www.water-alternatives.org Volume 14 | Issue 3

Chitata, T.; Kemerink-Seyoum, J.S. and Cleaver, F. 2021.
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Rufaro Irrigation Scheme, Zimbabwe.
Water Alternatives 14(3): 690-716

Engaging and Learning with Water Infrastructure: Rufaro Irrigation Scheme, Zimbabwe

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ABSTRACT: In this paper, we focus on changes made in the form and materiality of water infrastructure in a smallholder irrigation scheme in Zimbabwe. We use this focus on sociotechnical tinkering as a practical entry point to exploring how these changes matter in shaping knowledges and relationships in irrigated agriculture. Drawing on data collected through ethnographic methods, we show how history and politics matter in shaping the possibilities of rearranging infrastructure. Equally important are the knowledge-laden, embodied and discursive practices of the farmers, operators and engineers who engage with infrastructure. We argue that through the knowledges, creativity and agency of people interacting with irrigation infrastructure, water as well as power are (re)defined and (re)distributed in subtle and often unexpected, yet significant, ways.

KEYWORDS: Groundwater, irrigation infrastructure, smallholder farming, knowledge, Zimbabwe

INTRODUCTION

This research builds on a growing body of literature on the emergent nature of infrastructure (see, for example, Furlong, 2010; Anand, 2011; Meehan, 2014; Jensen and Morita, 2015). These studies highlight the messy and incremental development of infrastructure by paying detailed empirical attention to its constantly changing form – that is to say its characteristics of shape, structure and dimension – as well as to changes in its materiality and functioning. Central to this scholarship is the observation that infrastructure escapes control at least partly because of the notoriously capricious behaviour of water, as well as changes in the materials or elements with which water interacts, including pipes, cement, bolts, soil, plant roots and fertilisers. This approach differs fundamentally from some of the more mainstream bodies of literature, which tend to assume that infrastructure is an inert product of a meticulously calculated design process that is undertaken by impartial engineers (Ashcraft and Mayer, 2016; Lamri et al., 2020; Wang et al., 2020). Other strands of the mainstream literature assume that infrastructure is largely an outcome of politics in that its existence, form and functioning are substantially shaped by power laden social relations (Bijker, 2007; Bakker, 2012; Larkin, 2013; Shaw and Meehan, 2013; Obertreis et al., 2016).

We recognise that original designs and political influence do matter. We also argue, however, that water infrastructure undergoes constant change in particular times and spaces and that it is shaped by the knowledges and actions of those constructing, operating, using and maintaining it. The particular ways in which different people relate to infrastructure are made possible or foreclosed by its historical and contemporary material properties as well as social relations of power (see, for example, Anand, 2011; Kemerink-Seyoum et al., 2019; Sanchez et al., 2019). Building further on this dynamic view of water infrastructure, our main argument is that through the situated knowledges and everyday improvisations of people directly interacting with the infrastructure, water and power are often (re)defined and (re)distributed in subtle and often unexpected, yet sometimes crucial, ways.

We support this argument by presenting empirical evidence that shows three interrelated processes. First, our data shows how the (changing) form and materiality of infrastructure shapes the way people know water and determines how they can interact with it. Moreover, the form and materiality of infrastructure offers the possibility of both connection to, and disconnection from, water and provides actors with moral rationales to justify their actions. Second, different people exercise agency and creativity in reshaping infrastructure through everyday practices. These practices are often based on pragmatic decisions or ad hoc improvisations and are shaped by the availability of materials for recrafting the flows of water and the possession of knowledge as to how to do this. Third, these constant changes in the form and materiality of infrastructure alter the relationships among people and between people and water and, in the process subtly reshape social relations of power. Understanding these interrelated processes requires us to move beyond structural understandings of social difference by questioning the dichotomies of dominance – resistance, elite – marginalised, expertise – lay knowledge, and modern – traditional (Bossenbroek et al., 2015; Cleaver and Whaley, 2018; Zwarteveen et al., 2021). In this paper, we thus aim to bring nuance to more structural analyses and to show how distributions of water and power arise, at least partly, from the contingent coming together of different people, knowledges, water(s) and infrastructure (see also Kemerink-Seyoum et al., 2019; Boelens et al., 2016; Dajani and Mason, 2018; Naouri et al., 2020).

We mobilise the concept of sociotechnical tinkering[1] as a methodological entry point to observe the ways in which farmers exercise agency in abstracting, distributing, storing and using water (Kemerink-Seyoum et al., 2019). We understand sociotechnical tinkering to be acts that produce deviations from the initial plans and designs of water infrastructure in terms of the form, materiality and functioning of the infrastructure (see also Sanchez et al., 2019). Acts of tinkering can vary in magnitude and nature; they may take place as part of large-scale, planned rehabilitation projects or as small improvisations made by individual actors to overcome ad hoc issues or to serve particular interests. In this paper, we use sociotechnical tinkering not as an explanatory concept, but as a methodological device for identifying and studying changes in water infrastructure. This ethnographic focus on acts of tinkering enables and provides visible evidence of learning that is the result of interactions between (among others) people, water(s), infrastructure(s), crops and soils. Taking acts of sociotechnical tinkering as empirical entry points can therefore illuminate the subtle ways in which water and power are (re)defined and (re)distributed in attempts to access, share and/or protect water sources.

We posit that the current configuration of the Rufaro Irrigation Scheme (Figure 1) is an outcome of numerous changes in, and tinkering with, infrastructure as a result of the coming together of water, soils, crops, pipes, pumps and people. Following this first introductory section, we proceed to discuss the data collection tools used for this research. Acts of infrastructural tinkering are partly shaped by policy choices in different political eras, including state-building in the early years of independence (1980-1990), as well

[1] 'Bricolage' is closely related to tinkering yet differs slightly. Bricolage is used more for analysing the meanings given to the emergence, endurance and hybridity of institutions (see Cleaver, 2002) or technologies (see Kuper et al., 2017); tinkering, on the other hand, can go beyond simply piecing together existing tangible or intangible resources. 'Sociotechnical tinkering' refers to a more explicit analysis of how more-than-human entities shape everyday engagements with infrastructure. In this paper, the concept of sociotechnical tinkering helps us study how the form, materiality and functioning of infrastructure is the result of the (partly contingent) coming together of different entities. (For a more detailed discussion on sociotechnical tinkering, see Kemerink-Seyoum et al., 2019).

as irrigation policy trajectories and the reforms in land tenure and the water sector that followed in the 1990s. We therefore provide a brief characterisation of smallholder irrigation and analyse the historical accounts of the Rufaro Irrigation Scheme as contextualised in cooperative farming in the immediate post-independence era. In the process, we show how these historical moments have left traces on the current form and materiality of the irrigation infrastructure and have shaped who could tinker with it. This is followed by a detailed analysis of more recent acts of tinkering, those that occurred between 2015 and 2020. From there, we go on to reflect on how actors learn through tinkering with the infrastructure and how this has led to specific embodied ways of knowing (ground)water. We particularly show how changes in the type of pumps that provide groundwater to the irrigation scheme have produced gendered knowledge on the state of the aquifer. We also provide empirical evidence on how changes in the form and materiality of this infrastructure have altered relations among irrigators, and we detail how (changes in) infrastructural arrangements provide rationales that farmers use to justify their irrigation practices. In the final section, we return to our main argument, that a focus on the everyday practices of actors tinkering with water infrastructure can shed light on how water and power are (re)defined and (re)distributed in subtle ways.

METHODOLOGY

To empirically anchor our argument, we have documented acts of tinkering by engineers, operators and smallholder farmers involved in the groundwater-based Rufaro Irrigation Scheme in southeast Zimbabwe (Figure 1). These acts are situated in their specific context through a detailed study of the historical development of the scheme and its contemporary functioning. Data was compiled through the analysis of design maps, project documents, aerial photographs, satellite images and direct observations and measurements of the current infrastructure. This combined data was used to identify moments and places of change in the form and materiality of the infrastructural network; this formed an entry point to further data collection through in-depth semi-structured interviews. Twenty-six farmers of the irrigation scheme were interviewed for this research (Table 1). They were selected based on a stratified random sampling technique in order to ensure representation of different gender and age groups and to include farmers with landholdings at various distances from the irrigation water source – in this case the water storage tank.

Table 1. Location and gender of interviewed farmers in the irrigation scheme.

Interviewees	Male	Female	Total
Upstream	5	4	9
Downstream	5	4	9
Middle section	4	4	8
Total	14	12	26

The narratives of the interviews with the farmers were coded (F1 to F26) and these codes are used in the paper to identify the farmers interviewed. The interview data was triangulated with participant observations. Observations were made during the operation and maintenance of the infrastructure, during the preparing and irrigation of the fields, and during interactions among farmers during irrigation-related events and meetings. To further detail the data and cross-check preliminary findings, three focus group discussions were organised with farmers; several participatory mapping activities were also conducted in order to track changes in the infrastructure.

We interviewed seven government-employed engineers (coded GE1 to GE7) who had been involved in the design, construction and maintenance of the scheme. We also interviewed three engineers (coded CE1 to CE3) who were involved in 2015 as consultants in designing the rehabilitation of the Rufaro

Irrigation Scheme. All are men, as none of the engineers working on this irrigation system were women. Additionally, two government-employed officers (males) from the Ministry of Women Affairs, Community, Small and Medium Enterprises Development (coded GO1 and GO2) were interviewed. This is the ministry under which cooperatives are administered. The engineers and other interviewees were selected using convenient sampling that was based on easy accessibility and availability. All interviews were carried out between June 2019 and April 2020 and were analysed using a thematic analysis method[2] (Sundler et al., 2019).

CHARACTERISING SMALLHOLDER IRRIGATION IN ZIMBABWE

Farmers in Zimbabwe were already practising dryland and irrigated farming in precolonial times, using hand-dug furrows to divert water from the rivers for irrigation (Bolding et al., 1996, 2004; Kemerink-Seyoum et al., 2017). A number of families often shared irrigation furrows and canals as well as the hard work required to maintain them. The colonial invasion in the 1890s coincided with severe food shortages caused by drought and animal diseases; further, in order to create dependency and ensure the acceptance of their rule, the European settlers also destroyed most of the grain the people had stored (Chigodora, 1997). In response to these famines, missionaries started to actively support collectives of indigenous farmers in expanding irrigated agriculture (Rukuni, 1988). During the colonial occupation by Britain (1890-1965), and subsequent unilateral Rhodesian rule which lasted until independence in 1980, smallholder irrigation increased considerably. The British and Rhodesian government used the establishment of 'native' irrigation schemes as an active strategy to free up fertile land for settler farmers, as well as to support the colonial economy on income from agricultural-based exports (Mlambo and Pangeti, 1996; Bolding et al., 2004). In order to implement the Land Apportionment Act of 1930 (amended in 1950), for instance, Zimbabwean farmers were dispossessed of their land and relegated to the poor soils of what were referred to as Tribal Trust Lands (TTLs). This colonial resettlement programme led to the establishment of dryland producer cooperatives and smallholder irrigation schemes on lands not well suited for agriculture (Akwabi-Ameyaw, 1990). At the same time, the colonial government invested heavily in supporting European settler farmers to acquire large pieces of fertile land, secure water rights, and receive subsidies for the construction of infrastructure to irrigate their farms (Scoones et al., 2019; Manamere, 2020).

