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Ruling by Canal: Governance and System-Level Design Characteristics of Large-Scale Irrigation Infrastructure in India and Uzbekistan

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ABSTRACT: This paper explores the relationship between governance regime and large-scale irrigation system design by investigating three cases: 1) protective irrigation design in post-independent South India; 2) canal irrigation system design in Khorezm Province, Uzbekistan, as implemented in the USSR period, and 3) canal design by the Madras Irrigation and Canal Company, as part of an experiment to do canal irrigation development in colonial India on commercial terms in the 1850s-1860s. The mutual shaping of irrigation infrastructure design characteristics on the one hand and management requirements and conditions on the other has been documented primarily at lower, within-system levels of the irrigation systems, notably at the level of division structures. Taking a 'social construction of technology' perspective, the paper analyses the relationship between technological structures and management and governance arrangements at irrigation system level. The paper finds qualitative differences in the infrastructural configuration of the three irrigation systems expressing and facilitating particular forms of governance and rule, differences that matter for management and use, and their effects and impacts.

KEYWORDS: Canal irrigation, design, governance, management, India, Uzbekistan

INTRODUCTION

Large-scale irrigation systems have sparked the imagination of social scientists for a long time. Karl Wittfogel (1957) proposed a theory of 'hydraulic societies' in which 'oriental despotism' was linked to the need for centralised control of extensive irrigation canal systems. Despite heavy criticism of Wittfogel's thesis, it inspired a lot of research, notably in anthropology, on the role of irrigation in development, and the role of the state in irrigation management. The school-making anthropologist Clifford Geertz, for instance, has looked closely at Balinese irrigation, for theorising the nature of the Balinese state and the role of religion in its state-society configuration and, comparatively, how cultural and natural resource contexts shape irrigation infrastructure and institutions in Bali and Morocco (Geertz, 1972, 1980).

The continued presence of Wittfogel in irrigation and water infrastructure studies, notwithstanding the quite devastating critiques, may be related to the role large-scale water infrastructure has played in post-independence development planning. The post-independence pursuit of planned development in many developing countries had a strong emphasis on large-scale water infrastructure investment (irrigation, hydropower and flood control). It has been aptly described as the pursuit of a 'hydraulic mission' (Allan, 2006). The term captures the dedication with which irrigation and water resources bureaucracies have remained focused on building large scale infrastructure, notably storage dams, to 'harness' the world's rivers.

Critical analysis of these state-led large-scale infrastructure based development strategies has often taken a binary form. Such analyses have suggested that instead of large-scale infrastructure focused approaches, small-scale, village or community-based development strategies should be pursued ('small is beautiful' vs. 'big is beautiful'), they have condemned the 'western' and 'imperialist' origins of the science and technology used to build large-scale infrastructure, and suggested the need for a focus on 'indigenous' science and technology, while proponents have posited 'modernity' against 'tradition' and 'backwardness'.[1] Single-adjective characterisations of large-scale canal irrigation, be it as large, modern, western, imperial, centralised, hierarchic, wasteful or as anything else, suggest how these large technological systems have been 'technologies of rule' (Lansing, 1991) for governments and part of societal development of a particular kind. They tend to leave, however, these infrastructures as 'black boxes' in a binary counterposing to 'local' and 'traditional' forms of water control. Critical approaches do not, in our view, ask in sufficient detail what it is about large-scale irrigation infrastructure that makes it part of particular projects of rule. They, consequently also do not ask whether and how large-scale irrigation infrastructure could be designed differently to suit other forms of rule, say, incorporating equity, democracy and sustainability concerns. Addressing these two questions would seem necessary to us for transcending the "strategic essentialisms and analytical reductionisms" (Baviskar, 2003) associated with binary framings.[2]

Theory and methodology

The theoretical perspective we draw on to translate this claim into a grounded argument is the literature on technology-society relations that started as the 'social construction of technology' perspective (Pinch and Bijker, 1984). We are interested in the question whether and how irrigation system technology bears the imprint of the societies in which that technology was designed and constructed. Irrigation studies using a 'social construction' perspective have provided good evidence on how individual irrigation artefacts bear this imprint. In particular, how so called division structures are the materialisation of property rights in and entitlements to water and the associated water management principles and practices, is well researched (Coward, 1986a,b; Gerbrandy and Hoogendam, 2002; Boelens and Vos, 2014). The study of individual artefacts, however, does not capture system characteristics. It is these system characteristics that are the focus of this paper – on the (complex systems theory) premise that it matters how the components of irrigation systems are put together, i.e. what the system's structural configuration is.

