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Radical reassemblages: The life history of a Nile Delta pumping collective

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Abstract
This article investigates how people, technology, and water flows act together in using and transforming infrastructure to improve water access. Analytically, we propose to study collective action over time through the relationships between humans and non-humans as they collaborate to mediate water and other flows. Our case-study lies in Egypt. Over four decades, the Irrigation Improvement Project has introduced various sociotechnical and institutional measures to improve water management in the Nile Delta. By establishing collective pumping infrastructure and Water User Associations, water users were compelled to collaborate to reduce water extraction and over-irrigation. For heuristic purposes, we examine in detail the life history of one pumping collective facing increasing water scarcity. The article presents four life phases of the pumping collective and analyses what drives the assemblage and its transformations. Through time, we understand pumping collectives as heterogeneous and shifting assemblages of human and non-human agents that provide differentiated access to multiple resource flows. We describe the surprising stream of events that unfolds. The pumping collective radically dismantles the standard technological and organizational set-up and replaces it with a more flexible and disaggregated form of irrigation. By

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tracking this trajectory, the article demonstrates the remarkable agency of a pumping collective in renewing and reassembling itself. On this basis, we argue that the complex entanglement of material objects, human actors, water (and other resource flows) can explain this. Hence, it is important to look beyond the society-nature dichotomy to understand the transformational capacity of collectives.

Keywords
Water governance, agency, collective action, pumps & pipelines, irrigation management

Introduction

In recent decades, critical water studies have emphasized the need to transcend epistemologies that divide water, technology, and society into separate ontological realms (Linton, 2010; Swyngedouw, 1996). The hegemonic conception of "modern water" as a natural resource detached from society has arguably led to environmental destruction, but also to analytical straightjacketing (Swyngedouw, 2009). In the fusion of society, technology, and water flows, the components evolve relationally and become inseparable as long as it lasts. The life history of a pumping collective can illustrate who or what acts together in this process.

But, first, what is a pumping collective and how is it assembled? How do, pumps, pipes, and canals shape collective action around water flows, and how does nature act in this equation? These are relevant questions when studying how human, material, and water properties of agency collaborate and invisibly "dance" together in making water worlds (Pickering, 2012). Understanding agency as collaborative requires a focus on the complex interconnections and partial confluences that emerge between people, technology, and water flows in everyday water-use practices. It is one way to account for the material and natural qualities of water flows in infrastructural landscapes that co-shape collective action.

In this article, we investigate the agency of a pumping collective in the Central Nile Delta, as it increasingly adapts to an insecure water supply. The improved pumping collective with a single lifting point and imposed organizational form faces the limitation of collective access to water flows as they are available. Further constraints are the decreasing availability and a downstream position in the larger Nile irrigation and drainage network. We show how the pumping collective unexpectedly dismantles its straightjacket and replaces it with a more disaggregated form of irrigation. On this basis, we argue that the remarkable agentive capacity of a pumping collective to reassemble itself emanates from the heterogeneous assemblage and emergent properties of "material" objects, "human" actors, and water flows. This is important because policy actors generally explain collective action with dichotomous models of rational actor behavior, best practice blueprints, or universal natural laws. We show that a pumping collective's success cannot be explained by design principles, blueprint improvement, or environmental factors per se. Instead, we suggest the key is their transformational capacity.

We focus on this extreme but insightful case having analyzed a large variety of pumping collectives in the Nile Delta. The study purposefully sampled and constructed this particular case study to understand collective action and agency under water scarcity conditions by means of mixed research methods. For heuristic purposes, it focuses on a single pumping collective on the Hoz *mesqa* (tertiary canal)[1], along the (secondary) Ibrahim branch canal of the Meet Yazid command area in the central part of the Nile Delta. We studied in detail the everyday life and sociotechnical trajectory of this pumping collective under severe water scarcity. A series of water management surveys, which we have reported elsewhere, resulted in the sampling of this case (Ezzat El-Agha et al., 2020; Molle et al., 2018; Molle et al., 2019; Rap et al., 2019). Given the qualitative objective of understanding the nature of agency, no statistical representativeness was sought. Sampling criteria for the mesqa were technical and organizational improvement (as defined below) and size (>50 feddan)[2]. The willingness of farmers to cooperate in the research was of crucial importance. Also key to this article were three months of fieldwork (June–August 2013) in the selected mesqa for a Master's thesis, combining observation, semi-structured interviews, GPS and participatory mapping, and EC measurements (de Bont, 2013; Rap, 2020). Several subsequent follow-up visits in 2014 and 2015 completed the picture. Results were analyzed according to a qualitative methodology inspired by grounded theory, which integrates quantitative data.

Following this introduction, we start with a theoretical discussion and a review of irrigation development in the Egyptian Nile Delta. The article then describes the four life phases of a pumping collective at the tertiary level, focusing on particular moments of uncertainty when it is transformed by new associations (Rap, 2017). Using the term "life phases" to recount this (hi) story does not imply a linear progression in time, but intends to show the interactive nature of infrastructural development and highlights the changes as well as the continuities in the pumping collective. The life phases are indicated by the dominant water-lifting devices and irrigation technologies in use: sakias (1950s–1970s), mobile diesel pumps (1980s), collective pumping stations (2003–2013), and a deep pipe-collective (2013–present). Finally, the conclusion presents our contributions to the debate about agency in water collectives.

Theoretical discussion

In the 1980s, Walter Coward (1980, 1986) introduced "hydraulic property" to explain water users' collective action in managing their shared hydraulic infrastructure. Farmers and governments establish hydraulic property or ownership rights when they invest in the construction of new irrigation systems or the modernization of existing systems (Rocha López et al., 2019). This creates normative arrangements and institutional structures for irrigation management on a collective basis. By identifying both object–user relationships and user–user relationships, Coward interlinked humans and non-humans in understanding collective action, yet the role of water availability was lacking.

In response, Uphoff et al. (1990) proposed a curve that related the value of collective action to the availability of water (see Figure 1). Collective action increases when moving from an abundance of water to relative scarcity, but decreases when approaching absolute scarcity. In our Egyptian case, irrigation scheduling is the prime expression of collective action, which follows this curve. To view water availability as an exogenous environmental factor and disregard the role of technology in this relationship is a limitation associated with environmental determinism.

Building on these ideas, Elinor Ostrom (1990) developed a neo-institutional theory to "craft institutions for self-governing irrigation systems" that came to inspire much water policy. Ostrom views institutions for collective action in common property resource management as "rules in use," and identified "the core design principles used in long-enduring, self-organized irrigation institutions throughout the world," helping to account for "the success of these institutions in sustaining the physical works and gaining the compliance of generations of users to the rules in use" (Ostrom, 1993: 1907). Ostrom identified eight design principles in irrigation institutions, which are useful as normative principles, but less so in analyzing collective action and water user organization in practice. Ostrom conceptualized a collective as individual rational actors grouped under a nested system of rules and incentives. Such an understanding structurally delimits agency and disregards technology. Society, technology, and nature remain separate realms.

So how can we rethink wet collective action in a way that transcends the society-nature dichotomy? Science and Technology Studies is useful to investigate how associations between society, technology, and water flows transform collective action. De Laet and Mol (2000) examined the

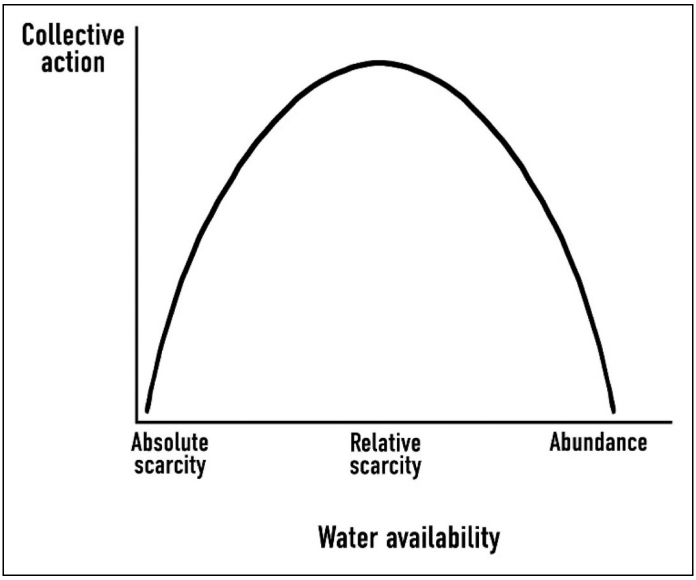

Figure 1. Curve depicting the relationship between collective action and water scarcity (free after Uphoff et al., 1990).

Zimbabwe Bush Pump as a technology of water access, fluid in its boundaries, incorporating users. Thus, it is a changeable object, holding its form by shifting its relations (Law and Mol, 2001). While pumping water, it also builds community: It brings together water users, villagers, and families. Barnes (2012) subsequently pointed out that pumps can also fragment downstream communities, for example by releasing more saline water. Both convergent and divergent forces deserve equal attention.