The post-independence government of Zimbabwe aimed to redress the colonial legacy by buying settler farms and redistributing the land, its associated water sources and the infrastructure to the indigenous population of Zimbabwe. In its policies, the Zimbabwean government defined several different modalities of resettlement (see Kinsey, 1982; Jacobs, 1983). In so-called Model A resettlements (which were most common) farmers received about 6 hectares (ha) of land for individual crop production and a commonly shared grazing area. In Model B resettlements, farming cooperatives were established in which the members jointly owned land and infrastructure that often had been taken over from a settler farmer; cooperative members were expected to jointly organise labour and other farming inputs for the benefit of the collective enterprise. The Rufaro Irrigation Scheme on which this paper is based was initiated as a Model B resettlement arrangement. The history of this particular modality of farming will be narrated in more depth below. Model C resettlements referred to 'out growers', or smallholder farmers who were settled around a core estate and who were partly making use of its infrastructure; the estates were often still owned by a settler farmer or foreign agribusiness. Model D resettlements, lastly, referred to resettlements to areas with low crop potential where farmers engaged in livestock production.

[2] This is a method of analysing qualitative data in which recurring themes, topics, ideas, experiences and patterns of meaning are identified in the data set.

From a technical perspective, many of the smallholder irrigation schemes in Zimbabwe are built on centralised, single-unit infrastructure (Bjornlund, 2009) and operate as block schemes. Nowadays, individual plot sizes in most smallholder irrigation schemes range from 0.1 to 1 ha (Scoones et al., 2019). Most irrigation schemes fall under the responsibility of the Department of Irrigation Development, which is supposed to provide technical support and maintain infrastructure. Support, however, is often sporadic once construction of the irrigation scheme has been completed, and farmers are thus often dependent on foreign aid assistance. Among other reasons, the Department of Irrigation Development is not able to carry out its mandate – particularly with regard to maintenance and repair – because it has for a long time been under-resourced. Agricultural, Technical and Extension Services (AGRITEX), a government Department, gives agronomic advice to (irrigating) farmers on what crops to grow and how to grow them (Bolding et al., 1996; Shah et al., 2002), as well as helping them manage and control crop diseases. Zimbabwe has, however, seen an increase in what is referred to in the literature as 'farmer-led irrigation', that is to say irrigation practices that are not sanctioned by the government. This term is generally used to typify smallholder irrigation that consists of (individual) irrigation schemes and gardens which are 'financially independent' of the state and which do not in most cases have formal water rights (Scoones et al., 2019; Duker et al., 2020; Asare-Nuamah et al., 2021). Even state-supported 'formal' irrigation schemes, however, can be considered to be farmer-led due to the absence of state-provided services and, conversely, in some cases so-called farmer-led irrigation schemes are in fact connected to the state, as officials from the Department of Irrigation Development provide input as private consultants. In practice, these categories of state-led or farmer-led irrigation are thus not strictly bounded; rather they are temporally fluid and depend on contextual logics, policies and scientific buzzwords.

The birth of cooperative farming in Zimbabwe

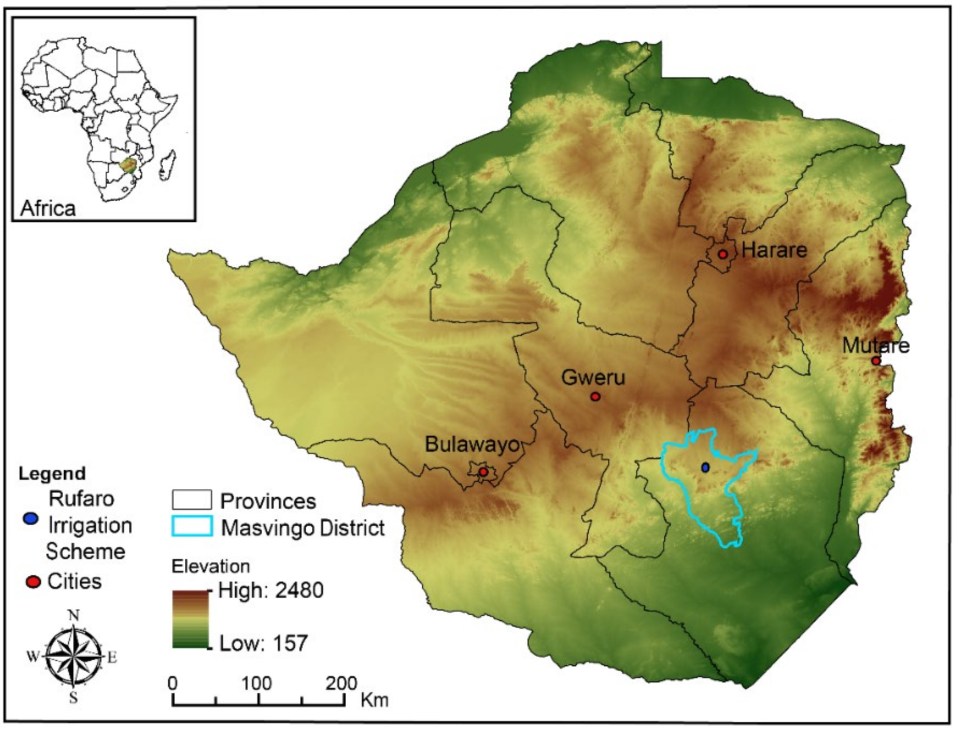
As mentioned above, the Rufaro Irrigation Scheme was modelled around collective cooperatives, which are referred to in Zimbabwean postcolonial agrarian policies as Model B resettlements (Jacobs, 1983). The Model B farming arrangements were partly inspired by pre-colonial practices of collective farming, as well as by the socialist ideology that the Zimbabwean government pursued in the early years of independence (see also Weiner, 1991; Sithole, 1993; Meisenhelder, 1994; Mukasa, 2003). In Model B, the members of the cooperative – which usually numbered between 50 and 200 – would collectively own 1000 to 5000 hectares of land; the landholding could be larger, depending on the size of the acquired farm (Weiner et al., 1985). Only men above 18 years were eligible for membership and each was able to own one share in the cooperative. Members of a farming cooperative were considered to be its formal employees and were not supposed to be employed elsewhere. The preference for men-only membership was closely tied to patriarchal ideas of men as owners of land (and other assets) and as income generators. Only in exceptional cases, such as if they were widowed, could women be nominated as members of the cooperative. In practice, however, women and children contributed significantly to the work of the cooperative, including helping with laborious tasks such as clearing and preparing the land, weeding, and harvesting; they were not recognised for their work, however, and were not allowed to operate farm machinery belonging to the cooperative or take part in the operation, repair and maintenance of infrastructure. A cooperative member’s share in the cooperative gave the members the right to a small portion of the crops for their own consumption, with the greater portion of the crops being sold; they also were entitled to a share in any profits the cooperative might make from the sale of crops. It was under this model of the resettlement programme that the Rufaro Collective Farming Cooperative was established and registered in 1983 (Figure 2).

The cooperative model of resettlement had implications for the form and materiality of the infrastructure as well as for the acts of sociotechnical tinkering that were possible. In most cases, groups of farmers (cooperatives) inherited infrastructure that had been initially designed for individual operation and use by settler farmers during colonial times. This individual-use irrigation infrastructure often was centrally controlled and, thus, triggered the need for collective or negotiated tinkering, with irrigators having to decide amongst themselves as to what to change. This resulted in collective learning about water as mediated by infrastructure; women, however, being excluded from membership, were unable to participate in operating, using or learning from the infrastructure. This differentiated access determined who could tinker with the irrigation infrastructure and thus gendered the knowledge of water.

Among the men, tinkering and learning opportunities were also not homogeneous. In recruiting people to join the cooperatives, the government appointed veterans of the liberation struggle who had played a key role during the war against the colonial occupation. This was done for pragmatic and political reasons. Pragmatically, these veterans had experience with mobilising large groups of people, an ability which was considered transferable to collective agriculture; politically, it was considered expedient to compensate them for their efforts during the war. These veterans were supposed to recruit people without discriminating against farmers who originated from other Tribal Trust Lands; in practice, however, veterans used their role as recruiters to favour those closest to them. Mister Fonyo,[3] the war veteran appointed to recruit people to the Rufaro Irrigation Scheme, explained that,

> [m]ost of these farmers are my relatives and friends; I wanted them to have a share of the fruits of independence. In fact, when we went to war, it was to liberate our parents and relatives form suffering, so essentially, we were fighting for our parents and relatives first and in the process fighting for the country. I was convinced they should be the first to benefit from the fruits of independence to the extent that I forced some of my relatives to join against their will (F16).

