),[2] although allocations have increased since, as earlier informal allocations have been approved. This radical reconfiguration of the agrarian structure has resulted in the need to re-establish agricultural production but at different scales and with different socio-technical arrangements compared to large-scale farming. Irrigation, particularly in dryland areas such as Masvingo, is essential.

Responding to this challenge, this paper reports on a study of farmer-led irrigation development in two sites in dryland Masvingo province, each on smallholder A1 resettlement areas established after 2000 as part of the land reform. The paper documents the extent of farmer-led irrigation – from rivers, streams, dams and wells – using a variety of technology combinations – including small-scale pumps, buckets and pipes – over a range of scales – from very small homestead gardens to larger collective and individual plots. Through 49 cases, we explore the socio-technologies assembled, the practices deployed and the production realised, and estimate the total area under irrigation. We also contrast the socio-technical assemblages and the area irrigated under farmer-led systems with two formal irrigation interventions in the same area.

Based on the case studies of farmer-led irrigation, we derive a simple typology – contrasting homestead, aspiring and commercial irrigators – and discuss the different ways in which water control technologies, land-use, market networks, labour and knowledge are combined. We also look at the implications for social differentiation, patterns of accumulation and longer-term agrarian change.

A BRIEF HISTORY OF IRRIGATION IN ZIMBABWE

The formal irrigation infrastructure of dams, canals, pipes and pumps has a long history in Zimbabwe. It was central to colonial support for agriculture. For example, in 1952 a major report on large-scale irrigation made the case for a substantial increase in investment in irrigation in Zimbabwe, then Rhodesia (Rukuni, 1988). The reason was growing concerns about national food security and the need to improve the production of land recently occupied by white settlers. From the early colonial period, the investment in dam building and irrigation infrastructure was impressive, but it was a particular style of water control, geared to a certain type of agriculture. It was a socio-technical assemblage that was

[1] These are collectively run gardens with a common water source and individual plots.

[2] Zimbabwe's land reform of 2000 allocated land to smallholders (with average arable areas around 5 ha) and medium-scale commercial farmers (with total farm sizes averaging 100 ha). These were designated A1 and A2 respectively. This study focuses only on A1 schemes, which in turn have two forms: one a villagised arrangement where there is communal grazing, a village site for housing, and separate, individual fields and a 'self-contained' arrangement, where grazing, arable and housing areas are contained in one plot.

fixed, standardised and controlled, reflecting a particular relationship of power between farmers, science and the state (Fontein, 2008).

One of the early investments was Kyle (now Mtirikwi) Dam in Masvingo province, completed in 1960, which linked to a major river and canal system providing water to the new sugar estates in the Lowveld. It was an impressive piece of engineering, reshaping the hydrology of the region. To rely on a large dam, with many kilometres of canal and carefully planned estates, was a style of 'modern' agriculture that impressed many, and was central to colonial state-building (Fontein, 2015). Today it is supplemented by other dams and canal systems, most recently through the creation of the Tokwe Mukosi Dam, also in Masvingo province.[3]

By Independence in 1980 Zimbabwe had about 150,000 hectares under 'formal' irrigation schemes (Rukuni, 1988; Manzungu, 1999). Large-scale, mostly white-owned commercial farms accounted for 68% of this, where government subsidies supported the massive expansion of small dams and irrigation areas. Another 27% was linked to commercial estates and outgrower areas, including those supporting sugar and citrus production in the Lowveld. Only 3.4% of the irrigated area was devoted to smallholder irrigation, however (Manzungu and van der Zaag, 1996). Indeed, at Independence, the distribution of water and irrigation capacity was even more unequal than that of land.

A major effort was therefore expended in the years after Independence in expanding smallholder schemes in the communal areas. This took the form of the establishment of block schemes with 0.1 ha plots, managed centrally with state support, often with a Ministry of Agriculture extension officer stationed on the scheme, directing the planting of crops and allocation of water (Bolding, 2004). Within Masvingo province there are currently 60 schemes, averaging 54.6 ha (range 8-360 ha), making up just 0.08% of the total area. The history of such schemes dates back to the 1930s. Focused on providing an irrigated complement to dryland agriculture (Manzungu, 1999), they emphasised welfare support to impoverished populations, and there were real limits to accumulation (cf. Cousins, 2013 for South Africa). Many of these schemes failed: the result of a litany of problems common across Africa (Adams and Carter, 1987). These included institutional failures, such as sustaining group cohesion, the challenges of covering recurrent costs and the inappropriate imposition of particular cultivation regimes. Economic analyses for Zimbabwean schemes have shown that the government covered 100% of capital costs and 89% of recurrent costs, and when this support dried up the schemes often collapsed (Meinzen-Dick et al., 1994; Makadho et al., 2001).

Following the major land reform of 2000 investment in irrigation schemes again became a priority. On the former commercial farms a range of irrigation infrastructure existed that had to be rehabilitated and repurposed for smallholder use. A number of different approaches can be seen (Zawe, 2006), but the standard block scheme model was often evident in the A1 smallholder areas, involving an organised group of irrigators supplied with water pumped mostly from rivers and dams, and small plots distributed to individual irrigators. Various programmes have promoted irrigation as central to a new push to upgrade and commercialise agriculture. For example, from 2016 'command agriculture' became the flagship programme of the ZANU-PF government,[4] including investment in irrigation facilities. Foreign donors, from the Brazilians to the Chinese, offered irrigation equipment, mostly suited to large-scale production. Today, as in the past, hydrological transformations and images of modernist progress are closely tied with a project of state-building and control (Fontein, 2008).

[3] See: https://zimbabweland.wordpress.com/2014/03/17/dams-flooding-and-displacement-the-tokwe-mukorsi-dam/ (accessed 10 January 2019).

[4] Command agriculture is a government programme aimed at boosting production. It was initially focused on crops in irrigable areas, mostly medium-scale farms. Loans are offered for inputs via a private company and are expected to be paid back in full before the following season (see https://zimbabweland.wordpress.com/2017/09/25/command-agriculture-and-the-politics-of-subsidies/, accessed 10 January 2019).