To understand the ontological weaving of water, society, and pump technology, the concept of heterogeneous assemblage is useful. It points to the intertwining of human and non-human worlds in interspecies engagements and their emergent effects in a wider landscape. Anna Tsing (2015) shows how these precarious wholes proliferate and overcome society-nature dichotomies. She conceptualizes such assemblages as open-ended entanglements, in which various natural histories and social rhythms intersect and shape each other. Tsing avoids structural or environmental determinism by recognizing the latent agency to act collectively in “entanglements that might be mobilized in common cause” (2015: 135).

Assemblage foregrounds “modes of ordering”: self-reflective strategies to configure heterogeneous entities that collaborate, disintegrate, or reassemble (Law, 1994; Wester, 2008). Agency is then “the result of associating humans and non-humans to form precarious wholes” (Müller, 2015: 27). To move beyond a concept of agency as solely attributable to humans, we view it as the ability “to make a difference,” through a continuous “dance” by human and non-human agents (Pickering, 2012). The association of various humans and non-humans results in a collective agentive potential (Mitchell, 2002). The constituents of this collaboration become something new and greater than the sum of its parts (Rutland and Aylett, 2008). Centripetal and centrifugal forces act on an assemblage and can shift its span, boundaries, and composition and its relationship with the wider environment (Bolding, 2008). A processual assemblage can thus transform its environment within flexible limits.

Concretely, therefore, a pumping collective is a shifting assemblage of wet infrastructure and lifting technologies used by a bounded water user community that facilitates multiple flows of water, energy, power, money, identity, and life (Larkin, 2013; Latour, 1987; Law, 1994; Kortelainen, 1999; Rap and Van der Zaag, 2019). The crucial act of pumping irrigation water is the lens through which we study the collective as the unit of analysis, which has particular but shifting boundaries. These composite beings acquire emergent properties and unexpected agentive potential through their working associations (Pickering, 1995). We operationalize the pumping collective as a living hybrid, by studying the confluence of distinguishable yet mutually dependent parts, when they assume collective action. Shifting associations within partial and fluid wholes sustain a pumping collective, albeit with a precarious degree of cohesion.

Marais's conception of a termite colony can serve as a useful metaphor when studying the assemblage of a pumping collective in its recurrent transcending of the society-nature dichotomy (Marais, 1937):

> [H]ow can I call a heap of dead earth like the termitary a living animal? Do not forget that the termitary is no more dead than the dead matter of cell walls which constitutes nine-tenths of your own body. We are ourselves no more than dead termitaries, through which a living substance circulates (Marais, 1937: 68).

Background: Irrigation development and nation-building in the Nile Delta

Long before the nineteenth century, hydraulic works reconstituted the Egyptian Nile as a social, technical, and natural phenomenon (Mitchell, 2002). For millennia, the Nile's annual flooding dominated the irrigation method: basin irrigation. When Napoleon invaded Egypt (1798–1802), he framed its hydraulic mission as follows: "If I am to rule this country, I will never allow a drop of fresh water to flow to the Mediterranean Sea" (cited in El Quosy and Khalifa, 2017; Wester et al., 2009). In response, Muhammed Ali (1805–1848) introduced deeper summer canals for the perennial irrigation of Lower Egypt (Willcocks, 1913). "The founder of modern Egypt" centralized water control to constitute a nation-state. Reconfiguring the Nile was important to govern the national territory. The Pasha and his successors constituted a state apparatus through the construction of hydraulic works, villages, towns, army barracks, and railway lines. At the vanguard stood an emerging hydraulic bureaucracy that principally used European expertise to "improve" the entire Nile river network and foment perennial irrigation of industrial cotton and sugarcane (Drayton, 2000). State formation contributed to a supply orientation in water management. The national hydrocracy increasingly centralized irrigation management activities: (1) storage, (2) distribution and rotations, (3) lifting points.

Through irrigation and drainage laws, the state regulated perennial irrigation and semi-autonomous pumping collectives in the Delta with varying degrees of success. The irrigation district licensed lifting points and calibrated the intakes to cap discharges (El Gamal and Zaki, 2017). Paper archives were kept of the locations, diameters, and farmer-leaders.

The British colonial state developed this system further primarily based on expertise from India (Willcocks, 1913; Ozden, 2014). Military engineers retook Muhammed Ali's deep canals for perennial irrigation that had fallen into disuse. With the building (1902) and heightening of the Aswan Dam (1912, 1933, 1970), Nile barrages, and an extended irrigation and drainage network, the colonial state increasingly regulated Nile flows into the coastal lakes, enabling the reclamation of coastal lands. Post-colonial military governments further reinforced this statist and supply orientation in agricultural water management, nationalized reclamation, and formed agricultural cooperatives.

In the postcolonial era, geopolitical relations continued to shape Nile water governance. In the aftermath of the 1979 Camp David Peace Accords, American and Western donor support for water projects increased. For four decades, successive irrigation improvement projects were implemented in the Nile Valley and Delta, financed by USAID, the World Bank, KfW, and the Egyptian government. These “national projects” institutionalized neoliberal policy to reduce public expenditure, decentralize irrigation management, increase water-user participation, and improve water-use efficiency (Molle et al., 2018; Molle et al., 2019; Rap, 2006; Rap et al., 2019). The improvement projects also influenced Egyptian attempts to limit increasing domestic and transboundary tensions as a result of a creeping water crisis in the Egyptian Delta (Merrey, 1998). This crisis was enveloping the larger Nile river basin as upstream countries developed hydroelectric projects and claimed more water, as epitomized by the Ethiopian Renaissance Dam (GIRD) built in the turmoil after the 2011 Egyptian Revolution.

Within this larger picture, we now zoom in on one pumping collective, Hoz, and its social and technological trajectory. It is situated along the Ibrahim branch canal in the northern part of the command area of the Meet Yazid main canal. This is a coastal area to the south of the Burullus lake in the northern Nile Delta, between the river branches. Ibrahim Canal receives water from Meet Yazid in an on/off rotation that is highly unpredictable, particularly in times of water scarcity.

The Hoz pumping collective is situated on a *hosha*—a circumscribed unit of reclaimed wetland. The name reflects the interdependent history of aquaculture and agriculture in the informal reclamation and settlement of these seasonally flooded, brackish marshlands. During the twentieth century, private and public companies reclaimed more of this lake area, extending cultivation in lots of 60 or 80 feddan, also referred to as *hoshas*. After canal and drain construction, fresh water was directed to the hoshas to leach them, while they were closed to prevent seawater from entering. Several hoshas were named after the first settlers, in this case the Hoz family. When referring to the *Hoz mesqa*, people mean the entire pumping collective of 81 feddan, including the shared infrastructure belonging to the community involved in lifting and distributing water. The Hoz collective is presently located in the middle reach of the Ibrahim branch canal, where water access has become critical in terms of quantity and quality (Ezzat El Agha et al., 2020).

In the following sections, we will present four consecutive life phases of the Hoz pumping collective.

Four phases in the trajectory of a pumping collective

1 Colonial improvement collectivized irrigation

Muhammed Ali’s deep canals for perennial irrigation were reliant on water lifting (Hopkins, 2005).[3] Along deltaic mesqas, this consolidated *sakia rings*, that is, circles of small to medium farmers sharing one *sakia* to lift and distribute water to the fields (Hopkins, 2005). A sakia is a Persian water wheel, which proliferated through the Middle East to Roman Egypt (de Sainte Marie, 1989; Gouda, 2016; Hopkins, 1999; Noaman and El Quosy, 2017). Farmers collectively invested capital and labor to build, operate, and maintain (O&M) a sakia and irrigate in rotation (Coward, 1980). Extended kinship and village relationships often tied together a sakia ring, but wealth, power, and generational differences also sustained collective action. The sakia head, usually a large landowner, patriarch, and family elder, whose authority rested on respect and submission, organized O&M and conflict resolution (Hopkins, 1999; Gouda, 2016). An operator maintained the sakia and was paid in kind by ring members. Sakia operation distributed embodied competencies to the operator, users, animals, and lifting devices. Members also maintained the mesqa through annual cleaning and dredging (Hopkins, 1999). State, cooperative, and village institutions, and Arab conflict resolution mechanisms, recursively shaped these pumping collectives, gradually shifting state-water user relations (Gouda, 2016).

The sakia ring is a living composite in which humans and non-humans converge around the activities to collect, lift, and distribute water flows (see Figure 2). In this composite assemblage, a waterwheel was powered by animals and farmers to collectively lift water from the mesqa to a field canal (*marwa*). As centrifugal forces balanced centripetal ones, the cow walked endless circles, carving out a trail. This heterogeneous assemblage increased water's potential energy and transformed it into kinetic energy directed through and dissipated by field canals. An associated "fuel" flow that powered the collective consists of Egyptian clover (*berseem*), a fodder crop, which animals convert to energy for lifting water and manure to improve the soil.