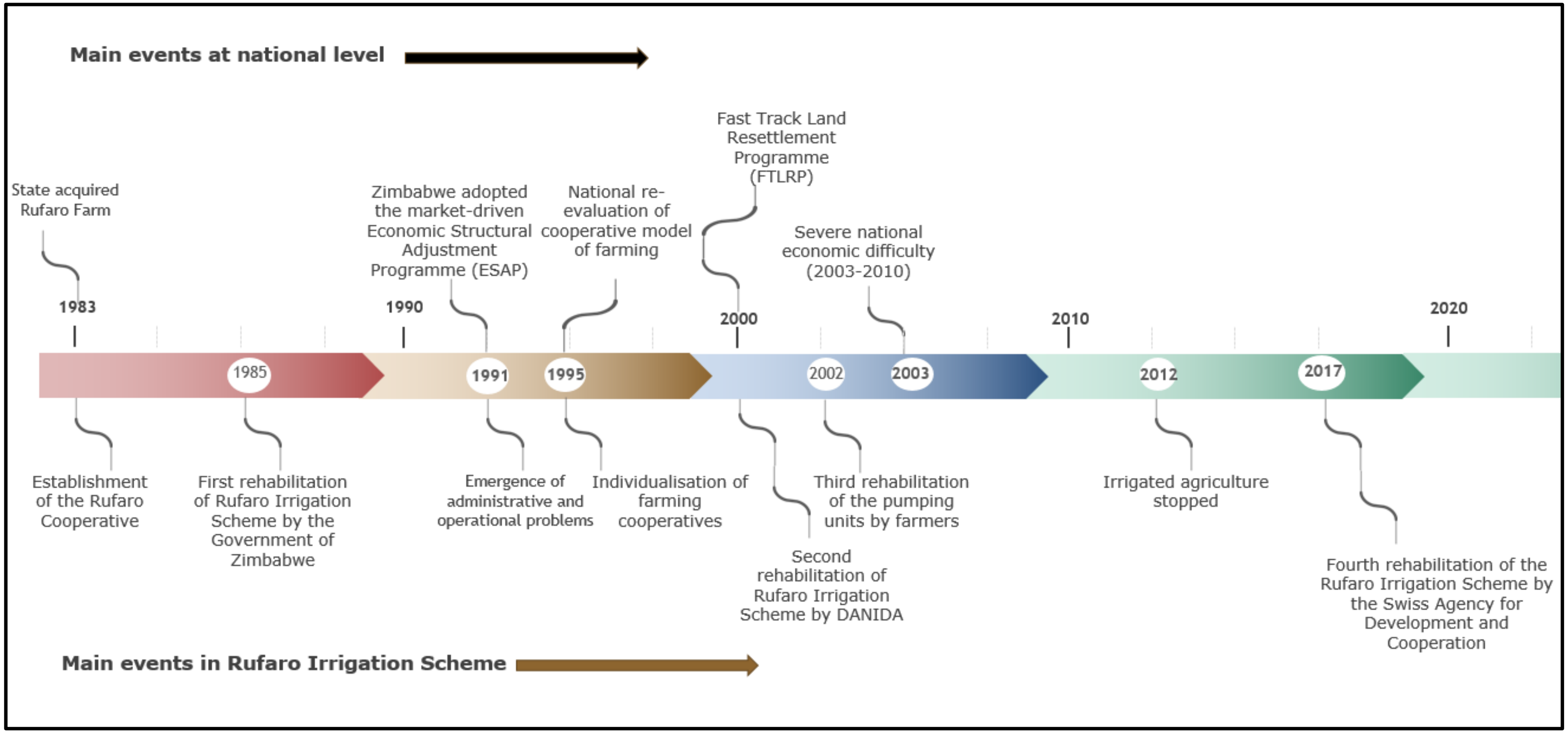
Figure 1. Location of Rufaro Irrigation Scheme.



Source: Tavengwa Chitata (2020).

[3] This is an alias for the man who was responsible for mobilising people for cooperative farming.

Figure 2. Timeline of important historical events at the national level and how they relate to changes in the Rufaro Irrigation Scheme.



Source: Tavengwa Chitata (2021) Infrastructure for collective farming.

The farmers who were recruited from the Gutu, Ndanga and Bikita Tribal Trust Lands to join the Rufaro Irrigation Scheme had no experience with irrigated agriculture or commercial farming, mainly having relied on subsistence rainfed farming. For them, engaging with the everyday agricultural activities of the cooperative farm was a process of learning about infrastructure and, with the infrastructure, learning about groundwater. In addition to farmers being recruited by Mister Fonyo, several members were selected through an application process that was based on their technical skills and qualifications. It was envisaged that these members would add value to the activities of the cooperative by providing their technical services (as, for example, mechanics, electrical technicians and financial administrators). Some of these members became more involved in the operation and maintenance of the irrigation infrastructure; they therefore had more opportunities to experiment and tinker with it and, in the process, to learn more about the behaviour of the infrastructure, the water flows and the aquifer.

When the government purchased the farm for the Rufaro cooperative, it was equipped with a farmhouse, one mill room, one storeroom, one equipped workshop, one dip tank, animal handling facilities, and nine high-yielding boreholes. Of the nine boreholes, seven were connected to electricity, of which one was used for watering cattle; an eighth borehole had a diesel engine attached and a ninth was equipped with a handpump and was dedicated to domestic use. The eight boreholes for irrigation and the other required irrigation equipment were all functional and in good condition. The infrastructure included an earthen night storage dam into which the water from the boreholes was pumped and used to irrigate 40 of the 80 hectares of land available for cultivation. To irrigate the crops, the pumped-up groundwater was conveyed from the dam to the fields by unlined earthen canals. For three years, during the period of recruitment and training of cooperative members (1983-1985), the government leased the farm to an individual farmer who was not part of the cooperative. The lessee used the irrigation equipment for a few seasons; he thereafter started rainfed agriculture because the irrigation infrastructure and equipment had deteriorated due to poor maintenance. According to one of our informants who was also a government official, the lack of investment was most likely caused by the short-term nature of the lease, which deterred long-term investments (GO6).

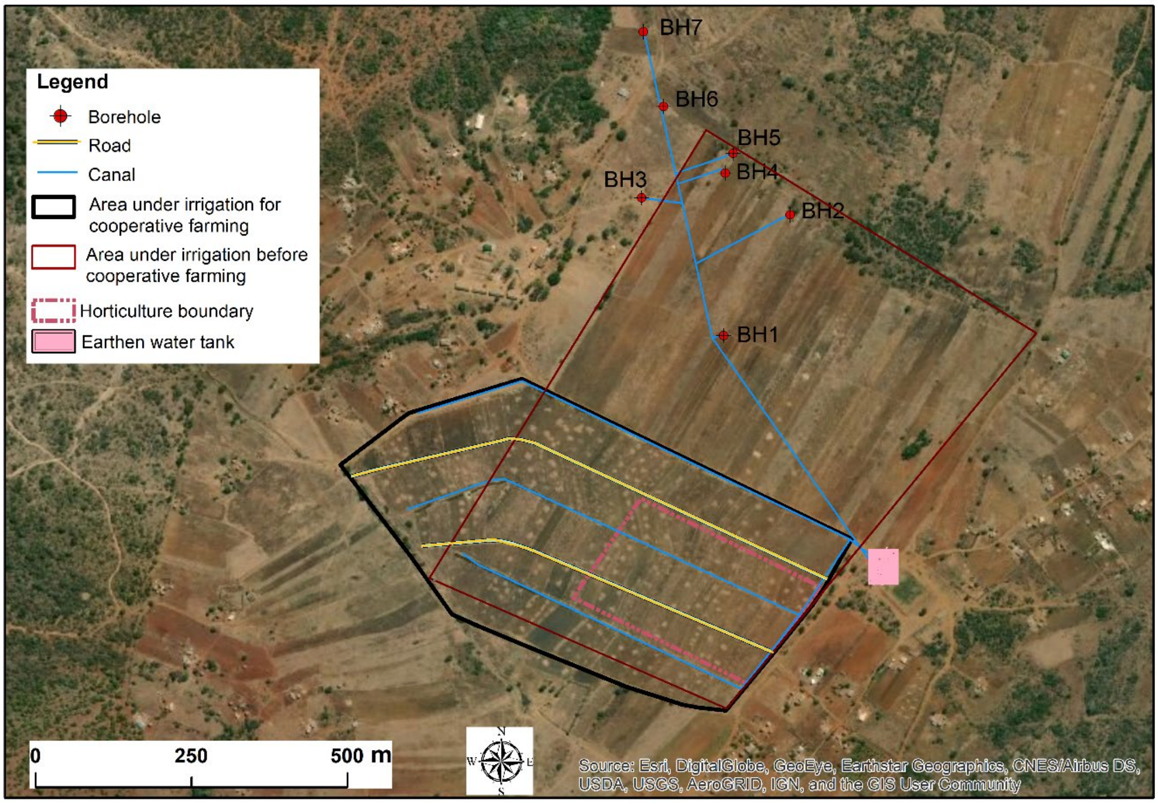
Between 1985 when the lease ended, and 1988, the government rehabilitated the irrigation scheme, repairing the deteriorated infrastructure. The government-employed engineers were constrained in their tinkering options by the infrastructure that they had inherited and by the model of cooperative management that had been chosen. Given that the initial form and functioning of the infrastructure was designed to be operated by an individual farmer, and given that the cooperative was expected to function as a single entity, the engineers decided to adopt the layout of the existing earthen surface irrigation system and only change its materiality to concrete-lined canals. This was less costly than redoing the entire system, and rehabilitating at minimum cost was also preferred because of the pressure to reduce budget deficits that was being placed on the government under structural adjustment programmes (Riddell, 1984). The area under irrigation was reduced from 40 to 25 ha (Figure 3). This was done in line with the dominant thinking of the time, in that it was intended to facilitate a move towards intensive agriculture, where inputs like fertilisers and herbicides were concentrated in a smaller area with the aim of increasing yields and water efficiency (Whitlow, 1985; Ray, 1988; Weiner, 1989). The government engineers also recommended restoring the power supply system as well as replacing three pumps and repairing the other four, thus maintaining the overall capacity of the pumping system (Figure 3). As part of the rehabilitation project, several male farmers were trained on how to repair the electricity-powered monoblock[4] pumps and how to pull out the pipes from the borehole whenever there was a problem with them. Three of these farmers were further trained on borehole maintenance, including repairing diesel engines. The government's repair of the earthen tank was part of the rehabilitation project; this was not successful, due to the absence of proper soils, and the tank continued to leak excessively such that most

[4] A monoblock pump, or mono pump, is a pump with a coupled motor and pump mounted on a platform outside the borehole.

of the water would be lost overnight. This kind of failure to make water behave invited tinkering with the infrastructure. One farmer, for instance, explained that,

> [w]e looked for clayey soils from anthills and spread it at the bottom of the earth dam, and we drove cattle into the tank to compact the soil with their feet. The water seepage was significantly reduced, but it increased again with time. Later on, we constructed a small concrete canal within the earthen tank. The canal linked the inlet pipe from the boreholes and the outlet canal which supplied water to the irrigation scheme, thus by-passing the night storage and pump the water directly into the primary canal (F1).

Figure 3. Rufaro Irrigation Scheme before cooperative farming, and in 1988 after completion of the rehabilitation for cooperative farming.