The plausibility of our premise is suggested by, for instance, the already mentioned example of Balinese irrigation. Horst (1996) reports farmer responses to the Indonesian government's 'irrigation modernisation' remodelling of division structures of Balinese *subak* irrigation in the 1970s. His analysis shows the relevance of the technical design characteristics of division structures not only for irrigation management *sensu stricto*, but for the broader cultural, political and economic logic of this irrigation society. Bolding et al. (1995), who set out to map the missing infrastructural link in social science accounts of Bombay Presidency (India) irrigation development in the early 20th century (notably the work of Attwood, 1985, 1987), is a second supportive example. They found a dynamic and contested process of infrastructure innovation, internally related (Sayer, 1984) to the 'social' dimensions of irrigation development, which was invisible in extant social science accounts.

[1] For an interesting exception to this schematic in the Indian context, see Attwood (2007), who argues that 'small is deadly' and 'big is wasteful'.

[2] On binaries in social analysis, also see Castree (2002).

Our characterisation of the 'governance regimes' associated with the irrigation systems discussed loosely draws on the 'cultural political economy' perspective as developed by Sum and Jessop (2013). "Loosely" because our aim is not to contribute to state theory and governance analysis as such, but to understand how the economic, political and cultural 'context' of irrigation system design and construction acted as a 'selection environment', and thus shaped and shapes the system characteristics of the irrigation systems we study. The cultural-political-economic trinity functions as a background heuristic for descriptive exploration of the relevant elements of the governance 'context' in a way that avoids (disciplinary) reduction to a single dimension. The focus on 'governance' rather than on the (cultural) political economy more broadly, derives from the fact that the irrigation systems studied were created as a part of state-led development efforts, and built by state agencies or under their strong tutelage.

The paper undertakes a qualitative comparative analysis (Mollinga and Gondhalekar, 2014) of selected situations (irrigation systems), by means of which structural similarities and differences can be explored. We selected two irrigation systems in India (one built in the colonial era (the Kurnool-Cuddapah Canal), one post-independent (the Tungabhadra Left Bank Canal), and one in Uzbekistan built in the Soviet period (the Khorezm irrigation system). All three are large-scale gravity surface canal irrigation systems, built as part of state-led development projects, strongly shaping, if not defining, the regional economies they are part of. We consider them as being of one kind in this general sense. The differences of interest are the (hypothesised) combined variation in governance regimes under which the systems have been conceived and built and their technical characteristics.

Methodologically our endeavour faced several challenges. Generally speaking, irrigation engineers hardly write about the technical part of their work, particularly not about the design and construction *process*.[3] The process dimension is relevant because, notwithstanding the proverbial 'blueprint' approach of civil engineering, the large-scale irrigation systems discussed in this paper were in all likelihood, apart from the main structures (river offtake, dam, main canal), *not* designed in great detail before construction started, and much was adapted and improvised ongoing.[4] Original design documents of the three systems, to the extent that they existed, were virtually untraceable.[5] What is 'published' are the final outcomes, often in the form of maps and accompanying design tomes with 'hydraulic particulars'.

As a result, research on the technical characteristics of the systems had to be done largely through close observation and inference. We therefore selected systems with which we were well acquainted through fieldwork,[6] made use of what limited documented design evidence we had access to, and, to allow contextualisation of technical data, focused on systems that are otherwise reasonably

[3] As one reviewer of this paper correctly pointed out, this was different in colonial times in India, when engineers had active and lively discussion in journals and technical papers on field-level technical design issues (see Mollinga et al., 1995 for evidence of this). One of the mysteries of Indian irrigation history is the abrupt halt of this in the 1950s.

[4] For the Tungabhadra Left Bank Canal this is very clear (see Mollinga, 2003).