The critical moment of water stress in perennial irrigation was during hot summer months, demanding high water supply to meet crop transpiration. Due to a limited discharge (15 l/s) of the animal-powered sakias, irrigating one feddan took almost a day, and farmers had to rotate cows and buffalos (Gouda, 2016). As a result, other farmers waited impatiently for their turn, and conflict would erupt (Hopkins, 2005). A collective solution was an irrigation schedule that established consecutive irrigation turns (*warsha*) along the marwa (Gouda, 2016). Yet, to increase water supply farmers also reassembled the sakia ring. Larger, vertical, and metal sakias gradually increased the discharge capacity and irrigated surface. Sakias were increasingly powered by diesel engines and external fuel sources, which gradually increased the agency, reach, and irrigated surface of the water-lifting collective (see Figure 3). Amplifying the agency of the sakia ring meant reducing the demand on local human and non-human labor and fuel sources, but increasing their dependence on supra-local scales for water, fertilizer, mineral, and energy flows (Mitchell, 2002).

Replacing humans and non-humans in a pumping collective does not erase its shared trajectory, however. Mature trees can be seen today that were planted during reclamation to shade the animals as they make their endless turns of the sakia. Corrugated sakias lie about. The spatial configuration of the hoshas and sakia rings continues to shape land and water use. The canal intake, the mesqa perpendicular to the branch canal, the lifting points along it, and the corresponding marwas and

Figure 2. An animal-powered metal sakia (Photo: F. Molle).

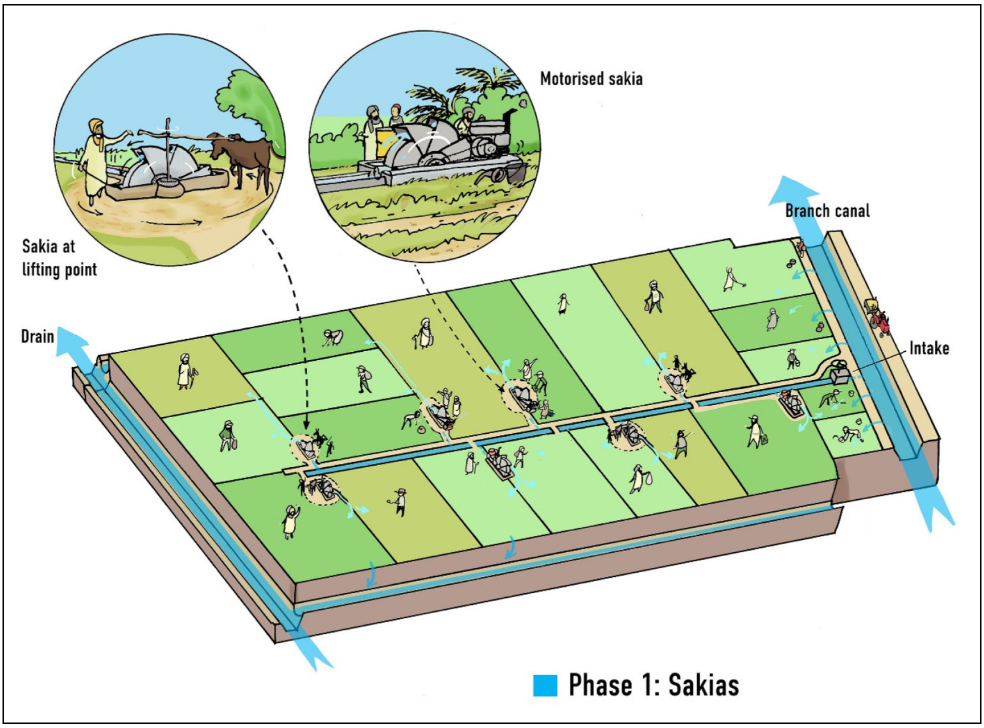

Figure 3. The spatial distribution of the Hoz pumping collective with sakias (Artwork: O. Rijcken).

fields bounded by drains are still in partial use. Particular nodes and patterns of the evolving pumping collective continue to matter and exercise agency. In the Hoz mesqa, all 17 of the original sakia locations (3–5 feddan) went on to serve as lifting points.

The life and history of this pumping collective in the Hoz mesqa is interwoven with the extended Hoz family and their collective memory (de Bont, 2013). The family's story provides a foundational myth and organizational identity to the hosha which enables collective action, even among the currently diverse group of water users (landowners, tenants, and sharecroppers) who are no longer immediate family. Hence, the Hoz collective is a water-user community using the mesqa infrastructure in a concrete place, but it is also an imagined collective with a history of settlement.

2 Mobile pumping dismantles the sakia ring

In the second life phase, collective water lifting with a sakia fragmented into more autonomous nuclear families and farmers with mobile pump sets along the mesqa. Major events manifested as centrifugal forces. First, the High Dam (1972) reinforced the shift from sakias to mobile pumps by supplying more water, which relaxed water control at the branch and mesqa level and expanded irrigation opportunities. Meanwhile, discharge and irrigation schedules that restricted water access contributed to farmers' increasing dissatisfaction with the sakia rings (de Bont, 2013). Second, after a petroleum boom and Sadat's open-door policy in the late 1970s, the freer borders meant that many farmers migrated to work in the Middle East and Europe and began to send home remittances. Some of this, and other semi-urban income sources, was invested in new irrigation technology (de Sainte Marie, 1989), namely the portable diesel pumps that appeared on the market. Relatively affordable Indian, and later Egyptian, pump sets became available to ever more rural families with migrant and urban income. Migration also coincided with the weakening of social and family structures, and with water-user diversification (buying, renting, or sharecropping land), further undermining collective action in the sakia rings (Gouda, 2016).

These centrifugal forces led to the eventual demise of the sakia rings, ending collective water lifting and distribution in many places. Since the 1980s, the sakia ring as a composite entity gradually disassembled into smaller independent entities of farmers with mobile pump sets along a mesqa (Barnes, 2012; de Sainte Marie, 1989; El Gamal and Zaki, 2017; Gouda, 2016; Ruf, 1986) (see Figure 4). Water use became more flexible through the use of these mobile pumps which could abstract water where and whenever available. Overall, this improved farmers' individual water access and reduced irrigation time, drudgery, and insecurity. The new pump mobility enrolled non-humans, such as animals, tractors, and cars (see these "multispecies engagements" in Figures 2 and 5 (Tsing, 2015)) and opened up the crucial possibility of pumping directly from a branch canal or drain to reuse drainage water (Roest, 1999).

In their turn, centrifugal forces were kept in check by centripetal forces. At the level of the Hoz mesqa, a centrifugal force was the cohesion based on family relations and a collective identity. Although operating ever more autonomously, the fragmented pumping farmers also remained partially past-dependent on the hosha layout, marwa orientations, and sakia locations. For water acquisition they still collectively depended on the same mesqa intake. The collective task of the seasonal cleaning and maintenance of the mesqa and marwa canals remained necessary. The waterwheels at the marwa heads were gradually replaced by open pits, which became pump sumps from which

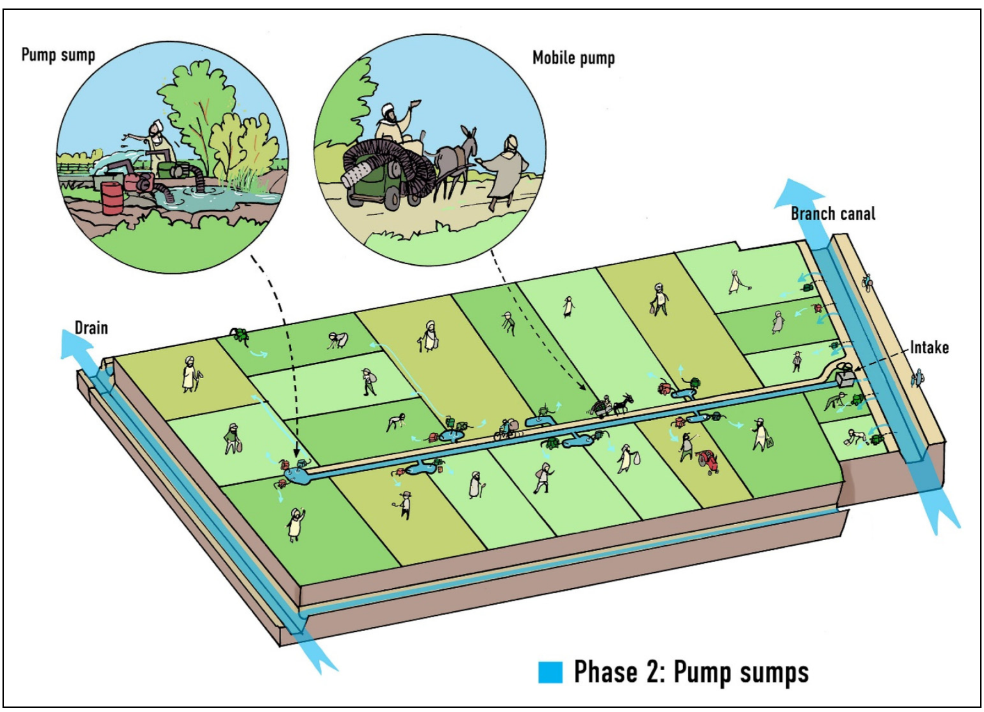

Figure 4. Mobile pumps transform the pumping collective (Artwork: O. Rijcken).