Source: Tavengwa Chitata (2020)

The individualisation of cooperative farming

In the first seven years after the first rehabilitation (1988-1995), the irrigation was relatively productive. The cooperative supplied cabbages, potatoes, tomatoes, rape and green maize to the former tribal lands in the region as well as to Masvingo town. It was referred to by the government as a success story and a vindication of the government's political and ideological direction (F1) (see also Weiner, 1991). Even in dryland agriculture, the cooperative was performing well, with substantial production of cotton and maize. These successful years of irrigated agriculture were characterised by opportunities for learning to use the infrastructure and for gaining an understanding of the behaviour of the (ground)water and the crops and of how soil responded to irrigation and to the growing plants. Tinkering with the infrastructure was characteristically limited to minor adjustments and regular maintenance, as the infrastructure was relatively new and did not need much attention.

With time, however, collective farming in the cooperative became difficult because of administrative and operational challenges. Farmers considered the workload of the cooperative to be high because of the many activities in which the cooperative was involved besides cropping; these included raising pigs, broilers, and layers, and dairy production. There were also a series of thefts of cooperative savings, especially by members who assumed managerial positions in the scheme. These challenges were picked up by proponents of a neoliberal ideology that promoted individualisation of property regimes and which questioned the fundamentals of collective action in natural resources management (Lebaron et al., 2002; Navarro, 2007). This culminated in the re-evaluation of cooperatives at a conference in the city of Gweru in the mid-1990s. The conference was attended by representatives of the World Bank and of the Organisation of Collective Co-operatives in Zimbabwe (OCCZIM), which is an overarching body of Zimbabwean (agricultural) cooperatives; members of government were also present, as were (international) agricultural experts and representatives of aid organisations. It was decided at this conference that cooperative members were to own individual plots of land and would only share the irrigation infrastructure but that members would still contribute a part of their yield to the cooperative as share capital for collective investments.

Between 1995 and 1996, land in the Rufaro Irrigation Scheme was distributed among farmers. Distribution was done in the order in which farmers were listed in the cooperative register. First, plots of 0.3 hectares were given to each member, starting furthest upstream with the first person on the list and moving downstream for members who ranked lower on the registration list. A second and third round followed; each of these distributed plots of about 0.12 hectares and continued until the 25 hectares of land in the irrigation scheme was allocated. The result of this process was that all farmers had several pieces of land in different parts of the irrigation scheme, but that those who registered first – primarily Mister Fonyo and his relatives – ended up with most of their plots in the upstream part of the irrigation scheme, which was closer to the water source. Later, land was further distributed among siblings, including women, through inheritance. As a result, some farmers own only upstream land while others have only downstream plots. After land division, the composition of beneficiaries – including the number of men (32) and women (23) – remained the same, as only registered members of the cooperative were eligible to receive distributed land.

This change in land tenure relations brought new forms of tinkering as farmers learned to irrigate their individual plots. Although there were no significant changes in how the boreholes were operated nor in the management of the night storage tank, farmers still had to negotiate relations with each other as the water had to be shared within an irrigation block. Farmers' interests became more focused on increasing the harvest of their own fields than on the harvest produced by the irrigation scheme as a whole. As such, it became increasingly attractive for farmers to tinker with the infrastructure so as to secure more water than they were entitled to according to the irrigation schedule; for instance, they added extra siphons or broke irrigation canals to let more water flow to the furrows in their irrigation plots. The individualisation of land also created a hierarchy in the irrigation scheme, with upstream farmers having better access to water. Farmers thus negotiated mainly with their upstream neighbours and were less concerned about the acts and interests of downstream irrigators.

Even though the land was now allocated to individual farmers, the main infrastructure such as pumps and canals was still owned collectively; it therefore required collective action and joint learning for proper operation and maintenance of the irrigation scheme. Unfortunately, the changed relations between the farmers made these collective efforts difficult; as a result, infrastructure deteriorated and agricultural production declined. This invited aid interventions by various donor organisations in attempts to revive the irrigation scheme, and different kinds of infrastructure were experimented with to increase its productivity (Figure 2). Of note is the rehabilitation of boreholes in early 2000, which was funded by the Danish Development Agency (DANIDA). The rehabilitation work involved changing the electric pumps of the boreholes from monoblock to submersible pumps.[5] The rehabilitation work, however, did not alter the pumping capacity and neither did it alter the power supply system of the boreholes. The submersible pumps installed by DANIDA were all damaged by lightning because their installation had not included proper grounding to avoid short circuiting. Another rehabilitation in 2002 by the farmers, with the assistance of a Canadian organisation, reverted to new monoblock pumps similar to the ones that had been installed at the beginning of the irrigation scheme.

These interventions by various organisations, however, did not succeed in improving the irrigation scheme and halting the decline in agricultural production. For some years only the diesel engine pump was functional, and when this also broke down beyond repair in 2012 the farmers were forced to practise rainfed farming in the irrigation scheme.

Another round of rehabilitation and the rebirth of irrigation

In 2017, after five years of rainfed farming, the irrigation scheme was selected by the Department of Irrigation to undergo rehabilitation; this was to be funded by the Swiss Agency for Development and Cooperation (SDC). The programme was implemented in partnership with the United Nations Food and Agriculture Organization (FAO) and was meant to transform the management and technical aspects of the irrigation scheme. On the management side, efforts to establish an Irrigation Management Committee (IMC) separate from the cooperative committee were resisted during the 2017 rehabilitation period. The IMC was meant to adapt the irrigation management structure to the contemporary trends in irrigation management, however the cooperative committee remained in place, with the addition of supervisory, water and production, and marketing management subcommittees. There was thus a fusion and patching together of the cooperative setup and the IMC (Figure 4).

On the technical side, the earthen storage tank was replaced with a concrete tank of approximately similar size, since the earthen dam had continued to leak despite the farmers' efforts to fix it. The boreholes were also changed from mono pumps to submersible pumps, all now operated by electricity. The engineer who was responsible for the rehabilitation of the scheme highlighted that the submersible pumps were to make electricity use more efficient; nevertheless, the pumps fitted to the boreholes have a capacity that is 60% lower than the previous pumping units. The boreholes are all connected with a 60 mm diameter pipe to a mainline PVC pipe which supplies water to the water storage tank, and from this tank water is piped into the irrigation scheme. For irrigating their fields, farmers can open and close hydrants that are installed on the pipes every 25 metres, with one or more hydrants being adjacent to each plot. The rehabilitation work also transformed the Rufaro Irrigation Scheme from an open canal irrigation system to a pressurised piped irrigation system. The rationale of the implementing organisations was that the open canal irrigation system was not efficient in transporting water because water could evaporate and because canals could be destroyed by farmers and thus were susceptible to leakage. (Partly underground) pipes were therefore considered to increase the water efficiency of the irrigation scheme. As one of the engineers commented,

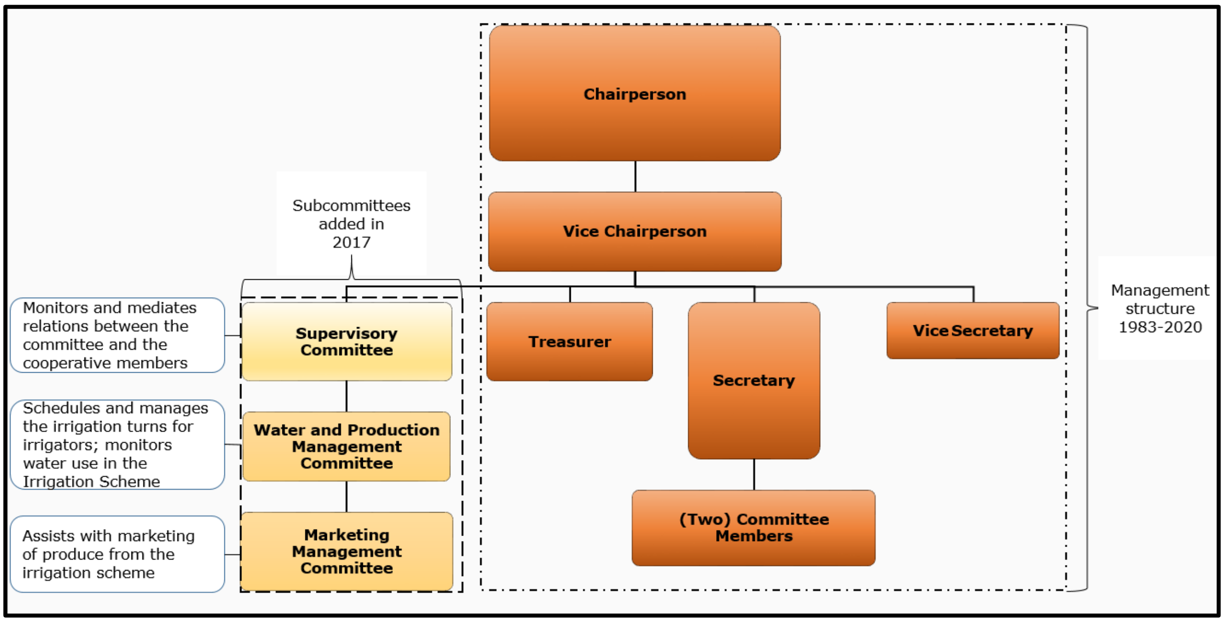
> We have changed the water infrastructure from the open canal irrigation system to a pressurised pipe surface irrigation system. With this change, we have managed to improve the overall efficiency of this irrigation system to sixty-five percent from forty-five percent. This is a commendable accomplishment and will lead to the sustainability of this irrigation scheme (GE1).

The engineers did not consult the farmers on the choice of the form and material of the water distribution. The piped system was presented to the farmers as a better system, as more technologically advanced, and as a smart choice compared to the open canal system they had before the rehabilitation work took place. Farmers disagreed with this decision, however, because they believed that the pipe

[5] A submersible pump is directly coupled to a motor which can work under water. The pump and motor can thus be placed close to the bottom of the borehole where they are submerged in groundwater.

system would be less flexible for irrigation than were the open canals; nevertheless, they did not openly question the decision because they felt the FAO and the engineers from the Department of Irrigation Development were more knowledgeable than they were when it came to irrigation engineering.

Figure 4. Organisational structure of the Cooperative Committee (later with added elements of the Irrigation Management Committee) for the Rufaro Irrigation Scheme.



Source: Tavengwa Chitata (2021).

After the changes were implemented, farmers started to complain that the flow rate in the pipes was even lower than it had been when they were relying on open canals and that it thus took more time to irrigate their plots. For some farmers, the low flow necessitated cooperation with their neighbours; this was highlighted by a young male farmer who said that, "I use more pipes and hydrants from neighbouring plots to supply large quantities of water, enough to overflow and reach the end of my irrigation plot" (F8).