[5] For the KC Canal built in the 1860s we haven't been able to find any, and it is not even clear in what form they existed; only documents on recent infrastructure rehabilitation exist. For the Uzbekistan system built in the 1950s-1980s they may exist, but, if so, uncovering may require extended archival search. From interaction with engineers in Uzbekistan we infer that field-level design documents in construction may have been no more than rudimentary maps, possibly with more detailed drawings of the division points. For the Tungabhadra Left Bank Canal constructed in the 1950-1970s the first author managed to find some of the design tomes of one secondary canal during 1991-1992, and save some of that information, lying in field irrigation offices, from heat, dust and termites.

[6] Both authors graduated with an MSc degree in irrigation and water engineering from Wageningen University, the Netherlands, and both did interdisciplinary PhDs of the multidimensionality of water control in large-scale irrigation (Mollinga, 2003; Veldwisch, 2008).

researched.[7] The historical circumstance that all three systems have experienced governance regime changes over time, further helped to open the 'black box' of irrigation design. The limitation of the paper that follows from this is that our analysis can at best establish 'proof of concept', and is not a systematic comparison covering all possible types of large-scale irrigation systems.

The paper proceeds as follows. Section 2 develops the 'social construction of technology' perspective that we use to unravel the technology-governance puzzle. We present the three analytical angles that we employ for the case study analysis. Sections 3 to 5 are presentations of the three selected systems in terms of the social construction of their design, the role of infrastructure in water use and management, and the significance of infrastructural traits for agrarian development. Section 6 provides a comparative summary of the three case examples to identify their qualitative differences as systems, based on the identified system characteristics. We also discuss some of the research and policy implications of our findings.

IRRIGATION SYSTEMS AS COMPLEX SYSTEMS: A SOCIAL CONSTRUCTION OF TECHNOLOGY PERSPECTIVE

Stone's description of colonial northern Indian irrigation development as a project of imperial rule captures the key message of the political economy and political ecology inspired historical literature on the role of irrigation in long-term societal change.

> [Canal irrigation] was intended to serve the perceived interests of its masters (…). In its design, modes of operation, and intended effects, canal irrigation was ultimately a cultural expression, representing the priorities and aspirations of its western architects, and was inextricably bound up with some of the most vital aspects of colonial rule (Stone, 1984: 8).
>
> (…) on a policy level it was simultaneously linked with famine prevention, revenue stability, the settling of unruly tribes, expansion of cultivation, extended cultivation of cash crops, enhanced taxable capacity, improved cultivation practices, and political stability. (ibid: 9).

The technological gigantism of Soviet rule has been described by Josephson (1995) for a broad range of technologies including canals (also see Richter, 1997). For the early history of irrigation in Soviet Uzbekistan (1924-41) as part of Bolshevik nation building, see Teichmann (2007); for the post-1939 period, see Obertreis (2007).

Analysis of the specific structural characteristics of the technical systems is sparse and sketchy in this literature. Analysis tends to focus on the developmental effects of state infrastructure projects, the symbolic importance of such projects as projects of modernity, and on what these infrastructures displace and destroy in terms of people and their livelihoods, ecosystems, and local knowledge and infrastructure (cf. Gilmartin, 1994; Weil, 2006; D'Souza, 2006; McCully, 1996; Agarwal and Narain, 1997).

To incorporate irrigation infrastructure characteristics into such analysis, we start from the SCOT (Social Construction of Technology) perspective as developed in the 1980s (Pinch and Bijker, 1984; Bijker et al., 1987; Bijker and Law, 1992).[8] The initial focus of SCOT research was to trace the 'making of…' histories of individual artefacts, whether they are bicycles, refrigerators, or machine tools (MacKenzie and Wajcman, 1985). In irrigation studies such work has inspired investigation of the role of irrigation artefacts for explaining management problems in government-managed systems. Such

[7] The Uzbekistan case has been intensively researched through ZEF's (Center for Development Research, Bonn, Germany) Khorezm project (see Lamers et al., 2014). The Tungabhadra Valley in which the other two systems are located has been the location of significant academic research on irrigation and development (see Wade, 1988; Ramamurthy, 1995).

[8] For an overview of the evolution of SCOT analysis see Bijker, 2010 (also see Wajcman, 2002). For a listing of ways in which artefacts 'have politics', see Bijker, 2006.

research studies the material dimension of the day-to-day encounters of government managers and irrigators on the canals. Important sites of contestation are the bifurcation/take-off points in the canal systems where it is determined how much water goes where, when and to whom (Mollinga and Bolding, 1996).