Irrigation infrastructure and technology are always social and political (Bolding et al., 1995). Visions of modernity and progress are often tied to ordered, large-scale, 'commercial' systems and too often ignore what is happening on the ground. With a different agrarian structure, with many more smallholder farmers, past socio-technical assemblages suitable for large-scale commercial production usually no longer make sense, despite their advocacy as symbols of agricultural modernisation. A massive centre-pivot, for example, is not much use on a one or two hectare plot unless collective arrangements are made, and few new resettlement farmers can afford sophisticated computer-synchronised, satellite-linked drip irrigation systems either. Agrarian transformation also requires technological transformation and, despite their appeal, conventional, high-cost, large-scale systems are rarely appropriate.

While the dominant image of irrigation is of a formal, ordered, managed scheme, alternative systems of water control have a long history in Zimbabwe. For example, *dambo* (valley-bottom wetland) cultivation dominated the agriculture of the 19th century, as farmers farmed intensively in valley bottoms in the hilly areas, often hiding from raids (Scoones and Cousins, 1994). In the early colonial era missionaries encouraged irrigation at times of famine, and, from the late 1920s, government initiatives built on local systems, with support to small irrigated plots under farmer control (Rukuni, 1988).

What then are the contemporary versions of farmer-led irrigation? How are they fitting into the new agrarian system post-land reform? What socio-technical innovations and improvisations are evident? And how do processes of social differentiation in socio-technical choices and trajectories co-evolve, with what implications for agrarian dynamics?

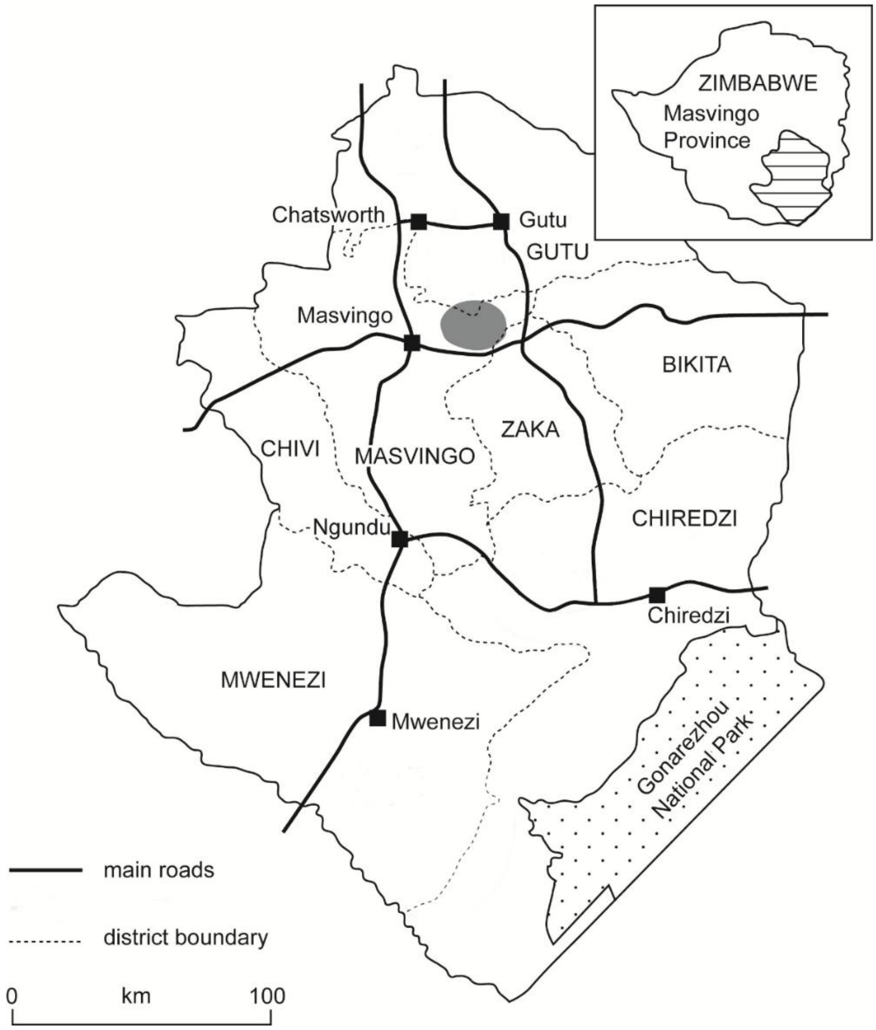
EXPLORING FARMER-LED IRRIGATION IN MASVINGO DISTRICT

In this study we examined farmer-led irrigation practices in two neighbouring land reform sites in Masvingo district, contrasting them with those observed in a rehabilitated formal scheme and a group garden in the same area (see Figure 1). The sites are on adjacent former large-scale commercial farms near the regional town of Masvingo in the southeast of the country. Both are A1 smallholder settlement schemes, one involving larger self-contained farms, including arable, grazing and housing in one area (a farm originally called Extension), and one a villagised scheme, where arable land is separated from communal grazing and village areas (a farm originally called Wares). In each site, resettlement farmers have initiated new, market-based horticultural enterprises to complement their dryland field crops and livestock production. In the same area such farmer-led irrigation initiatives sit alongside a rehabilitated irrigation scheme and a new group garden.

This is a dryland region, where average rainfall was 662 mm in nearby Masvingo town between 2000-01 and 2016-17.[5] The area is traversed by several small rivers and streams with irrigable areas along water courses, especially in Extension, as well as in sites where water can be extracted from wells and boreholes. In the past, former landowners largely ranched livestock, with very small irrigation plots near the farm compounds, but since then land-reform irrigation – and arable production generally – has expanded massively. Our sites are part of a long-term study of livelihoods after land reform established in the early 2000s (cf. Scoones et al., 2010; Scoones, 2013, 2018), and in this study we build on this long-term data to explore the explosion of interest in farmer-led irrigation that we have observed.

[5] Based on Meteorological Department records, the coefficient of variation was 29%, maximum 982 mm, minimum 290 mm, and five of the 17 years had rainfall levels more than 20% below the mean, indicating a high frequency of drought.

Figure 1. Location of study area.