The low flow rate of the new infrastructure prompted the irrigators to negotiate with the Cooperative Committee to change the time for irrigation to 24 hours a day, an increase from the 6 am to 7 pm timing that had been recommended in the design documents that were developed by the Department of Irrigation Development during the SDC/FAO rehabilitation programme. This change allowed farmers to irrigate at night in order to compensate for the increased time that was now required to irrigate their plots; however, it also increased operating costs as it had become necessary to pump water continuously from the aquifer.

This last round of large-scale rehabilitation works has further shaped the current form, materiality and functioning of the irrigation scheme; it has also increased agricultural production for most farmers in the irrigation scheme (for the current infrastructure see Figure 5). In the next section, we reflect on how – through all these acts of sociotechnical tinkering – the farmers have accumulated knowledge on the aquifer they draw from and how this knowledge is shaped by the form and materiality of the infrastructure the farmers use.

Figure 5. a) Borehole equipped with submersible pump and mounted on a platform previously used for a mono pump; b) concrete tank which replaced the leaking earthen tank; c) a T-junction and gate valve for the control of water in the buried pipeline; and d) a hydrant fitted with a stop cock ball valve on which the pipes for irrigating the plots are connected.

Source: Tavengwa Chitata (2020)

WAYS OF KNOWING

Differentiated infrastructure, gendering knowledge

The pumps in the Rufaro Irrigation Scheme, as well as in many other irrigation schemes that rely on groundwater, form the nodes that connect farmers with the aquifers from which they draw water. As such, pumps play an important mediating role in the relations between groundwater and farmers; through them, farmers learn about the state of the aquifer and the availability of water. Our data indicate that the type of pumping technology matters in this process. Most male farmers in the Rufaro Irrigation Scheme, for instance, are not worried about over-exploiting the aquifer; they have access to in-field infrastructure such as the hydrants and pipes for irrigating, but have never operated the mono, submersible, or diesel pumps. Their main responsibility is irrigating their plots and they only occasionally participate in maintenance and repair of the boreholes used for irrigation. According to these farmers, the groundwater level does not change and has been the same for as long as they can remember. This opinion is based on their observation that the pumps' water supply remains consistent throughout the season and there is no evidence of variation in their behaviour. These farmers do not anticipate water shortages in the (near) future and do not see a reason to change their irrigation practices. Because of their limited access to, and interaction with, the boreholes, they do not get to know the behaviour of groundwater.

A few male farmers, however, have a different view. These are the farmers who were responsible for operating the diesel pump when it was still functional. As mentioned above, the diesel pump was for several years the only functioning pump in the irrigation scheme and, since it had to be refuelled to keep working, the interaction between the farmers and this piece of infrastructure was more frequent and intimate. The farmers who had been involved in that process of refuelling and maintaining the diesel pump believe that there are significant fluctuations in the groundwater level. Even though they had never actually faced water shortages, the farmers told us that these fluctuations were most noticeable when the irrigation scheme was in full operation; this was based on their familiarity with the sounds that the diesel engine made in response to different water levels and with the amount of fuel required to fill the water storage tank. They could distinguish the changing sounds of the diesel motor even from their plots a few hundred metres away. They complained that the current system of submersible electric pumps did not allow for this embodied way of knowing the condition of the groundwater source. Corroborating this, one of the men told us that,

> [w]ith the diesel engine, it was easier to know if the water levels were getting low. The sound of the diesel engine would change when the groundwater levels were low, and the time it would take for water to get to the tank was dependent on the groundwater level. With these electricity-powered submersible pumps, you can only tell if it is pumping or not when you are within a metre of radius to the borehole, and they cease in silence (F6).

The sound of the diesel motor and pump also served to warn the farmers if there was a technical problem with the borehole; this allowed them to stop the engine immediately and repair the pump before it was completely broken. With the submersible pump, however, the sound does not change even when it stops pumping water. The warning sign of the diesel mono pump helped farmers save their crops, as they would plan for the repairs before the reservoir would run dry and thus would avoid affecting their irrigation schedules. The farmers also indicated that the diesel pump was easier for them to repair because it resembled a car engine – with which they had more experience – and because it could be maintained with locally available car engine spare parts.

Several female farmers and children in the irrigation scheme indicated that the groundwater levels were decreasing. Since their farming tasks mainly involve seeding and weeding, and not irrigating the fields, they do not base this on their interaction with aquifers for agricultural purposes but rather on their daily domestic interactions with groundwater. As mentioned earlier, the borehole for domestic water supply is of the same depth as the other boreholes and is located near them; it is thus likely to be drawing water from the same aquifer, but is equipped with a handpump. These women and children share an embodied knowledge of groundwater levels similar to that of the male farmers who used to operate the diesel pump. According to them, the handpump produces a defined squeaking sound when the water level in the borehole is very low and this sound is more noticeable when all boreholes for irrigation are pumping water simultaneously; the sound probably occurs because more pipes are above the water table (see also Manandhar et al., 2020). The women and children also say that the water levels are decreasing and that they need to put in more and more physical effort into pumping the water out of the borehole (Figure 6). One woman attributed the gendered knowledge about the aquifer to the different kind of infrastructure that women use to obtain their groundwater:

> Those whom you asked [interviewed male farmers] do not know that the groundwater levels are decreasing. How can they know when water comes to them or is pumped to the tank after one person presses on the

> [electricity] switch? We know the water is decreasing because of the physical efforts we put into getting water out of the borehole. When the water level is close to the surface, we use less effort, but when the water level is too low, we need to use more effort. These days we work hard to get the water out, and it is a pity they tell you the water level is not decreasing (F21).

Whether these are seasonal fluctuations or a declining trend in groundwater levels remains unclear, as data on the aquifer is very limited and we thus cannot cross-check these embodied knowledges. It is also not (yet) possible to explain all the ways of knowing the quantity of groundwater in the Rufaro community. Among the interviewed farmers, some women could not explain how they knew that the groundwater level was decreasing, but they still stressed their intimate knowledge of it, agreeing amongst themselves that, "we know [the aquifer] because we come and fetch the water every day" (F15), while the men only irrigate once in a while.

Figure 6. a) The Zimbabwean bush pump that supplies water for domestic uses and is predominantly operated or used by women; b) a pump house, showing the borehole with a submersible pump which supplies water for irrigation; a farmer indicates the remains of the coupling which was used for the mono pump.

Source: Tavengwa Chitata (2020)

Knowing with the soils, knowing the aquifers

Knowledge about groundwater in this case study area is obtained not only by listening to the pumps or through gauging the bodily efforts needed to pump up the water. It also comes by observing the landscape, understanding the material configurations of the soil and the rainfall patterns, and linking these to the locations and yields of the different boreholes.

The Rufaro area has clay soils that expand when wet and shrink when dry, leaving fissures in the soil which increase infiltration rates and thus allow for faster recharge of the aquifer. The farmers became aware of soil characteristics when they tried to repair the earthen reservoir; their lack of success was accompanied by observations of excessive water losses from the reservoir. This learning with the infrastructure and knowing the behaviour of the soils and its importance in replenishing groundwater was highlighted by one of the male farmers:

> Every morning the whole area around the earthen tank would be wet, and there will be less water in the dam. It was leaking excessively. The water would go back to be groundwater even before it was used, and it is the same with the rains it infiltrates quickly into the ground (F1).

The farmers – and with them, the engineers who became involved in the rehabilitation of the irrigation scheme – thus learned about the soil properties and the behaviour of the water from tinkering with the earthen dam in their attempts to stop the leakage. They used this knowledge to make some of the infrastructural adjustments, as discussed in earlier sections; these included using clay to waterproof the dam, lining the irrigation canals with concrete, and later replacing these with pipes.

The farmers also learned how the groundwater is linked to, and dependent on, other flows of water. Some Rufaro farmers attribute the abundance of groundwater in the Rufaro area to the aquifer's hydrological connection to Lake Mutirikwi, a large natural water body about 20 km from the scheme. It is also believed that this link to a large natural water body sustains the aquifer from which they draw during drought years. One of the farmers explained it as follows:

> There is more groundwater as we move towards the direction of Lake Mutirikwi and this Rufaro area we think gets its groundwater recharge from that Lake. As you can see, there is no other indication as to where this groundwater is coming from except it being linked to the Lake. That is why we do not go dry even during drought years because the Lake does not dry up as well (F11).

As people got to know their soils and their aquifers, they also learned to identify suitable places for abstracting groundwater. In 2007, for example, farmers and their families moved their homesteads outside the command area of the Rufaro scheme, to an area which is believed to have higher groundwater levels. Between 2015 and 2020, six farmers drilled private boreholes in this area for irrigation and domestic use and several other farmers expressed aspirations to do the same, which were contingent on having the financial means. Community members also used their knowledge of the aquifer to locate the position of a new communal borehole for domestic water supply; this was installed in 2014 and was equipped with a handpump. They also use the aquifer to explain why they had abandoned both the former domestic-use borehole and the borehole used for watering cattle. One of the five farmers who were trained in borehole repair by the then Ministry of Small and Medium Enterprises and Cooperative Development, explained this as follows:

> When we came here [in 1985], we had to figure out on our own with the help of the physical landscape and existing water infrastructure the extent of this aquifer. We now know the extent of this aquifer by the locations and yields of the boreholes on this farm and the neighbouring farms. Beyond that small mountain, there are no good yields of groundwater, and our neighbouring farmer settled just after that mountain cannot irrigate using groundwater. Even the two [abandoned in 1985] boreholes closer to the mountain were not of good yield (F1).

Relearning to irrigate

The knowledge that farmers obtained on soil behaviour prompted learning on how to irrigate. After shifting from canal to pipes, the farmers soon noticed that the ways of irrigation as designed by the engineers did not work in practice and would not meet the crop water requirements. As one farmer explained, "These soils crack and form fissures just like it was with the earthen tank. Water will go into cracks till they are filled, and only then the water will flow down to the other parts of the irrigation plot" (F8).

When the irrigation scheme still consisted of open canals, the farmers – according to the 1985 design documents – were supposed to use a single siphon to divert water into a furrow. Because of cracking soils and a high infiltration rate, however, a single siphon could not supply enough water to irrigate to the end of the furrow. This explains some of the acts of tinkering discussed earlier, in which farmers used more than one siphon or, in some cases, punctured the tertiary canal to allow a high volume of water into the furrows, since only high volumes would allow for surface water flows to all parts of their plots.