Figure 5. Farmers using a donkey to move a portable pump set to a water source (Photos: E. Rap).

numerous diesel pumps would lift water to the marwa level. Pump sumps often emerged at the same location as the sakias. Farmers also still shared the marwa canals. It is for these reasons that de Sainte Marie (1989) somewhat optimistically claimed that "the introduction of these new materials [did] not lead to the fragmentation of irrigation communities of the Delta" (p.82).

The increasingly diffuse and unregulated pumping by a multitude of farmers around the Nile Delta in response to an unpredictable rotational water distribution impacted water management (IWMI and WMRI, 2013). Because mobile pumps could take water directly from canals, farmers started to crowd in time. The resulting peak use increased the importance of the canals' storage capacity but induced higher fluctuations in a once more constant flow rate during the on-period. Further, over-irrigation by head-end farmers to secure water whenever available and store it in the soil profile resulted in increasing head-tail differences along canals. Night irrigation was also largely abandoned. At the national policy level, farmers were blamed for over-irrigating and wasting water, while the cost of public irrigation management was rising. In international policy and expert debates, these trends resulted in a series of internationally financed projects to improve Egyptian irrigation management in the Nile Delta: the Irrigation Improvement Projects (Molle et al., 2019).

3 Irrigation improvement assembles a new pumping collective

In a third life phase, from the 1980s onwards, "improvement projects" implemented technological and institutional blueprints to address diffuse pumping and over-irrigation in the Nile Delta (Molle et al., 2019). The solution was to regulate pumping collectives by concentrating pumping in a single station with a standard organizational form. International donors supported these "national projects" of the Ministry of Water Resources and Irrigation (MWRI) with finance and expertise. In this phase, Hosni Mubarak's government (1981–2011) reinforced neoliberal policies. The normative direction was to transform the supply orientation of the hydraulic bureaucracy and its infrastructural expenditure into reducing both demand and public expenditure.

Four improvement measures reassembled the pumping collective:

1. Continuous flow in branch canals;
2. Branch Canal Water User Associations (BCWUAs);
3. Collective pumps at the mesqa level;
4. Water User Associations (pump station WUAs).

Continuous flow promised to improve farmers' irregular water supply, yet was ineffective for reasons of structure, management, and bureaucracy (Molle et al., 2019). Consequently, the existing rotation schedule between branch canals remained (e.g. 4–5 days on, 4–5 days off at Ibrahim Canal). The absence of continuous flow in the branch canal reinforced the weak organization of water users in the BCWUAs. These branch-level interventions did not support or build on mesqa-level improvements or water-user participation (Rap et al., 2019).

Improvement projects replaced all the mobile pumps in an open mesqa with a single lifting device at the intake and a pressurized pipeline operated by a WUA. Water users managing a collective pumping station were expected to restore the former collective action of the sakia rings. In fact, the pumping collectives aggregated the farmers, infrastructure, and irrigated area of all the sakias pertaining to the same mesqa.[4] The trajectories emanating from these infrastructural blueprints varied immensely: disuse, appropriation, reshaping, fragmentation, parallel use, and other adaptations. Moreover, the organizational blueprints produced mixed results, which we analyze elsewhere (Molle et al., 2019; Rap et al., 2019). Improvement projects reassembled precarious pumping collectives that only persisted when farmers succeeded in appropriating these collectives for use.

Technocratic expertise works as an effect of the neatly separated realms of social and technical interventions in improvement projects (Mitchell, 2002; Murray Li, 2007). Irrigation improvement organized institutional and infrastructural interventions as dichotomous and top-down processes (Gouda, 2016; Rap et al., 2019). The Irrigation Improvement Sector (IIS) carried out the technical design of collective pumping stations, while the Irrigation Advisory Service (IAS) designed and implemented WUAs for these stations. In the ministerial structure with a strong civil engineering tradition, design and construction positions in IIS had more authority, privilege, and money than locally stationed IAS engineers. These professional and bureaucratic hierarchies skewed the design and assemblage of infrastructural and organizational blueprints.

In IAS, WUA formation preceded the design and construction of collective pumping stations, which were later transferred to WUAs. Despite the formal procedures, water-user participation in the design of the WUAs and collective infrastructure was minimal, limiting their sense of hydraulic property. At the Hoz mesqa, IAS engineers arrived with the aim of acquiring the signatures of five influential landowners to establish the WUA board and initiate and receive works. If they refused, others would be approached. The five men who signed at the Hoz mesqa represented four landowning families connected to the original founding family. Water users understood that only these privileged signatories were effective WUA "members," rather than all the users (including landowners, tenants, and sharecroppers). Notwithstanding most farmers' opposition to mesqa improvement and enforced collective action, the promise of continuous flow was very appealing. Landowners were due to contribute to the cost of improvements, but at the time of research they had not yet paid anything (Molle et al., 2019).

Water users only selectively adopted and appropriated these formal models. The five initial WUA members were not reappointed, and several have since died without being replaced. Consequently, while the WUA figured on paper, and at the government-water user interface, it did not determine the everyday collective action at the mesqa: operation, maintenance, administration, or conflict resolution. Yet, the establishment of WUAs was not entirely without repercussions, as we will see in the next phase.

IIS engineers designed the collective pump station and irrigation network from an office in Cairo and barely consulted water users over its construction. In 2003, IIP staff reassembled the pumping collective by bringing around 30 farmers together in a WUA with a pumping station and piped mesqa serving 81 feddan. The set-up facilitates water to flow from the branch canal through an intake structure, via a pit, the pumping station (a concrete building with two diesel pumps), and a tower to regulate pressure, into the mesqa pipe. Several outlets (valves) along the pipe deliver water to smaller field canals (marwas) and then to nearby fields. Engineers located the valves at the exact same locations as the 17 original sakias (phase 1) and the later pump sumps (phase 2). The resulting layout thus significantly reproduced the original hosha and the field and canal orientation (see Figures 3, 4, 6, 9). While improvement did not radically alter the hosha's spatial boundaries, it concentrated, rescaled, and restricted pumping through a single lifting device. Centralized pumping required collective action in water distribution, maintenance, and administration. For the irrigation administration, a single pumping station together with a WUA also centralized control.

The central node in the life of this reassembled pumping collective became the pumping station (see Figure 6). The continuous buzz, flows, smells, and activities in and around the pumphouse demonstrate how pumps connect with people walking in and out to ensure water flows to their fields. The constant activity and flow of people, water, energy, and other fluids are similar to a termitary (Marais, 1937). The liveliness contrasts with several other pumping stations along the branch canal that were abandoned and became derelict and overgrown with weeds. When a pumping collective disintegrates, its pumping station stops working. Between those extremes of life and death, many precarious pumping collectives proliferate.

Central to the everyday management of the Hoz pumping station are two young men, who are not WUA members: Ramses, the operator, and Musa, the treasurer. They both have land in the mesqa and were chosen because of their honesty and reliability. In the summer of 2013, we observed Ramses on a daily basis around the pumping station, busy with starting up the diesel pumps, checking the pressure in the tower, organizing the diesel supply, and arranging the irrigation turns among farmers. Ramses is the only one with a key to the pumping station and is constantly involved in its operation (Figure 7). With the fluctuating water levels, this means he has to be reachable day and night, as farmers irrigate continuously. In the early morning, he carries a flashlight. Farmers see Ramses as responsible for the pumping station and pay him a small salary. The