The settlers in the new land reform areas mainly came from adjacent 'communal areas'. Compared to their neighbours, the settlers were a younger, more educated, better-linked and more entrepreneurial group of farmers (Scoones et al., 2010). Over the last 18 years patterns of success have been highly differentiated. Some failed on their new plots and subsequently left; others found it difficult to invest in the land due to lack of resources, illness or infirmity and so have not done well. But a significant group have been able to make use of the new land resources to produce, accumulate and invest (Scoones et al., 2012).

The two neighbouring study sites comprise 2,047 ha and are home to 147 households.[6] Within both sites there is considerable differentiation across households, with some 'accumulating from below'

[6] Based on data from a full census survey of both sites carried out in 2011-2012, households in the villagised site (Wares) had fewer assets, including arable land (4 ha vs. 12 ha), cattle (5.1 vs. 12.2) and ox carts (45% vs. 70% of households owning one) than those in Extension. Wares farmers also produced and sold less maize (995 kg vs. 3480 kg produced and 250 kg vs. 1175 kg sold) in the 2010 and 2011 seasons. Additionally, Wares farmers were more reliant on off-farm income, including remittances (36% vs. 21% of households receiving remittances), and invested less in gardens and well-digging (average 0.19 vs. 0.22 wells dug between 2006 and 2011). The purchase of 'luxury' items is also less evident in Wares, with 11% owning a car, compared to

(Neocosmos, 1993; Cousins, 2010), investing surpluses from agricultural production in new housing, other assets and agricultural inputs. Others are doing less well, simply surviving or, in some cases, leaving the area and abandoning farming. In class terms, those accumulating can be identified as 'petty commodity producers' (combining capital and labour to meet most of their simple reproduction needs from their own production) or even part of an emergent 'rural bourgeoisie' (extracting surplus from wage labour, achieving sustained capitalist accumulation). Others are a mix of 'worker-peasants' (representing a hybrid identity as wageworkers and petty commodity producers) and 'semi-peasants' (the most impoverished group, including many women) (cf. Cousins et al., 1992). In the more asset- and income-poor site of Wares, around a quarter of all households are successfully accumulating from below; this proportion rose to around 40% in Extension (Scoones et al., 2010; Scoones 2018).

However, many have found that there are severe limits to accumulation from the main dryland crop-livestock systems that were established on settlement. As farms became established, many settlers, particularly those making surpluses from their dryland crop and livestock farming, looked to intensify, expanding and diversifying markets. Water control in such a dryland area was essential. One option was to sign up for formal irrigation schemes that were being rehabilitated in the mid-2000s (see below); the other was to invest independently in farmer-led irrigation systems.

In 2018 we documented all farmer-led irrigation activities in both sites (defined as any activity that involves the movement of water for agricultural purposes) – from small homestead plots irrigated by buckets or cans to larger areas where pumps and a more extensive piping system are used. Deep knowledge of the area, and assistance from local farmers, allowed for comprehensive coverage. As noted already, a total of 49 cases were identified (15 in Wares and 35 in Extension), and a detailed case study of each was developed. These represented 14% of households in Wares, where a combination of a lack of water sources and fewer assets restricted irrigation opportunities, and 92% of households in Extension, where nearby rivers and a greater asset base allowed more households to invest in irrigation. An estimate of the total area of farmer-led irrigation was derived, which could be compared to the extent of irrigation in the formal scheme and group garden in the same area.

In our examination of farmer-led approaches we looked at a range of criteria, describing the diversity of water control approaches being pursued. Case studies of individual plots were combined with biographies of farmers, highlighting how investments and management practices have changed since 2000. The next section reports on these findings.

A TYPOLOGY OF FARMER-LED IRRIGATION

Farmer-led irrigation takes many forms in our study sites. These include different land tenure (individually held, communal), different water sources (dams, rivers, wells), different types of technology (pumps, buckets, canals, pipes), different social arrangements (collective/individual management, hired or family labour and contrasting gender roles), different markets (local informal sales, spot markets, direct sales to supermarkets/wholesalers, contract farming) and different institutions (state, community managed and unregulated use).

Across the 49 cases we identified three broad groups, where different combinations of resources, technologies, labour, market linkages and knowledges were combined in different socio-technical assemblages. We have labelled these homestead, aspiring and commercial irrigators. As we explain below, these categories each have particular class characteristics, with different opportunities for accumulation. They are not, however, fixed categories. Indeed, when we started working in this area after land reform there were no commercial irrigators and only a few aspiring irrigators. Those who

31% in Extension. Finally, in Wares, 19% of households had bought a solar panel in the 5 years prior to 2011, compared to 31% in Extension.

have been able to invest in new forms of irrigation have accumulated resources from dryland farming and livestock production, often switching the focus of their efforts over time. Our typology focuses on the capacity to accumulate from different socio-technical assemblages, thus generating processes of social differentiation between farmers. Other studies from elsewhere in Africa offer typologies linked to business strategies (van den Pol, 2012) and market-based livelihoods (Hebbink et al., this Issue), each linked to diverse dynamics of agrarian change driven by farmer-led irrigation.

In 2018 there was a total of 41.3 ha of farmer-led irrigation (9.9 ha in Wares and 31.4 in Extension) in our study sites. Average irrigated plot sizes were higher in Extension (0.9 ha) than Wares (0.6 ha), but there was a wide range (0.01 to 5 ha). This represents 2.02% of the total land area. In 2011 we estimated that 42% of the land area was cultivated, meaning that current farmer-led irrigation covers 4.8% of arable area; although, as discussed further below, this is distributed extremely unevenly.

In terms of our typology, the commercial irrigators represent a class of petty commodity producers, able to invest and accumulate, hiring in labour. By contrast, those in the largest group – the aspiring irrigators – are managing to assemble some elements that would allow more sustained petty commodity production and commercialisation, often initiated through the purchase of a pump and some piping. However, they are not able to combine all elements, such as hiring labour or gaining access to more lucrative market networks, and are often reliant on off-farm work, as 'worker-peasants'. Homestead irrigators, on the other hand, are unable to accumulate through irrigation given the small scale of operations and follow a more subsistence style of 'semi-peasant' production.