The SCOT-inspired literature zooming in on irrigation artefacts like division structures has yielded several insights: a) technical designs and characteristics of irrigation artefacts are negotiated outcomes; b) their technical evolution continues during their use; c) technologies co-constitute social relations and processes, in time, in space, and in terms of social differentiation. A limitation of this literature is, as noted above, that it has not attempted to understand the 'whole system' of canal irrigation, but has remained focused on components. In terms of Bijker’s (2010) discussion of the units of analysis in the evolution of SCOT approaches we seek to move the analysis of irrigation infrastructure from 'singular artefacts' to 'technological systems'.

SCOT research moved its analytical gaze away from the specific technical characteristics of artefacts and systems to other questions quite soon. It became interested in, in terms of the same classification of units of analysis, 'sociotechnical ensembles' and particularly 'technological culture', abstracting from specific infrastructure design characteristics. Also the 'large technological systems' (LTS) focus on 'system makers' (see Janáč and van der Vleuten, in this collection), as originating in the work of Hughes (1987), focuses on social, as conventionally understood, strategies and behaviour, rather than on technical characteristics. Where social construction had to be taken quite literally initially, it acquired a more metaphorical meaning in SCOT’s fusion into the field of STS (Science and Technology Studies).

We aim to advance the analytical 'reverse salient' in irrigation studies as regards system characteristics by using a conceptualisation of the 'social dimensions of technology' as consisting of a) the social construction of technology, b) the social requirements of the use of technology, and c) the social effects of technology (Mollinga and Mooij, 1989).[9] This conceptualisation draws on the (original) SCOT perspective in its focus on technical characteristics, but adds to it a social relations and political economy perspective, taking on board critiques like that of Russell (1986) and Winner (1993) that the SCOT approach lacks a substantive social theoretical component.[10] By focusing both on the infrastructure 'as such', and on infrastructure 'in use', we can use both analysis of design and construction documentation and inference from irrigation practice as ways of identifying system characteristics.

We have translated this framing into three questions, which form the three angles of analysis for our investigation of the Indian and Uzbek irrigation systems.

- What is the 'match' between the governance regime and the characteristics of the canal infrastructure?
- How are the (specific characteristics of the) canal infrastructure relevant in water management and use?
- How do the (specific characteristics of the) canal infrastructure shape the process of agrarian development?

The first question is addressed through investigating the 'histories of emergence' of the canal infrastructure designs, or their 'social construction'. In this process choices are made, which are sometimes contested, giving clues on which design characteristics carry social significance, and what

[9] Stone (1984) implicitly echoes this conceptualisation with his 'design, modes of operation and intended effects', as cited above.

[10] Such criticism prefigures later debates on Actor Network Theory (ANT), which became a major influence in SCOT/STS; see, for instance, Lave, 2015.