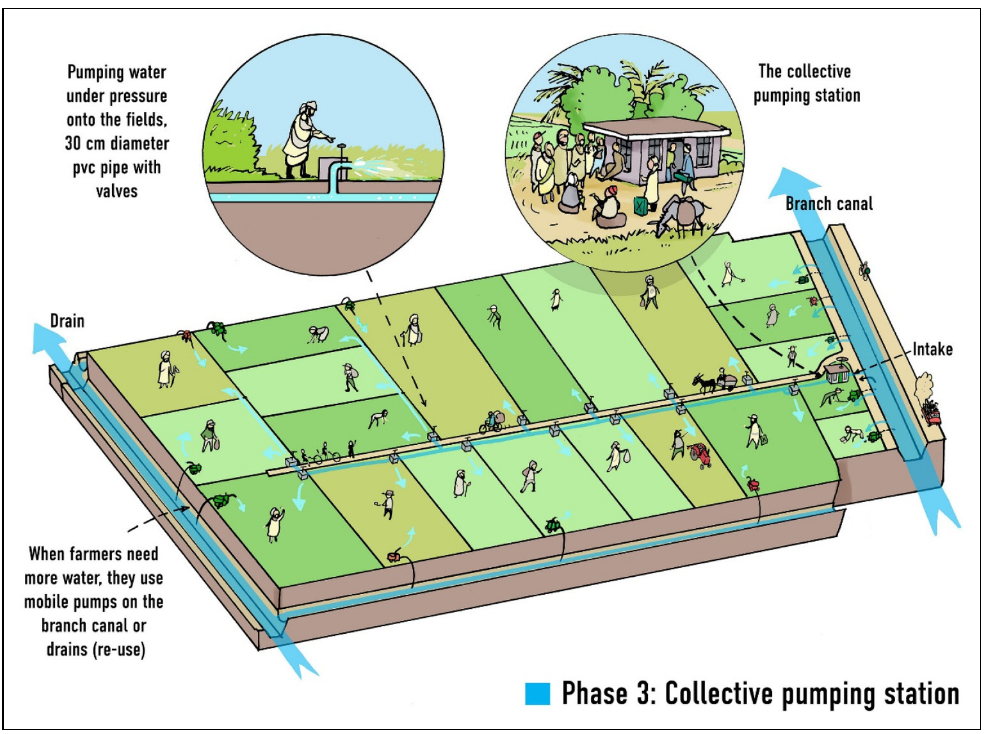

Figure 6. A pumping collective under improved irrigation (Artwork: O. Rijcken).

Figure 7. The operator and treasurer fixing a pump problem with a mechanic (Photos: C. de Bont).

embodied competence of this operator in connection with the pumping station enables collective water distribution (Rap and van der Zaag, 2019).

Musa is another unobtrusive character, who partakes in the pumping collective by mediating flows of water and money. He was selected as treasurer because of his ability to read, write, and account. He is a farmer but also a primary school teacher, as the former treasurer before him. Musa goes around to collect fees for the O&M of the pumping station (per feddan per season). In July 2013, one of the pumps needed to be remounted on its frame, as it was shaking heavily. The men organizing this were Ramses, Musa, and one other young farmer from the mesqa, aided by a mechanic. Two days later, the other pump needed repair. This time only Ramses and the mechanic were there to fix the malfunction. The following day, none of the farmers expressed any concern about the repair or its cost. For policymakers, the scalability of cost recovery is a daunting aspect of collective action, yet these events show the value of involving trusted local characters in the everyday life of the pumping station. It is perhaps telling that young people, rather than the older WUA members, manage the repair work, although it was older family representatives who chose them for the job. Nonetheless, collective action in the pumping collective does not necessarily follow the formal WUA (Rap et al., 2019).

Farmers describe the Hoz mesqa as having relatively little conflict. Problems may occur during rice transplantation in summer (April–September), when everyone needs ample water, but they tend to solve any differences in the field or through Ramses. If this fails, they might call the oldest family members to mediate. These familial structures and the idea of honesty are more influential in decision-making than any formal position. Ramses and Musa are trusted to make small O&M decisions. When a larger point of infrastructure is involved, farmers get together with different family representatives. Some—but not all—of these men are WUA members. They will in turn consult their families and come out with an approved decision.

Little conflict does not mean equal participation, however. Different water users are unequally integrated into the pumping collective. Their relationship with land, pumps, water-, energy- and cash flows, but also with family, village, gender, generational and power differences determines their place in the pumping collective. Obvious discrepancies exist between landowners, sharecroppers, and tenants, principally through their differences in (hydraulic) property and access to land and water infrastructure. Sharecroppers do not get a say in infrastructural investments and in water management. These differences in turn intersect with categories of class and gender (Rap and Jaskolski, 2019). In the Baz mesqa, the majority of land is owned by older men, who are dominant in decision making. Women do not own land, unless they are widowed, and are limited by social rules from speaking out at men and irrigating at night. Patriarchal family and village relations, extended kinship, as well as wealth, power, and generational differences, sustain collective action.

Without continuous flow, a rotation on the branch canal limits the pumping collective in summer, requiring irrigation scheduling. In winter, rotation water is plentiful, so an on-request system operates, but in summer, water demand increases to full supply. Rice transplantation (May–June) in particular requires ample water. The former treasurer divided the irrigated area into four parts—two upstream and two downstream—to be irrigated alternately (e.g. for half a day). One plot is irrigated after the other, and farmers have to wait their turn. The schedule is not written down, but farmers are aware of their irrigation turn. The schedule is perceived to be fair and just.

The collective pumping station was meant to eradicate unregulated pumping and over-irrigation. Yet, farmers unexpectedly kept their mobile pumps to overcome collective irrigation restrictions, especially when continuous flow remained elusive. After improvement, the mobile pumps moved from the pump sumps along the open mesqa to the field drains. Here, they could reuse drainage water immediately after an irrigation turn to supplement insufficient canal water supply. The unforeseen centrifugal force causing this outward movement was compensated by a centripetal force at the drain, where drainage water was now pumped and injected into the marwa in an opposing direction. The pumps and their farmers achieved remarkable inversions, subverting the classical head-tail structure: the tail temporarily converts into head and drainage water becomes irrigation water again and vice versa. While centrifugal forces pull the pumping collective apart, centripetal forces keep it together—provisionally. Reconnecting the mobile pumps to the pumping collective gives individual farmers additional water besides the collective pumping station. This is the decentralized room for maneuver with which farmers' pumps attenuate the limitations of the collective and the precarious water supply. The agency to re-pump drainage water mixes hydrosocial and sociotechnical flows irrevocably, as well as transforming the water quality, potential energy, and salt content.

Mobile pumps contributed to convergence here, but they can also have a divergent effect. While the waterscape boundaries of the pumping collective remained largely intact (81 feddan), they spatially contracted where one family benefited from direct access to the branch canal. These farmers escaped dependence on the pumping station with a mobile pump at the branch canal. They greatly improved their water access by placing the pump's inlet pipe far lower than the intake structure of the pumping station, enabling them to irrigate at lower canal levels. This family excluded itself from the pumping collective by not using its valve or paying fees. Consequently, 75 feddan were irrigated with only 16 valves.

Since 2003, heterogeneous changes gradually reassembled the pumping collective as a precarious whole. That year, the pumping collective replaced all the stolen valves and two broken-down pumps. To increase pumping capacity, they introduced two dual-piston diesel pumps, one of which was replaced by an electric pump in 2009. This partly disconnected the collective from regular diesel shortages but connected it to an electricity grid with power cuts. Irregular energy and water flow patterns coexisted. In 2010, farmers lowered the intake and later the pit of the pumping station to access whatever water was available from the main canal. Although four families still dominated the decision-making, certain family and village structures gradually disintegrated with the further diversification of the user population. Divergent forces thus competed with convergent forces and contributed to a reassembling of the pumping collective.

With reduced water availability, in 2013 the Hoz pumping collective found itself in a unique spot where canal and drainage water meet, which is visible with low water levels. This meant it was located at the tail of both water flows with uncertain water supply, aggravated by the lifting technology (explained below). The causes of this uncertainty were clearly explained by one of the farmers: "We never really know when and whether the water will reach us. Upstream farmers might use more water and the water might not reach here. The gate might also be closed before water gets here." Farmers believed that their situation was better before the improvements: no night irrigation, sharing, drainage water reuse, and everybody was responsible for their own mobile pump. This statement illustrates the farmers' frustration: The new technology decreased their water access, whilst increasing the transaction costs of collective action.

4 A pipe collective decentralizes pumping

The last life phase shows the collective agency to reassemble a pumping collective from below.

Clandestine pipelining of the Egyptian Delta occurs under the radar of government institutions. Several local workshops produce large cement pipes (between 60 and 80 cm in diameter) for subsurface water conduct. As keen observers of the surrounding environment, the Hoz mesqa water users noticed that some pumping collectives had introduced radical changes. These included replacing the pumping station and its pressurized pipe network by a deep pipe allowing decentralized and semi-autonomous pumping. They approached an experienced local builder, Hussain, to submit a tender for the reassembling of the Hoz collective, which they then approved. In the politically unstable aftermath of the Arab Spring and roughly a decade after IIP improvement, Hussain reengineered the pumping collective in three months over the winter of 2013–2014.