After the last round of rehabilitation, in which the open canals were replaced by pipes, the farmers had to relearn how to irrigate with the new infrastructure. In 2018, which was the first irrigation season after the installation of pipes, the irrigators, on the advice of the engineers, adopted the same irrigation turns that they had been using in the open canal surface system. In the open canal system, all the farmers supplied by a particular tertiary canal would irrigate on the same day. According to the design documents and the engineers, the rehabilitated irrigation system had a capacity for 22 irrigators to irrigate simultaneously, with each irrigator getting a flow rate of 9.27 m^3/hr. With this design capacity, the farmers should have been able to irrigate at least 3.4 ha per day (Table 2); soon enough, however, the farmers realised that the actual discharge per hydrant was lower than the designed discharge and that the infrastructure could thus not accommodate the expected number of irrigators per irrigation turn. The farmers therefore had to experiment with the infrastructure to determine the number of people who could be supplied with water simultaneously. Rescheduling the irrigation turns required collaboration and experimentation and, as such, transformed the decision-making process from being the responsibility of the water committee to something that was provisional, ambiguous and open for collective learning. The irrigators agreed to discard the recommended irrigation schedule and to jointly figure out the actual discharge capacity of the infrastructure by monitoring how many irrigators could irrigate at the same time. Mai Qoe, a middle-aged woman who is one of the two members of the Water and Production Management Committee of the irrigation scheme, noted in the concluding remarks of a monthly meeting that,

> [t]hose who are irrigating tomorrow should come, and they will open their gate valves, and we see with the flow rate how many irrigators the infrastructure can allow, and this will guide our next irrigation. The recommendations of the engineers are problematic as we experienced in the last irrigation season (F22).

The water pressure in the system was too low to produce sufficient water flow to saturate the soil, especially in the upstream section. Because of this water shortage, some of the farmers turned their upstream irrigation plots into dryland farming while others leased out their land. In the second irrigation season, the farmers experimented with allowing the downstream farmers to irrigate first; for the third season, this approach was formalised. Since then, water is first distributed to the irrigators of the downstream plots, and upstream farmers only irrigate after the other plots have finished irrigating. It took the farmers three irrigation seasons of experimentation and learning with the infrastructure to formalise a new irrigation schedule and considerably reduce the number of farmers that irrigate simultaneously (Table 2). The formalised irrigation schedule, however, has serious implications for the distribution of water and power in the irrigation scheme. This will be discussed further in the next section.

REARRANGING FLOWS OF WATER, RENEGOTIATING SOCIAL RELATIONS OF POWER

Reversing the upstream-downstream relations of irrigators

Neither the engineers nor the farmers had foreseen that by changing the infrastructure during the last round of rehabilitation, the upstream – downstream relationship among the irrigators would also be drastically changed. For three decades, those farmers with the pieces of land in the upstream parts of the irrigation scheme had had better access to water. They would irrigate first as they could easily direct the water from the open canals to their fields. Farmers with pieces of land in more downstream parts of the irrigation scheme had to negotiate with the upstream irrigators for the release of water. Most upstream irrigators would irrigate as often as they deemed fit for their crops and for as long as water was flowing in the canals adjacent to their land. Downstream farmers, on the other hand, only irrigated when the upstream farmers were not irrigating or when they formed teams to guard the upstream parts of the

Table 2. Operation details of the irrigation scheme as designed by the engineers in 2017 and as practised by farmers[6]

Operational parameter	Designed system	System in situ
Irrigation cycle	6 days	7 to 8 days for horticultural crops 20 to 25 days for other crops
Discharge rate	9.27 m3/hr	7.2 m3/hr in the downstream areas to 2.3 m3/hr in the upstream areas
Number of farmers irrigating simultaneously	22	3 to 4
Area irrigated per day	3.4 hectares	Less than 2.3 hectares

canals to secure water flow to the downstream irrigation plots. Although there are no historical records to compare the yields in the upstream and downstream plots, the farmers with land mainly in the downstream area indicated that in the past they regularly had to stop irrigating their plots because of water shortages and therefore could hardly harvest any crops.

The new piped system benefitted the downstream farmers because the pressure within the pipes is higher in low-lying downstream parts. In this system, water flows from the tank into the pipes and then enters the field by the first available openings. If the downstream farmers thus do not close their hydrants the water will continue to flow out of the pipes into their fields, leaving the upstream irrigators with no water in their part of the pipes. Because of this practice, especially in upstream areas insufficient pressure is available in the system to irrigate the fields. This situation influenced the decision to formalise the irrigation schedule such that downstream farmers would irrigate first. The change in the form and materiality of the infrastructure has thus essentially reversed the relationship between upstream and downstream irrigators, which has had actual implications for the livelihoods of the respective farmers. As one upstream farmer explained, "I used to irrigate at any time as I wished because I am in the upstream, but not anymore. Today I came to irrigate, but until those in the downstream have finished, I cannot irrigate. I will go home and come back later" (F6).

An owner of a plot downstream, meanwhile, welcomed the pressurised pipe system and the associated change in the water-access hierarchy. He commented that, "I once gave up on irrigating my plot in the downstream because I could not get water, but now that problem is over" (F14).

The favouring of downstream farmers in access to water has now also been institutionalised in the irrigation schedule. These schedules are maintained, sustained, and put into effect by the Water and Production Management Committee; also, the materiality of the infrastructure cannot allow for it to be used differently. This leaves the upstream farmers at least partly dependent on rainfed agriculture inside the perimeters of the irrigation scheme.

Changing hydraulic property relations

The change in the irrigation infrastructure also transformed hydraulic property relations for the farmers. Even though formally the new infrastructure is still owned collectively, and – as with the open canals – repair and maintenance is a joint responsibility, the form and materiality of the infrastructure has triggered a different arrangement. To clean and repair the open canal system, collective action was

[6] The data on the designed system was obtained from the design documents prepared by the Department of Irrigation; the data on farmers' practices was measured and recorded over one growing season under wheat crop and horticultural crops (tomato, onion, cabbage, rape and covo).

required to provide the necessary physical labour, while most materials and tools (such as shovels, clay, stones and cement) were easily available. In the new irrigation system, however, with its buried pipes, eight gate valves, and 65 hydrants spread 25 metres apart over the irrigation scheme, the requirements for repair and maintenance are different. First, blockages and/or leaks in the system are less easy to discover and locate; second, spare parts for the new irrigation system are difficult to acquire and, if available, are expensive.

What happens in practice is that hydrants adjacent to a farmer's plot are repaired by the plot holder. Farmers can, however, use hydrants from neighbouring plots, particularly hydrants in the downstream plots where water pressure will be higher than in the upstream areas. Downstream irrigators do not at all mind this practice as, in most cases, they irrigate their own plots first and then, when they are done, leave the upstream irrigators to use the hydrants near their plots. Fuzzy boundaries may thus exist in accounting for faulty hydrants, as the infrastructure is not used exclusively by a single farmer. This does not, however, alter the responsibility of the plot holders to repair the hydrants adjacent to their plots. This de facto practice implies individual ownership of the hydrants. Our data shows that farmers repair hydrants at a cost within their means, which often means conducting only the bare minimum of repair work. One farmer, for instance, attempting to prevent the hydrant being pushed up by the water pressure in the pipe, used a wire which cost less than US$1 to tie it down (Figure 7). The saddle for the hydrant is made of plastic and the hydrant is metal; with time and in the course of numerous couplings, the threads on the plastic saddle wear off. For proper repair of the hydrant, the plastic saddle needs to be replaced by a new one at a cost of not less than US$30, an amount that was too expensive for the farmer, who therefore used a piece of wire. Even though farmers, irrigation engineers, and members of the cooperative committee now consider the repair and maintenance of the infrastructure to be the responsibility of the individual farmer, the consequences if repair is not done in time and/or correctly has implications for upstream farmers' access to irrigation water in that, for example, if a hydrant cannot be closed properly it will reduce the water pressure in the pipe further upstream.

Another issue is the inability of most farmers to repair hydrants on their own, lacking both the labour needed to dig down to the hydrant and the expertise to fix it. Farmers who need to repair their hydrant are therefore forced to hire other farmers to assist them, paying them a fee or using some other form of payment, depending on their relations. Two farmers in particular are called upon for hydrant repair; these two farmers learned to repair the infrastructure in the course of installing the new irrigation system during the rehabilitation work. As explained by an elderly farmer who had his hydrant broken during tillage activities:

> You see, I have hired these two boys to excavate around the hydrant so we can repair it. It is difficult to do it and it is new to us. I will hire Davison [alias for one of the two farmers who has the knowhow to repair the hydrants] to do the repairs. I have to repair it quickly; otherwise, farmers in this irrigation block cannot irrigate (F17).

The introduction of hydrants for each plot has changed the relationship between farmers and the Irrigation Management Committee. The committee now has a tool – the hydrant that can be switched off – which it can use to pressure individual irrigators who fail to pay their electricity bills or to meet other financial obligations within and outside the irrigation scheme. One farmer, for example, had a cumulative debt of US$55 dating back to 2017; her hydrant was switched off, causing her to complain that, "this management has turned into robbers and thugs! How can they not allow me to irrigate as if I am the only one who has not paid, some in the committee have outstanding debts as well" (F7).

Farmers are also expected to jointly maintain the underground pipes to which the hydrants are connected. These pipes are regularly blocked by debris, especially on the gate valves. Small particles find their way into the piped network through the reservoir's outlet, which lacks a debris screen having not had one installed by the contractor at the time of construction. The irrigators did not get any training on repair and maintenance of this part of the infrastructure; they thus had to learn to troubleshoot in the case of blockages or leaks in the pipes and/or gate valves. The female production manager who is responsible for monitoring water use in the irrigation scheme stated that, "[t]his system is ok, but the canal system was better. We were used to it, and we knew how to repair broken canals as a group (…). However, with this new system, we experiment with it in [everyday] practice" (F22).

Figure 7. a) Davison [an alias] assessing the plastic saddle-hydrant joint that was excavated to allow for repairs; b) hydrant fixed in position and made able to withstand water pressure, using a pair of wires tied on the T-wings and strapped to an underground pipe.