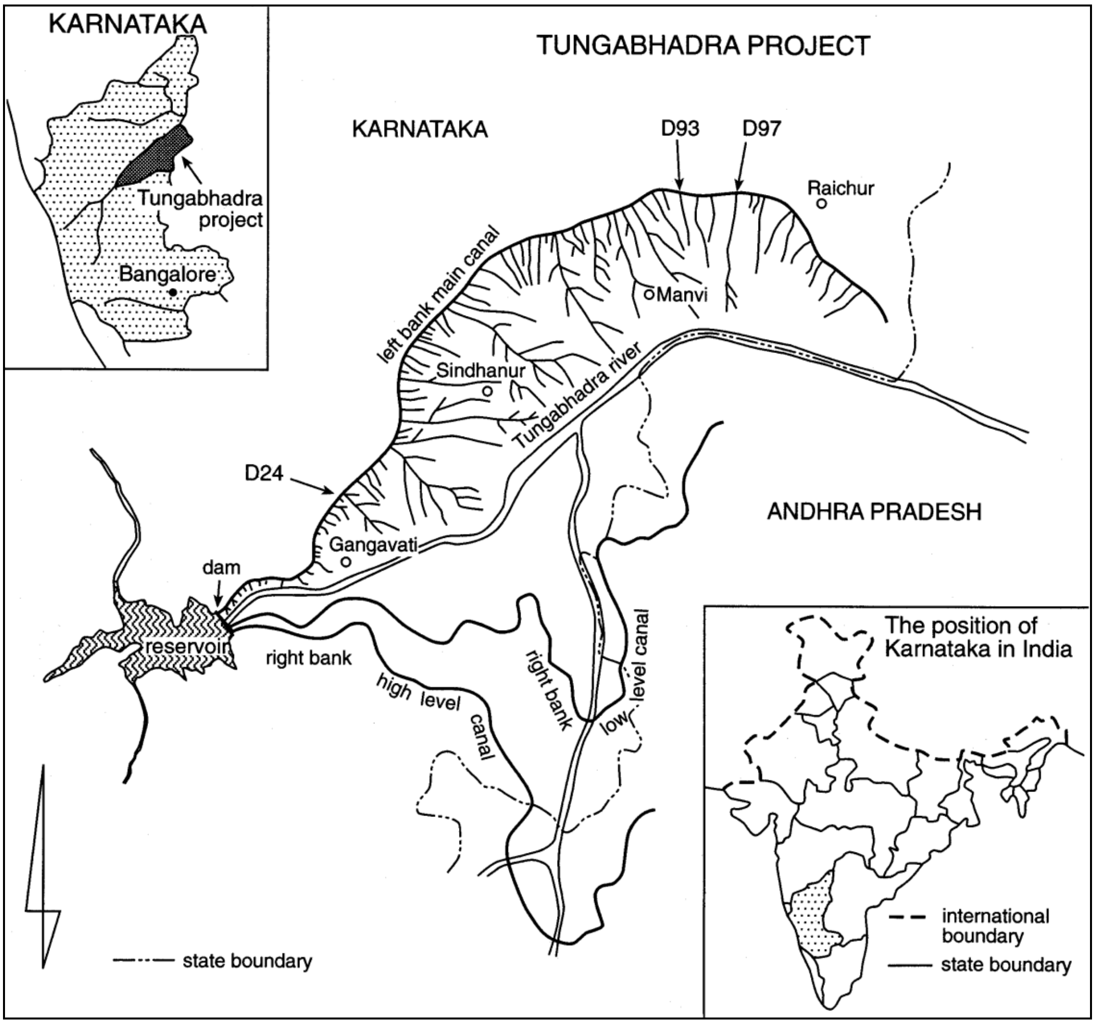
that significance is. The second question is addressed through detailed investigation of water management practices. By looking at the canal infrastructure 'in action' and at the way it is being 'remodelled' in that process, socially significant design characteristics can be traced. Lastly, the third question is addressed by situating water distribution and water use in the context of the process of agrarian (and rural) development that it helps to carry. The social meaning of canal infrastructure can be identified by looking at how canal infrastructure shapes the process of that development.

We now proceed to the presentation of the three selected irrigation systems from these three angles in sections 3, 4 and 5. At the end of each section a summary is given in the form of a table.

PROTECTIVE IRRIGATION IN SOUTH INDIA: TRANSLATING POLICY DUALITIES INTO INFRASTRUCTURE DESIGN

The Tungabhadra Left Bank Canal irrigation system is a reservoir-based protective irrigation scheme located on the Tungabhadra River, a tributary of the Krishna River, in South India, presently in the State of Karnataka (see Figure 1). 'Protective irrigation' is a category that was articulated in the second half of the 19th century, together with the notion of 'productive irrigation', as part of British Indian colonial irrigation policy (for detailed discussion see Mollinga, 2003: chapter 3).

Figure 1. Location Tungabhadra Left Bank Canal.



Source: Mollinga, 2003: 2. Note: D24, D93 and D97 are numbers of canals that were investigated in depth.

The pair productive/protective initially referred to how financially remunerative an irrigation scheme was, that is, the return on invested capital (the financial outlay) through revenue collection. Productive schemes yielded above a certain threshold (variably fixed over time), while protective systems yielded below that threshold and needed additional considerations to be constructed. Protective schemes in South India were constructed as protection against famine and aimed at spreading water thinly across a large number of farmer-irrigators. The concept was to provide supplementary irrigation to local food crops (notably sorghum and millet). Water was thus scarce by design as irrigation allowances were low and below full crop water requirements (Jurriëns and Mollinga, 1996). Protective irrigation was thus not only a financial and policy category, but also translated into specific scheme characteristics in terms of location, envisaged crops, water allowances, and, as will be shown, other infrastructure design characteristics.