Walking along the improved mesqa, we appreciate the smart but unobtrusive redesign of the pumping collective. The former pumping station and pipe network are replaced by a 5-m-deep, 80 cm, concrete pipe that takes in water directly from the branch canal and continues underground to the drain (see Figure 8). There are several manholes along the pipe so it can be aired and cleaned. The pipeline of more than 800 m has a light slope from head to tail of around 6–8 cm per 100 m for gravity flow. A tailgate structure reveals a dual nature: enabling the pipe to release excess water, while letting drainage water in for reuse. The depth, gradient, and connectedness of the concrete pipe maximize water supply from both branch canal and drain and minimize seepage, thus improving the supply-demand ratio of the pumping collective. The enlarged pipe size also facilitates water storage. The deep pipe connects with a series of parallel masonry boxes, which are lifting points from which farmers can irrigate using a portable pump, thereby overriding the irrigation schedule.

Bottom-up improvement differs from, while retaining elements of, the improvement project. A central leader in this transition was Hag Anwar Sadat, an influential and respected water user with land in the Hoz collective. In late May 2014, he explained that the idea to reassemble the pumping collective had emerged a year earlier. Although he had been a WUA president some years earlier, he said the board was not really functioning anymore and therefore had no role in this transition. Hag Anwar recounted that he had presented the central idea of the project at an initial meeting attended by 45 water users, who discussed and finally accepted it. A paper was signed by the attendees to confirm their financial commitment. A committee of 10 men was appointed, which interacted with workshop owner Hussain as the responsible implementer. Besides Anwar there were at least two representatives of the influential Hoz family in the group. Hag Anwar was the oldest

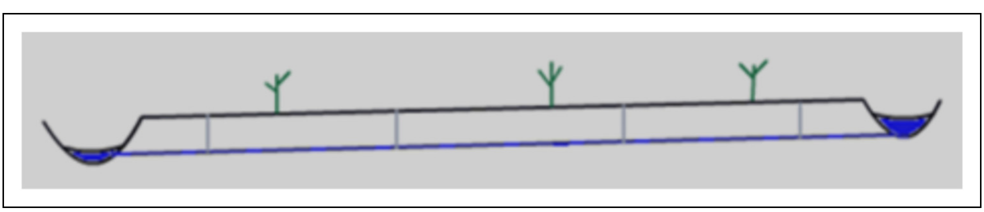

Figure 8. A side view of the new pumping collective (Drawing: E. Rap).

person in the committee and water users trusted him and the proposed project. Hussain enhanced the positive impression, because his workshop had carried out similar projects with good results.

The "ability to pay" is remarkable given the general policy challenge of resource mobilization among WUAs and BCWUAs (Ghazouani et al., 2012). Anwar began collecting money from the 45 landowners and first paid three quarters of the estimated expenses to Hussain, retaining a quarter of 10,000 Egyptian pounds until after a guarantee period of one year. The landowners paid Hussain around 2000 Egyptian pounds/feddan or 185 EP/meter of replaced mesqa pipe. However, from these total expenses, Hussain discounted the revenue from selling the used materials from the pumps, pipes, and valves. Despite being controversial, since the pumping station was not yet the legal property of the water users, this collective act reinforced their hydraulic ownership of the pumping collective. Furthermore, Hussain claimed that the mesqa improvement was three times cheaper than state improvement (200 EP/meter versus 600 EP/meter).

Hag Anwar explained that the principal reason for the radical transformation was the water stress experienced by users given the unpredictable water supply, single lifting point, and restricted irrigation time. At the branch canal, an ideal rotation in summer was four days "on" and six days "off." In its mid-canal location, sufficient water would reach the intake on only two days on average during the on-period. Hence, the irrigation time often amounted to 40 min/feddan/2 days in summer. This was rarely sufficient during rice transplantation, particularly when rice cultivation significantly expanded after the Arab Spring (IWMI and WMRI, 2013). Although the irrigation schedule was meant to reduce conflict, farmers increasingly experienced this problem. The interconnection of water stress with the sociotechnical and financial ability of the pumping collective to "make a difference" constituted the agency for its radical reassemblage.

Interestingly, this new mesqa set up, with continuous water availability, partially mirrors the idea of continuous flow, promising to reduce irrigation intensity. To escape collective irrigation and an irrigation schedule, the new pipe collective incorporates inflow from several sides (canal, drain, and field drains). The deep pipe also connects to many lifting points for farmers to irrigate independently with their mobile pumps. For this reason, Hussain surveyed how many irrigation points the farmers wanted. His survey resulted in 29 irrigation points, partially replacing the 17 former valves. Some who shared a valve before now have their own opening, for which they paid extra (Figure 9).

Farmers using the new pipe system state that it works better than the former pumping station, since it facilitates irrigation and improves water availability. If canal water is not available, drainage water can be used. Consequently, no water stress has been experienced since the peak of rice transplantation. Autonomy in irrigation timing is also valued. While farmers acknowledged the higher salinity of the drainage water, they preferred this to no water. Water is always present in the drain, whereas the branch can be empty for up to 10 days. Particularly in the critical summer period, farmers are not prepared to wait for water that is not coming. Water users thus experience less shortage and can immediately use water when it is available. Another advantage is the storage capacity of the 80 cm pipe, which allows opening intakes and round-the-clock access to water. Tail-end farmers in the mesqa anticipated the standing water in the pipe to be of lower quality, and that head-end users would receive more and better water. It remains to be seen how the new configuration will affect those without land or a pump. These and other effects, as well as the process of bottom-up improvement, should be part of more systematic and longer-term evaluation.

Radical reassemblage and bricolage of new and existing components recompose the pumping collective:

- Collective action to install a deep pipe similar to IIP to reduce evaporation and seepage with multiple lifting points allowing individual access.
- Collective investment creates and renews hydraulic property relations.

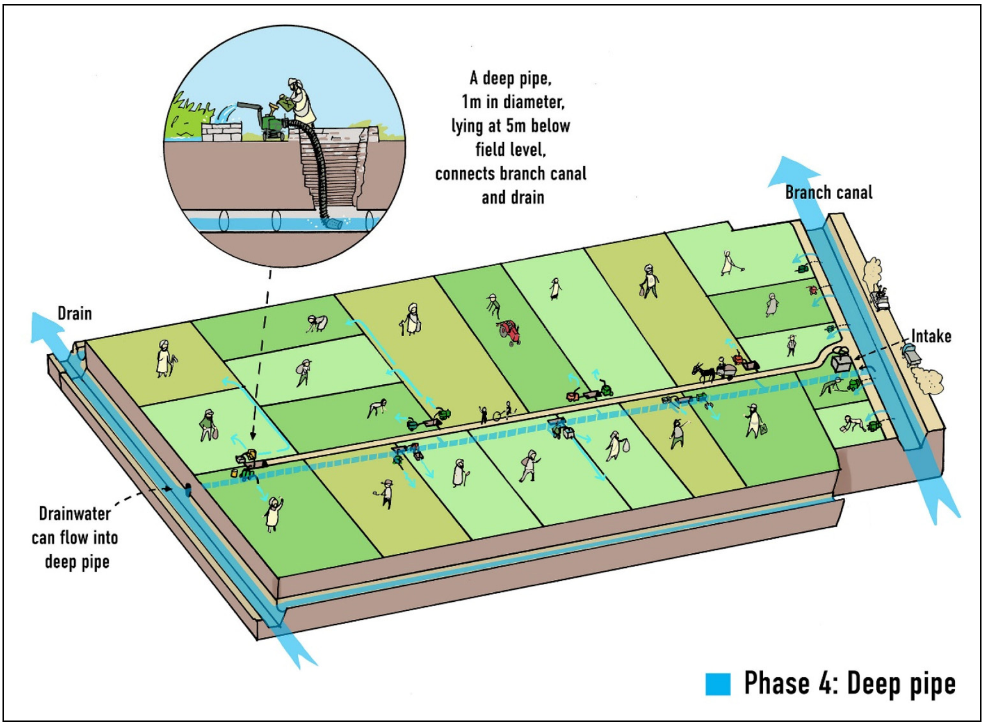

Figure 9. Radical reassemblage of the pumping collective (Artwork: O. Rijcken).

- Manholes, patterned on those of the subsurface drainage systems, provide multiple lifting points allowing individual access.
- The promise of continuous flow has partly materialized at the mesqa scale.
- Drainage water reuse is further incorporated.
- Deep pipes reflect Muhammed Ali's policy of perennial irrigation.
- Former WUA president leads reassemblage of the new collective, building on earlier trust.
- The Hoz collective, its foundation myth, identity, and familiar local names persist.
- Conflict resolution mechanisms possibly survive.
- Exclusion of land with direct pumping from the branch canal is confirmed.

The "endogenous" improvement of the pumping collective selectively appropriated the various design principles and blueprints of technocratic improvement. This bottom-up mode of ordering heterogeneous components exclusively interlaces parts of social, familial, and organizational structures with spatially situated, sociotechnical arrangements that lift and distribute water more fluently. The collective agency to reassemble a pumping collective under severe water scarcity and political unrest partially rests on making connections between human and non-human actors. The collective ability to reduce water scarcity shows that this is not simply an exogenous variable.