Source: Tavengwa Chitata (2020)

Where the canal required considerable labour for regular cleaning, this system requires – besides a bit of digging – special knowledge on how to locate the problem and (re)assemble the parts. Fewer people are thus required – and able – to do the work, and thus fewer people have the chance to periodically renew their hydraulic property relations to the system (see also Boelens and Vos, 2014). Since the changes to the infrastructure are still relatively new, it is not yet clear how this might affect access to the infrastructure in future. Our initial data shows, however, that especially for farmers in the middle ranges of the irrigation scheme a lot is at stake; they are only assured of a water supply if there are no leakages in the system and are therefore most active in maintaining the pipes and hydrants. Downstream farmers do not feel the same urgency to maintain the system because water will continue to flow to their fields more easily; upstream farmers, in the meantime, have given up trying to get water to their plots. How this 'differentiated' collective action affects hydraulic property relations in the long run, and whether it will lead to disfranchising upstream farmers in the irrigation scheme are questions for future study.

Conclusions

In this paper we focus on acts of sociotechnical tinkering as an empirical entry point to studying how the emergent infrastructure mediates relationships between people and water. With this, we have shown how the form and materiality of the water infrastructure means much more to its engineers, operators and users than just being a water conduit; water infrastructure shapes the way they learn with, know about, and interact with the water sources on which they rely. It allows them to make hydraulic (dis)connections with others and provides them with rationales to justify their actions. Based on our empirical data, we demonstrated that the constant changes in the form, materiality and functioning of water infrastructure shape the tinkering with, and learning from, that infrastructure. Our case indicates that, in this process, relationships among farmers and between farmers and the water itself are restructured, sometimes in unexpected ways.

This paper particularly highlights the fact that there are inequalities in terms of who can tinker with, and thus shape and learn from, infrastructure. Our data shows, for instance, that the pumping technology used to access groundwater matters for how people assess the behaviour and status of the aquifers. Because of gendered water practices – with men operating the pumps for irrigation and women operating the pump for domestic use – and because of the different types of pumps installed for the different water-use purposes, knowledge on groundwater is also gendered. We have also shown how male farmers involved in operating and/or maintaining the irrigation scheme have different knowledge than those who are only involved in irrigating their own plots. This difference also shapes how groups of farmers relate to and engage with groundwater, potentially with crucial implications for its sustainability. This does not, however, only affect the source of water; it is also highly political, as opportunities for sociotechnical tinkering can actually redistribute flows of water and affect people's entitlements to water. In the long run, some farmers may be particularly disenfranchised by the move from more collective to individual tinkering and learning.

The case also shows that several engineers who have been involved in the different rounds of rehabilitation have had considerable influence on the form and materiality of the irrigation infrastructure. Sometimes based on techno-managerial objectives such as efficiency, sometimes based on available budgets or (standard) designs, these engineers altered not only the appearance of the infrastructure but also how it functioned (see also Kemerink-Seyoum et al., 2019; Sanchez et al., 2019); however, they never fully knew nor controlled the infrastructure, as shown, for instance, by the persistent leaking of the reservoir or the blocked pipes. Their infrastructural choices nevertheless had major implications for farmers. Replacing the open canals with (underground) pipes, for instance, has reversed the upstream – downstream relations in the irrigation scheme, to the point where upstream farmers now have difficulty getting sufficient water for their crops. Through this empirical example, we unpacked how engineering solutions to techno-managerial objectives can lead to (unintended) consequences in terms of access to water and, as such, alter social relations of power (see also Schmidt, 2020).

We argue, based on this case study that water and power are (re) defined and (re) distributed in subtle yet sometimes crucial ways through the situated knowledges and everyday improvisations of actors engaging with water. This insight nuances more structural analyses and explains how distributions of water and power arise – at least partly – from the contingent coming together of different people, water(s), infrastructure and much else. We end this paper with a plea for more empirical studies that use acts of tinkering with water infrastructure as an empirical entry point; we suggest that it often provides very visible, and thus researchable, evidence of ways of knowing – and relating to – sources of water. This creates space for moving from a language which problematises quotidian improvisations of infrastructure by engineers, operators and water users, to one that appreciates them as processes of learning *with* infrastructure.

ACKNOWLEDGEMENTS

The work presented in this paper was funded by the Grantham Centre for Sustainable Futures at The University of Sheffield and Transformations to Groundwater Sustainability (T2GS) project. We thank our interviewees in the case study area, government, Department of Irrigation Development and the Rufaro community for sharing their knowledge, time, and opinions with us. We also thank our colleagues in the T2GS project for their inspiration and collective learning.

REFERENCES

Akwabi-Ameyaw, K. 1990. The political economy of agricultural resettlement and rural development in Zimbabwe: The performance of family farms and producer cooperatives. *Human Organization* 49(4): 320-338.

Anand, N. 2011. Pressure: The politechnics of water supply in Mumbai. *Cultural Anthropology* 26(4): 542-564.

Asare-Nuamah, P.; Mandaza, M.S. and Amungwa, A.F. 2021. Adaptation strategies and farmer-led agricultural innovations to climate change in Mbire District of Zimbabwe. *International Journal of Rural Management* 0973005221999913.

Ashcraft, C.M. and Mayer, T. 2016. *The politics of fresh water: Access, conflict and identity*. Routledge. https://doi.org/10.4324/9781315717432.

Bakker, K. 2012. Water: Political, biopolitical, material. *Social Studies of Science* 42(4): 616-623, https://doi.org/10.1177/0306312712441396.

Bijker, W.E. 2007. Dikes and dams, thick with politics. *ISIS* 98(1): 109-123. https://doi.org/10.1086/512835.

Bjornlund, H. 2009. Is water and land redistribution a driver of economic growth and poverty reduction? Lessons from Zimbabwe. *Water International* 34(2): 217-229.

Boelens, R.; Hoogesteger, J.; Swyngedouw, E.; Vos, J. and Wester, P. 2016. *Hydrosocial territories: A political ecology perspective*. *Water International* 41(1): 1-14. https://doi.org/10.1080/02508060.2016.1134898

Boelens, R. and Vos, J. 2014. *Legal pluralism, hydraulic property creation and sustainability: The materialized nature of water rights in user-managed systems*. *Current Opinion in Environmental Sustainability* 11: 55-62. https://doi.org/10.1016/j.cosust.2014.10.001.

Bolding, A.; Manzungu, E. and van der Zaag, P. 1996. Farmer-initiated irrigation furrows: Observations from the Eastern Highlands. University of Zimbabwe (UZ) Publications.

Bolding, A.; Manzungu, E. and Zawe, C. 2004. Irrigation policy discourse and practice: Two cases of irrigation management and transfer in Zimbabwe. In Mollinga, P. and Bolding, A. (Eds), *The politics of irrigation reform,* pp. 166-206*.* Ashgate Publishing Co.; Burlington, Vermont.

Bossenbroek, L.; van der Ploeg, J.D. and Zwarteveen, M. 2015. Broken dreams? Youth experiences of agrarian change in Morocco's Saïss region. *Cahiers Agricultures* 24(6): 342-348. https://doi.org/10.1684/agr.2015.0776.

Chigodora, J. 1997. Famine and drought: The question of food security in Zimbabwe. *Drought Network News (1994-2001)* 40.

Cleaver, F. 2002. Reinventing institutions: Bricolage and the social embeddedness of natural resource management. *European Journal of Development Research* 14(2): 11-30, https://doi.org/10.1080/714000425.

Cleaver, F. and Whaley, L. 2018. Understanding process, power, and meaning in adaptive governance: A critical institutional reading. *Ecology and Society*, https://doi.org/10.5751/ES-10212-230249.

Coche, A.G. 1998. Supporting aquaculture development in Africa: Research network on integration of aquaculture and irrigation. Rome.

Dajani, M. and Mason, M. 2018. Counter-infrastructure as resistance in the hydrosocial territory of the occupied Golan Heights. In Menga, F. and Swyngedouw, E. (Eds), *Water, technology and the nation-state,* pp. 131-146. Routledge. https://doi.org/10.4324/9781315192321-9.

Duker, A.E.C.; Mawoyo, T.A.; Bolding, A.; de Fraiture, C. and van der Zaag, P. 2020. Shifting or drifting? The crisis-driven advancement and failure of private smallholder irrigation from sand river aquifers in southern arid Zimbabwe. *Agricultural Water Management* 241: 106342 , https://doi.org/10.1016/j.agwat.2020.106342.

Furlong, K. 2010. Neoliberal water management: Trends, limitations, reformulations. *Environment and Society* 1(1): 46-75.

Jacobs, S. 1983. Women and land resettlement in Zimbabwe. *Review of African Political Economy* 10(27-28): 33-50, https://doi.org/10.1080/03056248308703545.

Jensen, C.B. and Morita, A. 2015. Infrastructures as ontological experiments. *Engaging Science, Technology, and Society* 1: 81-87, https://doi.org/10.17351/ests2015.21.

Kemerink-Seyoum, J.S.; Chinguno, N.L.T.; Seyoum, S.D.; Ahlers, R.; Bolding, J.A. and van der Zaag, P. 2017. Jumping the water queue: Changing waterscapes under water reform processes in rural Zimbabwe. *Water SA* 43(3): 423-432, https://doi.org/10.4314/wsa.v43i3.07.

Kemerink-Seyoum, J.S.; Chitata, T.; Guzmán, C.D.; Novoa-Sanchez, L.M. and Zwarteveen, M.Z. 2019. Attention to sociotechnical tinkering with irrigation infrastructure as a way to rethink water governance. *Water* 11(8): 1670, https://doi.org/10.3390/w11081670.

Kinsey, B.H. 1982. Forever gained: Resettlement and land policy in the context of national development in Zimbabwe. *Africa* 52(3): 92-113.

Kuper, M.; Benouniche, M.; Naouri, M. and Zwarteveen, M. 2017. 'Bricolage' as an everyday practice of contestation of smallholders engaging with drip irrigation. In Venot, J.; Kuper, M. and Zwarteveen, M. (Eds), *Drip irrigation for agriculture*, pp. 256-265. Routledge.

Lamri, A.A.; Easa, S.M.; Asce, M. and Bouziane, M.T. 2020. Stability criterion for uniform flow in open channel cross sections with different shapes. *Journal of Irrigation and Drainage Engineering* 146(11): 1-5, https://doi.org/10.1061/(ASCE)IR.1943-4774.0001512.

Larkin, B. 2013. The politics and poetics of infrastructure. *Annual Review of Anthropology* 42: 327-343, https://doi.org/10.1146/annurev-anthro-092412-155522.

Lebaron, F.; Campbell, J.L. and Pedersen, O.K. 2002. The rise of neoliberalism and institutional analysis. *Contemporary Sociology* 31(5): 548-549, https://doi.org/10.2307/3090039.