Table 1 offers data based on our studies contrasting the three groups in relation to sources of water, water extraction and distribution, cropping patterns, labour-hiring, product-processing and marketing. As the table shows, the homestead irrigators use small plots of land, drawing water from wells dug near the homestead using buckets. When land was allocated after land reform, no households had wells, and since then many have dug shallow, open wells for domestic water supply as well as small-scale irrigation. The volumes of production are small, and mostly for household consumption, with tomatoes and green vegetables dominating. Some vegetables, fresh or processed, are sold locally in small quantities to neighbours or occasionally itinerant traders. Many in this group want to expand. One has bought a Chinese-made mobile pump, which can now be purchased for as little as US$250. However, a lack of access to suitable land and the amount of water available in shallow wells constrains upgrading. Many in this group are relatively poor, with limited income from either farm or off-farm sources. The lack of social or political connections also constrains access to new land. Women are especially significant producers in this group, as they combine irrigation with domestic work around the homestead. Virtually all production is based on family labour, with only a couple of households employing any labour, and then only on a very part-time basis.

Three-quarters of the aspiring irrigators, by contrast, have purchased a pump. These are either mobile pumps for extracting water from dams or rivers or submersible pumps that can be used in a well. Most mobile pumps are powered by diesel or petrol engines, while submersible pumps also include solar-powered electric engines. However, these pumps are very often used in conjunction with well and bucket irrigation, which allows an expansion of the irrigated area (0.43 ha on average, range: 0.02 to 1). On these larger areas the focus can be expanded from tomatoes and green vegetables to other crops, including green maize. This group is the largest in our sample and demonstrates a hybrid socio-technical configuration, straddling the more subsistence-focused homestead assemblage and more commercial systems. Aspiring irrigators are most common in the Wares site, where access to rivers and streams is lower. This is not a stable assemblage, and many are attempting to expand production and commercialise further. They are purchasing new equipment and extending their market networks, with many taking produce to the nearby Masvingo market. However, lacking their own transport, or the means to hire it, many rely on traders coming to the area. This requires investment in networks of relationships with market intermediaries to assure reliable marketing and good prices. Their plans for expansion include getting access to land near the dams, rivers and streams of the area, but as later arrivals with fewer political connections compared to those in the commercial irrigator group, this is often difficult.

Table 1. Three types of farmer-led irrigation in 2018.

Socio-technical dimension	Specific element	Homestead irrigators	Aspiring irrigators	Commercial irrigators
N=		12	24	13
Scale	Area irrigated (ha)	0.03	0.43	2.36
Water sources	Well (%)	83	42	38
	River (%)	0	38	54
	Dam (%)	17	38	54
Water extraction method	Bucket (%)	92	42	0
	Mobile pump (%)	8	46	53
	Submersible pump (%)	0	29	46
Water distribution	Hand (%)	92	17	0
	Drip (%)	0	4	8
	Pipe (%)	8	83	100
	Length of pipe (m)	4	161	319
Crops	Nos grown	2.9	3.4	4.2
	Maize (%)	25	33	46
	Tomato (%)	83	92	100
	Rape (%)	50	38	54
	Onion (%)	17	25	38
	Cabbage (%)	8	50	77
	Cucumber (%)	8	17	31
Labour	Hiring (%)	8	38	69
Processing	Vegetable drying (%)	58	38	46
Marketing	Local (%)	92	13	0
	Traders (%)	8	42	38
	Masvingo (%)	0	79	92
	Supermarkets (%)	0	8	23

Other aspiring irrigators focus on sinking new, deeper wells to allow irrigation near homesteads and on dryland fields. This requires cash resources to hire a well-digging unit, and so surplus production from other areas of farming is essential, as is off-farm and remittance income. This group has a more diversified livelihood portfolio than either of the other two, with households combining on- and off-farm income. Irrigation is important in this mix but not necessarily the main emphasis. Both men and women are involved, often sharing roles within the irrigation plot, with women taking over if men are working away. Overall, this group is younger than the other groups and often in the process of establishing an independent home. Irrigable land may be borrowed from relatives within a process of land subdivision that has been underway since land reform. In this group 38% of households hire in labour and are on track to establish an irrigation-based form of petty commodity production. However, the remaining 62% are more oriented towards dryland farming, combined with various kinds of off-farm employment, and can be seen as 'worker-peasants' pursuing a diversified livelihood.

Finally, the commercial irrigators, representing 27% of our sample, have focused on irrigated horticulture as the main focus of their agricultural activities, irrigating on average 2.36 ha of land (range: 1.1 to 5). Men are often in the lead in this group, and over two-thirds hire in labour for a variety of activities. These are established, older households often with good social, church-based and political connections in the community, allowing for preferential access to land and other resources. There is a clear gendered division of labour observable, with men focusing on irrigation and marketing, while women assist with particular production tasks and are involved in processing (usually drying vegetables for market sales). All commercial irrigator households have purchased equipment for water pumping and distribution, with most owning several pumps, sometimes including at least one with a large horsepower. Everyone has some piping, averaging 319 m in length. This group grows the largest number of crops, expanding beyond tomatoes, green vegetables and maize to high-value crops, such as cucumber, cabbage and onion.

A focus on commercial production means considerable investment in market networks, with around a quarter linked up to supermarkets through regular contracts. Regular marketing in Masvingo complements this, and a number still rely on itinerant traders. Most in this group have their own transport, usually an open truck, which helps with the regular and timely marketing of perishable products. This group is particularly evident in Extension, where land areas are larger in 'self-contained' plots. Others are negotiating with relatives and fellow church members for access to land and water. Those with the largest land area under irrigation have dug new, deep wells to accommodate powerful submersible pumps, allowing significant expansion of production. With the focus on commercial production, the socio-technical assemblage of the commercial irrigators has a particular land-water-technology-market configuration. It has to be flexible, as people shift their crop mix to respond to market demand, and for this reason having multiple water sources and different pumping systems, deploying labour flexibly across plots and through the seasons, is essential.