Not many protective irrigation schemes were built in South India in colonial times. The productive concern tended to override protective considerations, and infrastructure investments were primarily focused on enhancing revenue collection. The boom of protective system construction came after independence in 1948, as part of the planned (rural) development approach, aiming at a combination of (food) production increase and poverty alleviation.

Irrigation systems in semiarid areas with water allowances below crop water requirements required a managerial and governance solution to the issue of rationing water: spreading a limited amount of water over a large number of agricultural producers. In South India the rationing method attempted was called 'localisation'. Localisation is a form of what would now be called land use planning, in which the government prescribes, per cadastral unit, which plots shall be irrigated and which crops shall be grown in a particular season in the concerned irrigation system, and whose violations are punishable under the law.[11] Localisation was, at least in concept, an extremely strong form of state regulation of agricultural production. The encounters this generated at the interface of government managers and the large number of smallholder farmer-irrigators are discussed below.

Main design features

The Tungabhadra irrigation system is reservoir-based, allowing 'full technical water control', that is scheduled releases into the main canal, to support a planned cropping pattern. The irrigation scheme is hierarchical in design: from the 240 km long main canal that starts at the dam a total of 87 secondary canals (called distributaries) take off by means of gated outlets, from which sub-distributaries may branch off, through gated outlets, and finally water is released into local irrigation units, again through gated outlets, in which several tens of farmer-irrigators have land. The government managers are supposed to set the gates at the outlets in a coordinated and calculated manner;[12] farmer-irrigators are supposed to distribute water amongst themselves by means of field channels. The distributary and sub-distributary canals 'command' the landscape as they are located on the ridges of the valleys and sub-valleys of the undulating landscape. The canal system is designed as a continuous flow system, having

[11] Localisation in all likelihood developed from hydraulic design practices (estimation of water demand for canal design) and what would now be called land evaluation. Localisation rules were gazetted by the revenue department of the Hyderabad State (successor of the Nizam's Dominions, one of the precursors of present Andhra Pradesh) in 1956, but the exact articulation of the localisation concept is still hidden in the archives (for details see Mollinga, 2003: chapter 3). In other regions of India the rationing requirement was operationalised differently. The Bombay Presidency attempted to introduce the so-called 'block system', while in northwest India the so called 'warabandi' system was introduced.

[12] The outlet structures at the lowest, tertiary unit level were designed as non-modular pipe outlets with steel gates, probably as a path-dependent design inspired by outlet designs in the (productive) coastal delta irrigation systems of South India. As non-modularity means dependence on both upstream and downstream water levels, which both tend to fluctuate in multiuser systems, exact determination of the outlet discharge is practically virtually impossible, assisting the unequal distribution discussed below.

no cross regulators for managing flow size and timing of water releases. The release point is at the dam; once released the water has to keep moving till it leaves the system. The canal system is thus literally a grid on top of the landscape, or in more evocative, Scott (1998)-like, phrasing, the canals as the long arms of the state reach out to every village where irrigation is envisaged, and which are thus incorporated in 'modern society'.

Important to note in the context of this paper is, firstly, that the Tungabhadra Left Bank Canal scheme, technically speaking, is designed for centralised management – in consonance with the notion of the centralised crop planning called localisation discussed above. Secondly, it brings tens of thousands of farmers into dependency relations across an area of about half a district. The type of dependency relation is that all water users are part of a large and complex queue: water users depend on the water consumption of smaller or larger numbers of upstream users for the timing and quantity of their own water supply, and all depend on the effectiveness of the government management of this queuing system. A third feature of significance is that the (sub-)distributary canals from which water is distributed for irrigation, run on the ridges. Among engineers this design is usually defended as being 'efficient': allowing irrigation to two sides reduces required canal length per unit area as compared to a contour canal. The design choice, however, has other dimensions as well. The ridges in this semiarid landscape were dry 'jungle' areas, hunting and grazing grounds, where little to no agriculture was found in the pre-irrigation system. Villages were located in the valleys of the landscape, where water accumulated – as flow in the rainy season, and as groundwater storage in sandy stream beds in the dry period of the year.[13] One of the implications of this is that the canals could be freely constructed: it was not difficult to acquire the land as this was considered of low value by local landowners, and there was little or no habitation and settlement that needed to be circumvented. The construction of canals on the ridges 'inverted' the landscape – making the earlier driest part the main source of water. The dramatic consequences of this are discussed in the next sub-section.