Makadho, J.; Matondi, P.B. and Munyuki-Hungwe, M.N. 2001. *Irrigation development and water resource management*. University of Zimbabwe (UZ) Publications.

Manamere, K. 2020. Remembering Tom the boss boy: The place of black immigrants in the establishment of the southeastern lowveld sugar estates, Zimbabwe, 1906-1972. *Settler Colonial Studies* 10(3): 403-421.

Manandhar, A.; Greeff, H.; Thomson, P.; Hope, R. and Clifton, D.A. 2020. Shallow aquifer monitoring using handpump vibration data. *Journal of Hydrology* 8: 100057, https://doi.org/10.1016/j.hydroa.2020.100057.

Meehan, K.M. 2014. Tool-power: Water infrastructure as wellsprings of state power. *Geoforum* 57: 215-224.

Meisenhelder, T. 1994. The decline of socialism in Zimbabwe. *Social Justice* 21(4): 83-101.

Mlambo, A.S. and Pangeti, E.S. 1996. *The political economy of the sugar industry in Zimbabwe 1920-90.* University of Zimbabwe.

Mosello, B.; Oates, N. and Jobbins, G. 2017. *Pathways for irrigation development: Policies and irrigation performance in Zimbabwe*. London: Overseas Development Institute.

Moyo, M.; van Rooyen, A.; Moyo, M.; Chivenge, P. and Bjornlund, H. 2017. Irrigation development in Zimbabwe: understanding productivity barriers and opportunities at Mkoba and Silalatshani irrigation schemes. *International Journal of Water Resources Development* 33(5): 740-754.

Mukasa, S.D. 2003. Press and politics in Zimbabwe. *African Studies Quarterly* 7(2): 171-183.

Naouri, M.; Kuper, M. and Hartani, T. 2020. The power of translation: Innovation dialogues in the context of farmer-led innovation in the Algerian Sahara. *Agricultural Systems* 180: 102793-102795, https://doi.org/10.1016/j.agsy.2020.102793.

Navarro, V. 2007. Neoliberalism as a class ideology; or, the political causes of the growth of inequalities. *International Journal of Health Services* 37(1): 47-62, https://doi.org/10.2190/AP65-X154-4513-R520.

Obertreis, J.; Moss, T.; Mollinga, P.P. and Bichsel, C. 2016. Water, infrastructure and political rule: Introduction to the special issue. *Water Alternatives* 9(2): 168-181.

Ray, A. 1988. Agriculture in a turbulent world economy. *Journal of Development Economics* 29(2): 242-244, https://doi.org/10.1016/0304-3878(88)90040-5.

Riddell, R.C. 1984. Zimbabwe: The economy four years after independence. *African Affairs* 83(333): 463-476.

Rukuni, M. 1984. Cropping patterns and productivity on small holder irrigation schemes. In Blackie, M.J (Eds). *African Regional Symposium on Small Holder Irrigation, 5-7 September 1984, University of Zimbabwe, Harare, Zimbabwe*, pp. 401-408. Overseas Development Unit of Hydraulics Research Limited.

Rukuni, M. 1988. The evolution of smallholder irrigation policy in Zimbabwe: 1928-1986. *Irrigation and Drainage Systems* 2(2): 199-210.

Rukuni, M. 1994. Impact of smallholder irrigation in Zimbabwe, Faculty of Agriculture, University of Zimbabwe (UZ).

Sanchez, L.M.S.N.; Kemerink-Seyoum, J.S. and Zwarteveen, M. 2019. Water infrastructure always in-the-making: Distributing water and authority through thewater supply network in Moamba, Mozambique. *Water* 11(9): 1926, https://doi.org/10.3390/w11091926.

Schmidt, J.J. 2020. Pop-up infrastructure: Water ATMS and new delivery networks in India. *Water Alternatives* 13(1): 119-140.

Scoones, I.; Murimbarimba, F. and Mahenehene, J. 2019. Irrigating Zimbabwe after land reform: The potential of farmer-led systems. *Water Alternatives* 12(1): 88-106.

Shah, T.; van Koppen, B.; de Lange, D.M.M. and Samad, M. 2002. Institutional alternatives in African smallholder irrigation: Lessons from international experience with irrigation management transfer. International Water Management Institute: Colombo, Sri Lanka.

Shaw, I.G.R. and Meehan, K. 2013. Force-full: Power, politics and object-oriented philosophy. *Area* 45(2): 216-222, https://doi.org/10.1111/area.12023.

Sithole, M. 1993. Is Zimbabwe poised on a liberal path? The state and prospects of the parties. *Issue: A journal of Opinion* 21(1/2): 35-43.

Sundler, A.J.; Lindberg, E.; Nilsson, C. and Palmér, L. 2019. Qualitative thematic analysis based on descriptive phenomenology. *Nursing Open* 6(3): 733-739, https://doi.org/10.1002/nop2.275.

Sutton, J.E.G. 1984. Irrigation and soil-conservation in African agricultural history with a reconsideration of the Inyanga terracing (Zimbabwe) and Engaruka irrigation works (Tanzania). *Journal of African History* 25(1): 25-41.

Wang, H.; Wang, J.; Yang, B.; Mo, Y.; Zhang, Y. and Ma, X. 2020. Simulation and optimization of venturi injector by machine learning algorithms. *Journal of Irrigation and Drainage Engineering* 146(8): 1489-1490. https://doi.org/10.1061/(ASCE)IR.1943-4774.0001489

Weiner, D. 1989. Agricultural restructuring in Zimbabwe and South Africa. *Development and Change* 20(3): 401-428.

Weiner, D. 1991. Socialist transition in the capitalist periphery: A case study of agriculture in Zimbabwe. *Political Geography Quarterly* 10(1): 54-75.

Weiner, D.; Moyo, S.; Munslow, B. and O'Keefe, P. 1985. Land use and agricultural productivity in Zimbabwe. *The Journal of Modern African Studies* 23(2): 251-285.

Whitlow, R. 1985. Conflicts in land use in Zimbabwe: Political, economic and environmental perspectives. *Land Use Policy* 2(4): 309-322.

Zwarteveen, M.; Kemerink-Seyoum, J.S.; Kuper, M.; Herrera, C.O.; Dajani, M.; Lu, F.; Cleaver, F.; Hartani, T.; Börjeson, L.; Bont, C. De; Mlimbila, E.; Joseph, K.; Komakech, H.; Aslekar, U.; Dhaval; Joshi; Deshmukh, R.; Kulkarni, S.; Kulkarni, H.; Leonardelli, I.; Bhat, S.; Sachin, B.; Saidani, A.; Bossenbroek, L.; Ftouhi, H.; Kadiri, Z.; Peterson, A.; Beckett, L.; Johnson, M.; Oré, M.T.; Verzijl, A.; Carolina, D.; Guzmán and Chitata, T. 2021. Transformations to Groundwater Sustainability: From individuals and pumps to communities and aquifers. *Current Opinion in Environmental Sustainability* 49: 88-97. https://doi.org/https://doi.org/10.1016/j.cosust.2021.03.004.

ANNEX. TIMELINE OF IMPORTANT HISTORICAL EVENTS AT THE (INTER)NATIONAL LEVEL AND HOW THEY RELATE TO CHANGES IN THE RUFARO IRRIGATION SCHEME.

Date	National (global) level		Rufaro Irrigation Scheme	
	Event	Commentary	Event	Commentary
1956	Co-operative Societies Act (Chapter 193) passed	Producer cooperatives were introduced in Tribal Trust Lands (dryland farming) by the colonial government		
1979	Lancaster House Constitution	Constitution was negotiated to pave the way for Zimbabwe's independence; land redistribution was discussed and included in Section 16 of the constitution		
1980	Independence from Britain	Lancaster House agreement on land redistribution to natives was put in place through the so-called Models A, B, C and D resettlement schemes	The Rufaro farm listed for resettlement	Farm was listed on the willing seller willing buyer principle
1981	Ministry of State for Community Development and Woman's Affairs established	Ministry established under the Prime Minister's Office with a mandate to eradicate rural underdevelopment; currently renamed the Ministry of Women's affairs, Community, Small and Medium Enterprises		
1982	Organisation of Collective Co-operatives in Zimbabwe (OCCZIM) formed	Main task of the organisation was to source and channel donor funds to collective cooperatives		

1983	Zimbabwe government had a significant budget deficit	This delayed resettlement progress, including in Rufaro	State acquired Rufaro farm (a small-scale commercial farm) and leased it to a local farmer	Farm was well equipped with functional irrigation infrastructure
1983-1984/5			Rufaro Collective Farming Cooperative was established and registered under the Cooperative Societies Act [Chapter 24: 05]	Mobilisation of people to join cooperatives took place; those who wanted to join were trained on the ethos of cooperative farming (only males over the age of 18 were allowed to be members)
1985			Cooperative members moved into the Rufaro cooperative farm	Irrigation infrastructure needed rehabilitation
1985-1988			Rehabilitation of the Rufaro Irrigation Scheme	The rehabilitation maintained the surface irrigation but lined the canals with concrete
1988-early 1990s			Operation of the Rufaro Irrigation Scheme	Remarkably high production in the irrigation scheme
1990-1995	Economic Structural Adjustment Programme (ESAP) launched	A neoliberal market-driven policy which led to reduced government subsidies and support to cooperatives	Emergence of administrative and operational challenges	The production level began to drop towards the mid-1990s
1995/1996	National re-evaluation of cooperatives at Gweru Conference	Recommendations were made for cooperatives to modify their mode of operation	Individualisation of cooperative farming	Farmers owned individual plots but jointly owned irrigation infrastructure
1998	New Water Act of 1998			
2000	Land Acquisition Act of 2000	The Act ushered in the chaotic Fast Track Land Resettlement Programme (FTLRP); the country was put on economic sanctions by the USA, EU and United Kingdom	Rehabilitation of the irrigation scheme by DANIDA	The rehabilitation changed electric pumps of the boreholes from mono pumps to submersible pumps

2002			Rehabilitation of the pumping units of the irrigation scheme by farmers	Pumping units reverted back to mono pumps
2003-2010	Severe economic difficulty			Farmers struggled to repair infrastructure
2012			Irrigated agriculture stopped	Irrigation infrastructure had broken down
2017/2018			Rehabilitation of the irrigation infrastructure	Rehabilitation was financed by the Swiss Agency for Development and Cooperation (SDC) and implemented in partnership with the Food and Agriculture Organization (FAO) of the United Nations