While highly differentiated across different types of irrigator, overall the volume of production from the 43.1 ha of farmer-led irrigation is significant, and is devoted to a range of vegetables, including tomato, cabbage, rape, *covo* (kale), maize and cucumber (in rank order),[7] resulting in significant incomes, especially for the commercial irrigators (see below). The employment benefits are large, with seasonal employment provided on 39% of irrigated plots. It is a highly dynamic system, with new socio-technical configurations being assembled all the time, as people attempt to expand production, especially when new, cheaper pumps become available.

SOCIO-TECHNICAL ASSEMBLAGES AND ACCUMULATION OPPORTUNITIES

Drawing on the typology laid out above, in this section we offer detailed case studies of the three irrigator types. These show how social and technological elements are combined, and how these configurations influence who is able to accumulate and who is not. The paper then moves on to a wider analysis of how socio-technical assemblages and processes of social differentiation and accumulation co-evolve.

The homestead irrigators

Across our two sites we undertook case studies of 12 homestead irrigators, mostly using water drawn from shallow wells and distributed by bucket or watering can (Table 1). The average area irrigated is only 0.03 ha. These plots are managed mostly by women, and are linked to household provisioning and local sales. The wells were dug largely to provide domestic drinking water. Some are covered but most are open, with depths of only a few metres. Tomatoes and green vegetables (kale and rape) are the most common crops, although a few also grow butternut, cucumbers and onions. Of these households, 58% dry their vegetables to allow year-round supplies to the home. The small gardens are fenced,

[7] Other vegetables grown by a smaller proportion of households include butternut, beans, green pepper, *tsunga* (mustard greens), carrot, sweet potato, garlic and wheat (again in rank order).

usually with brushwood and grass, and the cultivation is carried out with family labour, usually women and children.

The total production does not allow a very significant income, but all those we talked to mentioned how important it was. CC from Wares noted, "my small garden is really important for providing for the family. I am a widow and have ten children. I irrigate using a bucket and grow tomatoes and green vegetables throughout the year". In discussions all 12 homestead irrigators stated that they would like to expand the area, and get a pump to do so, saying they would make use of the extra income to pay school fees, buy livestock and improve the home. VC from Extension comments,

> We dug a deep well in 2003, which is protected with a brushwood fence. I am happy to say that I can supply enough vegetables for the family as well as selling some to meet our daily needs, like sugar, salt, stationery for the children and grinding mill payments. I raise an average of US$300 per year from the garden produce. But I dream of expanding the garden, if only I could get a permanent water supply from a drilled borehole.

These are highly flexible, small-scale systems, reliant on the hand application of water. This allows very focused watering regimes, which can be combined with various sorts of water harvesting, including the digging of pits, the creation of furrows and canals and the collection of rainwater from homestead roofs. At such a small scale and near the home such irrigation can be combined with other activities. Only one household occasionally hired in labour. While the intention to expand irrigation was frequently expressed, the opportunity for accumulation is currently constrained by a lack of surplus income to invest in equipment or well-digging. Lacking the social or political networks to gain access to land and water also limits opportunities.

The aspiring irrigators

The purchase of low-cost pumps (either surface water or submersible) has been extensive across our study areas, and is a recent phenomenon thanks to the availability of cheap pumps on the market. In this group 46% have purchased a mobile pump and 29% a submersible pump, all in the past few years. Such pumps are proving incredibly flexible routes to scaling up production from very small, bucket-supplied plots. These are highly flexible socio-technical assemblages that can be adapted to very different plots, with different soil patches, topography and crop types. With the modular format they can be up-scaled by purchasing additional or bigger pumps, and more piping. Mobile pumps can also be taken home at night to avoid theft. With investment from surplus dryland agricultural or livestock production, or off-farm income sources, aspiring irrigators have expanded irrigated areas and thus the capacity to accumulate.

Gaining access to irrigable land with a reliable water resource is, however, a major challenge for many. Dryland fields rarely have a well nearby, and digging one can be prohibitively expensive if the water table is deep. Access to land near rivers is closely managed, and the communal 'grazing area' is regulated by the local leadership. They only allow cultivation in the grazing lands selectively, depending on local patronage arrangements. Some therefore seek alternative arrangements. BC, for example, has developed a joint venture with RM and his son TM. He uses 0.8 ha of their land in exchange for sharing his irrigation equipment (a 6.5 HP engine and 300 m of piping), which he had purchased through off-farm work. They irrigate from the river and he produces tomatoes, cabbage, maize, onions and green peppers. They dry vegetables for year-round sale and sell fresh vegetables at the township on the Masvingo-Mutare highway. Over the last few years he has purchased seven cattle from the proceeds but wants to invest in drilling a borehole on his farm in the future, with the aim of becoming an independent commercial irrigator.

With a variety of socio-technical configurations involving more and less land, equipment and labour input, this group is developing the potential for more sustained commercial production and accumulation through irrigation. Often with insufficient land, capital and equipment, this group depends on social relations, involving, for example, hiring and sharing land, water and equipment, as they assemble new socio-technical arrangements for successful irrigation. Combining this with other livelihood activities, including dryland farming, keeping livestock and off-farm work is essential but all aspire to a more sustained form of commercial irrigation.

The commercial irrigators

A total of 13 cases were involved in larger-scale commercial production on irrigated plots ranging from 1.1 to 5 ha. They had invested in their operations either from incremental upgrading from a smaller operation, typical of the aspiring irrigators, or through a major injection of funds from outside sources, including parental support. The commercial irrigators' infrastructure is more fixed, with large engines and powerful pumps. However, unlike formal irrigation schemes, pipes can be used flexibly for different patches of land and the mix of crops can be expanded and shifted in line with market demand.

For example, EM upgraded his operations incrementally. Initially working on a plot next to the dam near his homestead, established in 2006, he started out irrigating with buckets. As a member of the John Marange Apostolic Church, he has many wives, and a very large family supplying labour. This allowed the family's enterprise to expand. They sold vegetables in nearby Masvingo and gradually accumulated enough funds to buy a pump. Their first 5.5 HP was bought in 2010, and allowed the expansion of the plot, but the neighbours accused EM of finishing the water, so he negotiated 0.3 ha of land on the councillor's plot, which was by the river. Later he gained access to some state land nearby, expanding his plot by 1.5 ha by 2012. He started by hiring irrigation pipes but later bought some and became a full-time irrigator with labour from his growing family. The veterinary department complained that he was using land near the dip, and another struggle with eviction commenced. Nevertheless, he continued and managed to secure contracts to sell with supermarkets and local buyers. He initially hired a neighbour's truck but later bought his own from sales proceeds.