The irrigation system in use

In the Tungabhadra Left Bank Canal system the pattern of water distribution is unequal in a 'head-tail' pattern, with an interface and interaction pattern between government managers and irrigators that involves intense, conflictive and sometimes violent interaction. It is, however, far from anarchic (see Mollinga, 2003: chapter 5-9; Mollinga, 2014).

In the practices of irrigation water distribution two basic social relations are enacted. The first is that of the social differentiation among farmer-irrigators, that is, the phenomenon that large farmers appropriate more water than their localised supplementary share to irrigate water-intensive and remunerative crops (notably rice), thus depriving small farmers of access to the water that localisation formally entitles them to.[14] The pattern is a multilevel pattern, in which tendentially large farmers occupy 'head end' locations on the upstream parts of the canals (at the front of the queue) while small farmers tendentially occupy 'tail end' locations at the downstream side of canals (at the rear of the queue). Location, access to water and economic status co-evolve and are internally related. Social differentiation takes on a distinctly spatial pattern, structured by the canal infrastructure.

[13] The 'nala' streams acquired a new role as the drainage system of the canal infrastructure. No separate drainage canals were constructed,

[14] Instead of a single irrigated crop head-end farmers double-crop their land. Instead of 'irrigated dry' crops, they predominantly grow rice. The water use of double-cropped rice is about 4-5 times that of a single crop of 'irrigated dry' coarse grains, resulting in highly unequal patterns of water distribution. Appropriation of excess water physically involves pushing maximum discharges through canals, manipulation of gate openings, and causing favourable leakages by damaging outlet structures.

The second social relation enacted on the scheme is that between the political and administrative arms of the state on the one side and the state's citizens on the other, as actually existing, everyday Indian democracy. The state administration in the form of the Irrigation Department should be in full control of water delivery to local irrigation units, undisturbed by farmer-irrigators and by the political arm of the state, the latter represented by the members of parliament who are elected from geographically defined constituencies. In practice, the set of relations among these actor groups is that large farmers lobby elected politicians to improve or secure their over-appropriation of water in exchange for their political support (while controlling the votes of small farmers through the economic dependencies of employment and credit). The elected politicians have leverage over the irrigation bureaucracy because they determine bureaucratic transfer and the allocation of budgets for repair and construction, the main source of (illicit) income through which Irrigation Department officers have to avoid unpleasant transfers and achieve favourable ones. In terms of shaping water distribution, the Irrigation Department officers are left with the relatively weak resources of the law and rules being on their side, and their managerial skill of 'playing the system'. In continuous negotiation with the other actors they mostly manage to secure a somewhat stable and regular, though unequal, pattern of water distribution.[15]

In the context of this paper the material dimension of this sociopolitical configuration is the point of interest. The spatial dimension has already been mentioned: the outcomes of water contestations depend on 'locational advantage', one's place in the queue, among other things, and tend toward a geographical pattern known as the 'head-tail' pattern in the irrigation literature. Secondly, the appropriation struggles are played out not only on the canal infrastructure, but also through it. The gated outlets at different levels are the subject of constant 'remodelling', cycles of damage by farmers and repair by the Irrigation Department, sometimes including adaptation of the hydraulic characteristics of the structures in an effort to consolidate certain patterns and practices of distribution, like 'pushing water to the tail'.