However, reassembling the Hoz pumping collective to increase water intake also has negative cross-scale implications, since ultimately the collective is but one among others along a branch canal, all tied together in the zero-sum game of water allocation. By lowering their intake, Hoz farmers contravened an age-old prerogative of state engineers—that of determining the sill level and size of mesqa intakes in order to limit abstraction and ensure equity along the branch canal.

Indeed, downstream pumping-collectives were conscious of their reduced water supply and complained to the ministry without effect. They were also considering a similar reconstruction of their pumping collective. However, from the state's perspective, this radical reassemblage is considered destructive. These are the limits to a positive bottom-up story. Still, the case provides hope, fragile as it may be.

Conclusions

This article shows how a complex entanglement of communities, technology, and water flows produces the agency to transform water access through collective infrastructure. Rather than separating the human and non-human agency, we chose to recognize their interconnection. You can dance by yourself, but the dynamic of moving together surpasses individual expression. The four life phases demonstrate that the pumping collective is a heterogeneous and shifting assemblage of human and non-human agents that provides differentiated access to multiple resource flows. The trajectory of the pumping collective consolidates a number of related farmers who consecutively irrigate their land with shared sakias, mobile pumps, a collective pumping station, and finally a deep pipe.

What stands out in the last phase is that the collective acts together to partially escape collective action. Nevertheless, the radically transformed collective survives as a functioning whole. Overcoming the restrictions inherent in a single pumping station, unilaterally imposed improvements, political instability, and irregular water supply, the pumping collective radically dismantled the standard set up and replaced it with a more flexible, autonomous, and disaggregated pipe collective. Hence, we argue that this remarkable agentive capacity to reassemble the pumping collective recursively shapes the complex assemblage of material objects, human actors, and water flows. Looking beyond the society-nature dichotomy is important to understand the transformational capacity of collectives.

The Hoz case demonstrates the agency of a pumping collective enabling it to radically reassemble itself and transform water flows in multiple ways, for example through:

- increasing water quantity by reusing drainage water, albeit compromising water quality;
- decentralizing the pumping collective by allowing autonomy in water lifting, thereby escaping irrigation schedules while retaining collective water-acquisition and distribution infrastructure;
- reshuffling water-access points and patterns of uniformity/equity;
- altering the fixity/mobility/fluidity of pumps;
- selectively appropriating and reproducing familial, communal, and organizational structures engaged in water use;
- changing the composition of the pumping collective and its waterscape, while the Hoz collective lives on.

The pumping collective largely retains its spatial and infrastructural orientation and shared identity over time, providing continuity in change. There is power in the longevity of the hosha and its shifting sociomaterial and cultural form: "An agency which represents the limits of human agency" (Miller, 2010: 94). This agency arises from a heterogeneous assemblage and shifts with every new component translated into this configuration.

The radical reassemblage of this pumping collective is remarkable but not unique. Its sociotechnical trajectory partly overlaps with others, experiencing: disuse, appropriation, reshaping, fragmentation, parallel use, and other adaptations (Molle et al., 2019). Some nearby pumping collectives under comparable water scarcity conditions have adopted a similar solution, when they succeeded in mobilizing sufficient collective action for this risky step. Understandably, such collective action that escapes state authority did not originate in formal WUAs. We see how water governance structures that try to formalize collective action through WUAs sometimes fail to grasp their (lack of) effectiveness at multiple scales and in different areas (Rap and Wester, 2017).

The aim of this case study has been to understand the heterogeneous and shifting nature of agency in a pumping collective. We seek not to essentialize this single case, nor to scale it up as an improved model for collective action. Nonetheless, the analytical perspective developed for this case highlights several wider trends and possibilities for generalization:

- Similar pumping collectives increasingly dominate water management globally, using surface and groundwater, in rural as well as urban spheres. Their analysis as heterogeneous assemblages offers the demonstrated advantages to understand their collective agency. As the termitary metaphor gave an understanding of the pumping collective as a living arrangement, the latter idea may also have a wider application.
- Pervasive pipelining of water networks in response to temporal and spatial scarcity and abundance produces pipe collectives which reassemble water flows and materialize water use (Björkman, 2015; Jensen and Morita, 2017; Shah et al., 2010; van der Zaag and Rap, 2012). The gradual and global tubing of water is often framed in terms of improving efficiencies. This case offers an additional reason to doubt such claims (Lankford et al., 2020).
- Irrigation engineers make functional distinctions between irrigation and drainage infrastructure, but the practice of water use often collapses them again (van der Zaag, 1992).
- Blueprint policies are characterized by systemic, and sometimes wilful, ignorance of agency and heterogeneity, by the mindsets they embody and indeed their very nature.
- Shifting state-water user relations are also embedded in this heterogeneous agency. The shift to mobile pumps marks an uncontrollable challenge to the old management regime with its sakias, calibrated sill levels and sizes, field enforcement, etc. IIP was an attempt by the state to "restore order" and control: the state designs, sizes the pumping station, imposes an institutional blueprint, promises (unachievable) continuous flow, all in the name of modernity and efficiency. But the very flaws of a uniform design imposed on heterogeneous environments and collectives could not keep it together. Farmers took advantage of a weaker state in troubled political times to once again reshape the pumping assemblage. So agency very much shapes, and is shaped by, structural and infrastructural transformation and dependence.
- These radical reassemblages have ramifications for diverse resource flows at much wider scales. For example, by introducing diesel pumps, farmers became increasingly involved in a wider economy of diesel, fertilizers, and other carbon-based fuels. This might lead to management changes upstream in the river basin, when water managers, politicians, and users, or upstream Nile countries, become aware of, or misinterpret, these trends. Further, they may also alter the vision of donors, such as the World Bank, which is now limiting funding for on-farm improvement.

Our perspective on pumping collectives has added the following points in terms of understanding:

1. Perceiving not only the "social of the technical," but also the "technical of the social" in a collective[5]. The deep pipe enables and/or hampers collective action. Centripetal and centrifugal factors mean technology is an energetic part of the collective.
2. By foregrounding (rather than backgrounding) "non-humans," we understand how their interconnections actively reconstitute the relationship between collective action and water scarcity, or the pumping collective and its "environment" (Figure 1 needs refinement).
3. Comprehending both continuity and change. The pipe collective holds its form by changing components and connections.

4. The metaphors of the sakia, termitary, and pumping collective serve to investigate what animates the world beyond humans (Marais, 1937; Ghosh, 2022).
5. Agency is a heterogeneous accomplishment, emanating from the confluence of people, technology, and flow.

Highlights:

- How people, technology, and water flows act together to transform collective infrastructure and improve water access.
- Pumping collectives as heterogeneous and shifting assemblages of (non-)human agents.
- Understanding both the "social of the technical" and the "technical of the social."
- The life history of a pumping collective illustrates who and what act together and acquire agency.
- Metaphors help to investigate what animates the world beyond humans.

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Notes

1. All names in this article are anonymized.
2. One feddan equals roughly one acre or 0.4 hectares.
3. In Egypt, colonial improvement has recurrently fomented collective irrigation through water-lifting devices (Oleson, 1984). Around 600 BC, Roman Egypt introduced the cattle-driven sakia that (groups of) farmers used to lift water from the Nile (Noaman and El Quosy, 2017), while the domestication of the Nile buffalo and cows preceded that significantly. Willcocks (1913) counted more than 110,000 sakias in Egypt at the start of the twentieth century. Ruf (1986) estimates that in 1982 there were more than 300,000 sakias in Egypt, each irrigating between 5 and 10 feddans.
4. Where sakia rings abstracted water directly from the secondary canals, these would be regrouped under a single collective pumping station with a pipe serving former marwas.
5. We thank Prof. Van der Zaag for this expression in personal communication.

References

Barnes S (2012) Pumping possibility: Agricultural expansion through desert reclamation in Egypt. *Social Studies of Science* 42(4): 517–538.

Björkman L (2015) *Pipe politics, contested waters: Embedded infrastructures of millennial Mumbai*. Durham: Duke University Press.

Bolding A (2008). *In hot water: A study on the sociotechnical intervention models and practices of water use in smallholder agriculture, Nyanyadzi catchment, Zimbabwe*. PhD Thesis, Wageningen University, The Netherlands.

Coward EW (1980) *Irrigation and agricultural development in Asia: Perspectives from the social sciences*. Ithaca: Cornell University Press.