The area by the river proved insecure, however, and in 2015 EM transferred his operation to his fields, having sunk two boreholes and installed two powerful pumps and two generators. The family is now able to irrigate five ha. The pumps allow a steady supply of water, and EM uses a complex network of pipes (300 m in all) to irrigate different patches of land. Given the fixed infrastructure, the system is less flexible than his former riverbank gardens, but he has scaled up production significantly and upgraded his equipment, reflecting a shift in focus in the style of his operation. He supplies dried cabbage and rape leaves to Zvishavane market, earning US$400 in 2017, while his income from fresh produce, all now linked to contracts with supermarkets in Masvingo, amounts to over US$30,000, covering expenses of around US$12,000 that include fertiliser, chemicals, fuel and transport. His family supplies labour, with up to 20 people working in the field at any one time.

The PV family have similar ambitions. However, they were able to move rapidly to commercial irrigation thanks to outside investment. They began irrigating in 2014 with funds from both PV's and his wife's jobs, alongside the sale of cattle. He is a provincial manager of a government agency and she is a research agronomist. They invested in drilling a borehole and fitting a submersible pump (US$15,000), buying storage tanks (20,000-litre capacity) and establishing a greenhouse (US$2700). PV also bought piping for drip irrigation (US$1500). He has three workers who were paid for 77 days in 2017. The family's income in 2017 was US$4700, with US$1200 in costs, including chemicals, fuel, transport and labour. Last season they grew maize, tomatoes and green beans. They are currently irrigating only 0.5 ha plus the greenhouse, which is 340 m^2. They are thinking of expanding the operation by hiring land elsewhere, probably in Chipinge where PV's wife works and the climate is ideal.

Irrigation on relatively small plots is also an option for young people who missed out on land allocations under the land reform. For example, AM is 25 years old and trained to be a physical education teacher. Unable to find a job, he decided to make use of his father's land. (His father is in the army and posted abroad.) AM sold two of his father's heifers and invested in fencing, pipes and pump equipment, costing US$1550. He began irrigating 1.1 ha in 2017 and made US$8700 from tomatoes and cabbages, incurring US$460 in expenses and US$450 to hire a truck to transport products to Masvingo, where he sells to traders in the town market. Labour was supplied by the family. He hopes to expand in time and get contracts with supermarkets. He also wants to purchase a truck from his profits. Overall, AM regards vegetable production as far better than looking for a teaching job, where the pay is very poor.

Socio-technical assemblages in farmer-led irrigation systems

Across these groups, the farmer-led irrigation systems we observed involved principles of socio-technical design that emphasised an adaptable, flexible approach. Rather than a single, large pump, vulnerable to breakdown, the availability of cheap, Chinese-made pumps, ranging from 5.5 to over 10 HP can be used flexibly. Where surface water is available, extraction is easy; in other cases, wells have been dug and submersible pumps installed. These can be combined with hand-irrigation using buckets; and if they break down, they can either be replaced or repaired (a secondary market in pump repair has been quick to develop in local towns and villages). Different sources of energy can be used, with petrol, diesel and solar electric pumps all being used, combined with the extraction and distribution of water by hand. Of all cases, 67% make use of pipes, with an average of 243 m of piping. Combinations and connections allow irrigation that can be responsive to soil and crops in ways that standard canal irrigation cannot. In three cases drip irrigation is being used, focused on particular crops, and linked in one case to an investment in poly-tunnels and greenhouses.

The new, cheap, flexible technologies available to farmers today – only in the last 5-10 years at prices making such options genuinely affordable for the majority – have transformed opportunities. In many ways the new socio-technology of water control extends the principles that characterised Zimbabwe's famous Model B bush pump. As de Laet and Mol (2000: 226) described nearly 20 years ago, "in travelling to 'unpredictable' places, an object that isn't too rigorously bounded, that doesn't impose itself but tries to serve, that is adaptable, flexible and responsive – in short, a fluid object – may well prove to be stronger than one which is firm". It is this fluidity and flexibility, adapting to diverse circumstances and uncertainties, that farmer-led irrigation relies on. Notwithstanding its standard design the bush pump was reliable, repairable and able to function under harsh conditions.

As with the bush pump, farmer-led irrigation must be understood not just in relation to water delivery and efficiency but according to a host of other criteria. These may include the identity of the user, with, as we saw in the cases above, women and youth being able to use the technologies for their own projects. Another criterion might be the ability of the socio-technical system to persist, even in the face of challenges, through repair and improvised shifts in use, creating a robust and adaptable system of use.

These are socio-technical systems, where the technological objects (pumps, pipes, wells, buckets and so on) are intertwined with market networks and the social and political lives of people, from the remote Chinese pump manufacturer to the village repairer to the farmers, who shift the boundaries, reconfigure the elements of the network and make incremental shifts in relations as things change. Unlike in ordered, formal irrigation schemes, there is no "privileged structure of relations" (Law, 2002: 99) but instead a low-cost, fluid, parsimonious system that is adaptable and resilient. As with the bush pump, farmer-led systems create a wide, encompassing sociotechnical network from the farm to the village to the market to the nation (de Laet and Mol, 2000). This contrasts with formal systems that are more bounded by fixed technical infrastructure and more structured socio-technical networks.

In today's globalised world the new technological resources used by farmers in Masvingo rely less on locally produced technologies than, for example, the Zimbabwe bush pump does and more on China's cheap manufacturing capacities. However, their similarities sustain the principles of fluid, adaptable resilience. Improvisation is at the core, with the elements of pumps and pipes combined in ingenious ways. It is not a system of designed and directed control but one in which individual initiative and innovation are essential.

A shift towards such a flexible socio-technical assemblage, in the context of a more capitalised, market-driven, labour-employing form of 'petty commodity production', as seen among the commercial irrigators and aspired to by others, generates other pressures, however. A key part of the assemblage is, of course, land and water, and gaining access to such resources is not easy, as the case studies have shown, especially for late-comers. Access to land, particularly that near sources of water, is governed by the local leadership, including village heads, local councillors and ruling party officials. Gaining access to land and water is possible through rental and sharing arrangements, but these are also negotiated through social and political networks, requiring kinship, church membership and political connections.

As more and more people in the area want to irrigate, pressure on water resources intensifies. Whether this is surface water from dams, rivers and streams or groundwater extracted through wells and boreholes there are limits to overall use. While the Water Act is supposed to regulate access through a permit system, its application is fragmentary in the resettlement areas due to the lack of enforcement capacity (Mapedza et al., 2016; Manzungu and Derman, 2016). Multiple, individualised private operations are less easy to regulate than government-run schemes, and systems of co-management of common property resources have yet to emerge. As we discuss in the conclusion, this highlights the potential for longer-term problems as water use increases in dryland areas.

IRRIGATION OPPORTUNITIES AND AGRARIAN CHANGE

Our case studies have shown how different types of farmer-led irrigation offer different opportunities for accumulation. Commercial irrigators derive significant income from irrigation and are investing in intensification and expansion, while aspiring irrigators aim to follow suit. Homestead irrigators are, however, constrained by a lack of income and assets, although, as we have seen over the past decade, this may not be permanent. In the period following land reform, therefore, a process of social differentiation is occurring, linked to class formation and both age and gender differences. Differential irrigation opportunities, then, have major implications for agrarian change following land reform.

The three socio-technical assemblages identified above are associated with class, gender and generational dynamics, with commercialising irrigators becoming established petty commodity producers, hiring in labour and accumulating from below, and the irrigation business activities dominated by older men. At the other extreme, the homestead irrigators are largely women, who are unable to accumulate given the limited extent of the production. Very often selling labour to others – including to the commercial irrigators – they are more classic peasant producers and also part of an expanding rural proletariat. The aspiring irrigators are intermediate, with class characteristics of each of the other groups, yet with a more diversified livelihood strategy involving both off-farm work (and remittance income) and farm production. They can be identified as 'worker-peasants' with many, especially younger, households aspiring to be petty commodity producers but so far with limited accumulation achieved.

Farmer-led irrigation is thus generating a new pattern of social difference in these areas, with class formation emerging from irrigation opportunities in ways that are linked to both gender and generation. How does this pattern compare with more formal systems in terms of the socio-technical characteristics and the implications for social differentiation, accumulation opportunity and agrarian change more broadly?

As noted earlier, within our study area there is one rehabilitated formal irrigation scheme and one group garden. The former is located in the Wares site, covering 12 ha and making use of some of the previous farm's infrastructure. The land was cleared between 2006 and 2008 and irrigation began in

2009 with support from the government's 'Maguta' programme that bought a pump and an engine. The scheme is divided into three blocks and the 85 members who initially signed up had to contribute 200 m of wire for fencing. The pump broke after only two seasons but was repaired for the 2014 season. Maize, wheat and beans were the main crops and were grown in rotation. Each member has 0.1-0.15 ha of land to irrigate. Groups irrigate at fixed times each week if there is electricity, and everyone contributes US$1/month for electricity and US$1/year for the land. Currently, the engine is not functioning and the number of irrigators has dropped significantly. The scheme relies on a single pump, a river water source that is unreliable due to siltation and an expensive but intermittent energy supply. The infrastructure is also in poor condition with collapsed canals and inadequate fencing. Irrigation is overseen by a strict regime, led by the local extension worker, so flexibility in the choice of crops and rotations is impossible.

The group garden was a local initiative facilitated by the extension worker. The group purchased a surface water pump to extract water from a nearby dam. The garden was established in 2005 with 30 members – 25 women and five men, each of whom was allocated eight 15 m x 2 m beds. Again, the garden is managed under strict rules, including the requirement that members enter only at stipulated times and irrigate on a rotational basis managed by the committee. Group cohesion has been the challenge, as people do not have the same motivation or vision. The original chair commented that she had abandoned the group and was now irrigating by herself, growing vegetables year-round on her individually held plot.

In both cases the extent of irrigation is way below potential. The formal scheme had produced effectively nothing in the last couple of years, while those producing on plots in both the scheme and garden suffered from intermittent water supplies. With everyone allocated similar-sized plots there is limited differentiation among irrigators. While some further from the pumped water supply suffer greater shortages no one is able to invest or expand due to the constraints of the schemes. These are welfare initiatives aimed at complementing other livelihood activities rather than driving entrepreneurial expansion. The possibility of accumulation through irrigation in both cases is therefore severely limited both by the limited land area allocated and the inflexibility of the system, compounded by the unreliability of water supplies due to reliance on a single, fixed pump and an electricity supply in the case of the scheme.

We undertook interviews and held group discussions with irrigators in the scheme and the group garden.[8] People repeatedly highlighted problems with the intermittent water supply and the loss of crops due to sudden stoppages when the electricity supply was cut. Some complained that the cooperative arrangements had broken down and those at the end of canals lost out. Free-riding was common, irrigators complained, and when fees were not paid there were no longer any state resources to support the scheme – to mend the pump, repair the fence, provide the seed, support the marketing and so on – as had been the case before. Some had developed alternative water provisioning systems, including their own pumps or hand irrigation when the main pump did not work, but the authorities frowned on such improvisation. Unlike in the past the level of extension support was limited. Some took advantage of this and planted the crops they wanted while others complained that the lack of guidance resulted in major market gluts and the potential for disease and pests.

In terms of their socio-technical configurations both are clearly bounded systems, constructed as a 'scheme', with standardised rules guiding operations, overseen by the state through an extension worker. They have a set of design characteristics – a boundary fence, levelled plots, a grid of canals and a large pump – that define the scheme. A set number of plots are offered to a limited number of

[8] Seven individual key informant interviews were undertaken, including three women. Focus group discussions were held at Wondedzo irrigation scheme (attendance 7, 3 women); extension group meeting (attendance 17, 4 women) and Mtirikwi Horticultural Association (attendance 18, 6 women).

scheme 'members' and, in the past, there were attempts at crop scheduling and restrictions on what could be grown when and where. Membership involves submission to these technical requirements and compliance with the collective rules, including the payment of fees, attendance at meetings and the management of water in line with regulations.