Coward EW (1986) Direct or indirect alternatives for irrigation investment and the creation of property. In: Easter KW (ed) *Irrigation Investment, Technology and Management Strategies for Development*. Boulder, Colorado: Westview Press, pp.225–244.

de Bont C (2013). *Responses to the Irrigation Improvement Project: An analysis of water users' re-ordering of the socio-technical water network*. Masters Thesis, Wageningen University, The Netherlands.

de Laet M and Mol A (2000) The Zimbabwe bush pump: Mechanics of a fluid technology. *Social Studies of Science* 30(2): 225–263.

de Sainte Marie C (1989) État et paysans dans les systèmes hydrauliques de la vallée du Nil (Egypte). *Études Rurales* 115–116: 59–91.

Drayton R (2000) *Nature's government: Science, imperial Britain and the 'improvement' of the world*. New Haven: Yale University Press.

EL Gamal T and Zaki N (2017) Egyptian Irrigation after the Aswan high dam. In: Satoh M and Aboulroos S (eds) *Irrigated Agriculture in Egypt: Past, Present and Future*. Cham: Springer, pp.47–79.

El Quosy D and Khalifa HEH (2017) Control of the Nile's flow: The Introduction of perennial irrigation for modern agriculture. In: Satoh M and Aboulroos S (eds) *Irrigated Agriculture in Egypt: Past, Present and Future*. Cham: Springer, pp.29–45.

Ezzat el-Agha D, Molle F, Rap E, et al. (2020) Drainage water salinity and quality across nested scales in the Nile Delta of Egypt. *Environmental Science and Pollution Research* 27: 32239–32250.

Ghazouani W, Molle F and Rap E (2012) *Water users associations in the NEN region: IFAD interventions and overall dynamics*. Report submitted to IFAD. Cairo: IWMI.

Ghosh A (2022) *The Nutmeg's Curse: Parables for a Planet in Crisis*. Chicago: The University of Chicago Press.

Gouda DM (2016) *Social capital and local water management in Egypt*. Cairo: The American University in Cairo Press.

Hopkins NS (1999) Irrigation in contemporary Egypt. In: Bowman A and Rogan E (eds) *Agriculture in Egypt: From Pharaonic to Modern Times*, Oxford, UK: Oxford University Press. pp.367–387.

Hopkins NS (2005) The rule of law and the rule of water. *Égypte/Monde Arabe* 1: 173–186.

IWMI and WMRI (2013) *An exploratory survey of water management in the Meet Yazeed Canal command area of the Nile Delta*. Water and Salt Management in the Nile Delta Project, Report No. 1. Cairo: IWMI, WMRI.

Jensen CB and Morita A (2017) Introduction: Infrastructures as ontological experiments. *Ethnos* 82(4): 615–626.

Kortelainen J (1999) The river as an actor-network: The Finnish forest industry utilization of lake and river systems. *Geoforum* 30(3): 235–247.

Lankford B, Closas A, Dalton J, et al. (2020) A scale-based framework to understand the promises, pitfalls and paradoxes of irrigation efficiency to meet major water challenges. *Global Environmental Change* 65: 10282.

Larkin B (2013) The politics and poetics of infrastructure. *Annual Review of Anthropology* 42(1): 327–343.

Latour B (1987) *Science in Action: How to Follow Scientists and Engineers through Society*. Milton Keynes: Open University Press.

Law J (1994) *Organizing Modernity*. Oxford: Blackwell Publishers.

Law J and Mol A (2001) Situating technoscience: An inquiry into spatialities. *Environment and Planning D* 19: 609–621.

Linton J (2010) *What Is Water? The History of a Modern Abstraction*. Vancouver: University of British Columbia Press.

Marais E (1937/1973) *The soul of the white ant*. Harmondsworth: Penguin.

Merrey DJ (1998) Governance and institutional arrangements for managing water resources in Egypt. In: Mollinga P (ed) *Water Control in Egypt's Canal Irrigation – A Discussion of Institutional Issues at Different Levels*. Wageningen: Wageningen University, pp.1–22.

Miller D (2010) *Stuff*. Cambridge: Polity.
Mitchell T (2002) *The rule of experts: Egypt, technopolitics, and modernity*. Berkeley: University of California Press.
Molle F, Gaafar I, Ezzat El-Agha D, et al. (2018) The Nile delta's water and salt balances and implications for management. *Agricultural Water Management* 197: 110–121.
Molle F, Rap E, Ezzat El-Agha D, et al. (2019) Irrigation improvement projects in the Nile Delta: Promises, challenges, surprises. *Agricultural Water Management* 216: 425–435.
Müller M (2015) Assemblages and actor-networks: Rethinking socio-material power, politics and space. *Geography Compass* 9(1): 27–41.
Murray Li T (2007) *The Will to Improve: Governmentality, Development, and the Practice of Politics*. Durham, NC: Duke University Press.
Noaman MN and El Quosy D (2017) Hydrology of the Nile and ancient agriculture. In: Satoh M and Aboulroos S (eds) *Irrigated Agriculture in Egypt: Past, Present and Future*. Cham: Springer, pp.9–28.
Ostrom E (1990) *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge: Cambridge University Press.
Ostrom E (1993) Design principles in long-enduring irrigation institutions. *Water Resources Research* 29(7): 1907–1912.
Ozden C (2014) The pontifex Minimus: William Willcocks and engineering British colonialism. *Annals of Science* 71(2): 183–205.
Pickering A (2012) Material Culture and the Dance of Agency. In: Hicks D and Beaudry MC (eds) *The Oxford Handbook of Material Culture Studies*. Oxford: Oxford University Press, pp.191–208.
Pickering A (2014) (1995) *The Mangle of Practice: Time, Agency and Science*. Chicago and London: University of Chicago Press.
Rap E (2006) The success of a policy model: Irrigation management transfer in Mexico. *Journal of Development Studies* 32(2): 1301–1324.
Rap E (2017) Performing accountability: Unanticipated responses to administrative reform. *Human Organization* 76(4): 358–369.
Rap E (2020) The skill of writing observations: What Monique taught me. In: Rasch ED, Salemink O, Büscher B and Köhne M. (eds) *Engaged Encounters: Thinking About Forces, Fields and Friendships with Monique Nuijten*. Wageningen: Wageningen Academic Publishers, pp.189–190.
Rap E and Jaskolski M (2019) The lives of women in a land reclamation project: Gender, class, culture and place in Egyptian land and water management. *International Journal of the Commons* 13(1): 84–104.
Rap E and van der Zaag P (2019) Engaging with flows: Embodied cognition in water provision. *Water* 11(1751): 1–20.
Rap E and Wester P (2017) Governing the water user: Experiences from Mexico. *Journal of Environmental Policy & Planning* 19(3): 293–307.
Rap E, Molle F, Ezzat El-Agha D, et al. (2019) The limits to participation: Branch-canal water user associations in the Egyptian Delta. *Water International* 44(1): 31–50.
Rocha López R, Boelens R, Vos J, et al. (2019) Hydrosocial territories in dispute: Flows of water and power in an interbasin transfer project in Bolivia. *Water Alternatives* 12(1): 267–284.
Roest CWJ (1999) Regional water distribution in the Nile delta of Egypt. Draft report.
Ruf T (1986) La sakkia égyptienne, interface entre l'aménagement hydro-agricole et les systèmes de production paysans enseignements pour l'aménagement de grandes zones irrigables. *Documents Systèmes Agraires* 6: 375–381.
Rutland T and Aylett A (2008) The work of policy: Actor networks, governmentality, and local action on climate change in Portland, Oregon. *Environment and Planning D* 26: 627–646.
Shah T, Krishnan S, Hemant P, et al. (2010) A case for pipelining water distribution in the Narmada Irrigation System in Gujarat, India. IWMI Working Paper 141. Colombo, Sri Lanka: International Water Management Institute.
Swyngedouw E (1996) The city as a hybrid: On nature, society and cyborg urbanization. *Capitalism Nature Socialism* 7(2): 65–80.

Swyngedouw E (2009) The political economy and political ecology of the hydro-social cycle. *Journal of Contemporary Water Research & Education* 142(1): 56–60.

Tsing AL (2015) *The mushroom at the end of the world: On the possibility of life in capitalist ruin*. Princeton, NJ: Princeton University Press.

Uphoff N, Wickramasinghe ML and Wijayaratna CM (1990) “Optimum” participation in irrigation management: Issues and evidence from Sri Lanka. *Human Organization* 49(1): 26–40.

van der Zaag P (1992) *Chicanery at the Canal: Changing Practice in Irrigation Management in Western Mexico*. Amsterdam, The Netherlands: CEDLA.

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

Wester P (2008) *Shedding the waters: Institutional change and water control in the Lerma-Chapala Basin, Mexico*. PhD thesis, Wageningen University, The Netherlands.

Wester P, Rap E and Vargas-Velázquez S (2009) The hydraulic mission and the Mexican hydrocracy: Regulating and reforming the flows of water and power. *Water Alternatives* 2(3): 395–415.

Willcocks W (1913) *Egyptian Irrigation*. Volume 2. London: E & FN Spon.