As in the past the formal irrigation scheme presents a particular political image of control and order wrapped in a modernising project of state control (cf. Scott, 1998; Molle et al., 2009). As part of irrigator 'groups', the schemes create subservient citizens who are reliant on a centralised hydrological vision that focuses mainly on offering welfare support on small plots rather than entrepreneurial opportunities for expanding commercialisation. Compared to formal schemes, farmer-led irrigation systems are more unruly and linked to private, market-based initiatives, where some irrigators can connect with a wider network on their own terms. This suggests a different social and political vision that is not only bound to an individualist, market-oriented neoliberal order, as some would argue, but in which local agency dominates and informal relations are created across social networks, from farmers to suppliers to repairers to traders, generating a more autonomous, less directed hydraulic politics.

In sum, different socio-technical assemblages generate their own patterns of social differentiation and thus potential for accumulation. The consequences for agrarian change are in turn divergent. Each requires a specific type of support as part of 'irrigation development', as we discuss in the conclusion.

Conclusion

In our study areas we identified three different types of farmer-led irrigation, each based on complex systems of water control. Farmer-led irrigation covers around 3.5 times more area than formal irrigation in the study sites. Farmer-led irrigation systems potentially offer opportunities for some to commercialise production through irrigation, generating surpluses, raising income, employing labour, investing and accumulating. Compared to formal irrigation schemes, which suffer multiple challenges, such systems, we found, have real potential in terms of the regeneration of agriculture following land reform.

Our data show farmer-led irrigation to be highly significant in our study areas. If these patterns are repeated elsewhere, it would represent a significant contribution to the agricultural economy of Zimbabwe. Yet, farmer-led systems remain poorly understood and are often not recognised in policy, as is common elsewhere in Africa where there has been a consistent under-estimation of informal irrigation systems (IWMI, 2016; Beekman et al., 2014). A recent study, for example, estimated that informal irrigation accounted for only 9.7% of Zimbabwe's total irrigated area (Manzungu et al., 2018: 37). Our data suggests that this may be a significant underestimate.

In Zimbabwe's new political environment there are frequent commitments to increase formal irrigation schemes many-fold through strategic state and donor investment. But is this the right approach? Formal smallholder irrigation schemes have suffered significant problems over the decades (Pittock et al., 2017; Moyo et al., 2017; Nhundu et al., 2015, among many others). A failure to cover recurrent costs, a reliance on costly technologies and a lack of effective governance arrangements have plagued them. In recent years, as the cases discussed here show, such schemes have further declined, with the infrastructure dilapidated and the irrigation only intermittently functioning.

By contrast, farmer-led irrigation is linked into responsive, flexible production and marketing systems and is reliant on often mobile, repairable technologies. The processes that establish these systems are diverse and not confined by restrictive plans or designs. While formal systems depend on state support and direction, farmer-led systems connect to a wide network of actors, including other farmers, traders, market buyers and pump suppliers and repairers. State agents are involved – not solely the agricultural extension worker but also others connected to land allocation, water management and credit supply, for example. The ability to respond to shocks and stresses – whether shifts in price, market demand or the availability of water or electricity – is a key feature of system sustainability, and the farmer-led systems show clear advantages.

Nationally there are around 600,000 ha of potentially irrigable land or 365,000 ha from internal renewable water resources (FAOSTAT, 2018). By the early 2000s only 120,000 ha were irrigated under formal schemes due to droughts and decaying infrastructure, down from a peak of 200,000 ha (Nhundu et al., 2015). A key policy choice is whether to continue to focus on this formal irrigation infrastructure, attempting to rehabilitate or expand it, or whether to emphasise farmer-led alternatives, which, as we have seen in Masvingo, can expand the irrigated area rapidly through private initiatives and make use of land not normally regarded as irrigable through improvised socio-technical practices.

More modest and less visible but with larger overall impact, farmer-led irrigation can be facilitated through small-scale finance systems, technological experimentation and development, expanding and conserving water bodies and investing in local governance capacity to manage common water resources. As discussed, such systems are complex, co-evolved, socio-technical assemblages adapted to local circumstances. They cannot be subject to simple technology transfer programmes; nor can they be replicated or scaled up in instrumental ways. Instead, the basic principles of farmer-led approaches must be appreciated. These include low cost, individual control, technological flexibility and modularity in design, flexible and adaptable systems for diverse cropping arrangements and socially appropriate configurations that allow diverse groups of people to participate in both production and connections to markets.

However, alternative pathways of socio-technical change imply political choices about directions of development. Farmer-led systems clearly have many advantages, but the benefits of commercialised irrigation are only available to relatively few, especially as environmental constraints limit expansion. Those without access to land, water, technology, labour or markets, for example, will not be able to accumulate through irrigation and must seek out alternative livelihood options. This process of differential accumulation has important implications, we argue, for the future dynamics of agrarian change in these areas, with some becoming 'petty commodity producers' or part of an emerging 'rural petit bourgeoisie', employing labour, purchasing and upgrading technologies and expanding irrigation areas through nascent, informal land markets, while others are unable to benefit from irrigation in this way.

This has implications for class formation, gender inclusion and generational dynamics, and thus who benefits from irrigation and who does not. The process of change, set in train by the various socio-technical assemblages of farmer-led irrigation observed in our study areas and in similar areas throughout Zimbabwe contrasts with the more regulated and controlled formal irrigation system, where the accumulation opportunities are less available, yet basic social welfare provision is offered more equitably to a greater number.

In order to irrigate post-land reform Zimbabwe, government, donor agencies and NGOs, and the engineers and water experts who advise them, may have to abandon past policy preferences and unlearn embedded professional practices. Rather than equating irrigation only with a scheme or group garden, going to the field can expose the diversity of farmer-led systems and hence a wider variety of irrigation options. Learning from farmers about their achievements and failures, being attentive to locally co-constructed socio-technical assemblages and exploring options for extending existing systems of farmer-led irrigation and water control may be a significant, but currently under-recognised, complement to engineer-designed formal schemes.

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