IRRIGATION INFRASTRUCTURE AND AGRARIAN DEVELOPMENT

Canal irrigation was a 'technology of rule' in both the colonial and independent period in terms of being a key governmental tool for effectuating agricultural growth and modernisation.[16] The transition in the Tungabhadra LBC irrigation scheme from low external input rain-fed agriculture with a strong subsistence component, to intensive irrigated and commercial agriculture involved two major 'movements', which happened more or less simultaneously. The first was the introduction of improved crop varieties, notably of rice, from the late 1960s, as part of the so-called green revolution. This allowed for much higher yields and financially more remunerative farming. From a famine-prone area in colonial times, Raichur District became a major rice production area of the State of Karnataka. The improved varieties made irrigation more attractive as timely irrigation resulted in higher grain yields. However, local farmers in the Tungabhadra LBC were initially hesitant to irrigate the 'black soils' for fear of damaging their crops and spoiling the land (cf. the reasons for the earlier lack of interest of farmers in irrigation in the adjacent KC Canal discussed below). It was a second movement that converted the irrigable area to a rice area: the settlement of farmers from the coastal areas of the neighbouring State of Andhra Pradesh in the newly constructed Tungabhadra irrigation scheme.

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[15] The macro aspect of this social relationship is the 1970s and 1980s role of large irrigated farmers in so called New Farmers Movements (Brass, 1995; Nadkarni, 1987).

[16] It can be noted that the Indian irrigation cadre and organisation grew out of the colonial army, and was thus very closely linked to the political rule of the colony. Indian colonial engineers sometimes became statesmen – before and after independence: M. Visvesvaraya (1861-1962) is an example of the former, Ajudhiya Nath Khosla (1892-1984) of the latter. Visvesvaraya published on planned development in the 1930s (Visvesvaraya, 1934).

The coastal, delta areas of Andhra Pradesh had witnessed intensive development of irrigated agriculture, much of which was irrigated rice, from the mid-19th century, following Sir Arthur Cotton's famously successful expansion of the delta's irrigation infrastructure. Land pressure was high, and holdings small. When new irrigation schemes were constructed in upland areas, considerable numbers of delta farmers would sell their land dearly, and purchase new land in the new schemes cheaply, thus expanding the size of their holding considerably (Anjaneya Swamy, 1988). In the Tungabhadra LBC the 'Andhra migrants' established 'camps' along the canals of the ridges on a large scale from the early 1960s (and some probably earlier than that). They were willing to pay what were in the eyes of the local population very reasonable prices for land located far from the villages in 'jungle' terrain, sometimes even before canals were actually constructed. The migrant farmers built their settlements near the new water source, often on crossroads of canals and roads with an eye to easy marketing of produce, and converted the 'jungle' into productive and profitable rice irrigation fields.[17] The landscape was thus 'inversed' quite dramatically – the local villages along the natural drains became tail-end locations, the newly created 'camps' along the canals became head-end locations, after some time also in an economic sense. Some 'camps' along the main road through the district have become important markets, and have acquired village status, while canal roads have become important interior transport routes.

Total water use in the system increased through the steady expansion of irrigated rice cultivation and land conversion for irrigation in general, leading to localised occurrences of water scarcity. The consolidation of locational advantage and secure water access and (over)appropriation over longer periods of time involved strategies like purchasing land further upstream, investment in political and bureaucratic relations, and investment in pump sets for lifting water from drainage streams and the river. Rural electrification caused a boom in the latter from the mid-1990s – lift irrigation representing a high degree of (individual or small group) water control, more independent from government control than canal supply (provided electricity supply is secure).[18]

Our three-angled analysis of the Tungabhadra Left Bank Canal irrigation system is summarised in Table 1.

ECONOMIC AND POLITICAL CONTROL IN USSR IRRIGATION DESIGN: THE CASE OF KHOREZM PROVINCE, UZBEKISTAN

Khorezm Province is a region in the west of Uzbekistan, in the lower reaches of the Amu Darya River, which is part of the Aral Sea Basin. The irrigation canal network of Khorezm Province is supplied by diversion of water from the Amu Darya River, with the river supply stabilised by the Tuyamuyum Reservoir (see Figure 2).

Irrigation has been practised in Khorezm since antiquity (possibly dating back to as far as 2,000 BC), and on a larger scale at least since the period of occupation by Tsarist Russia.[19] The current irrigation network has been, however, mainly developed in the period of the USSR with the aim to increase the production of cotton in the region. Initial investments after the civil war in the 1920s and 1930s were low and aimed at decolonisation and nation-building. Transforming water distribution practices played a central role in the transition to socialism (Teichmann, 2007). It was only in 1939 that large-scale investments started, after the Central Committee of the USSR adopted a resolution 'On measures

[17] This conversion was not without problems, technical and institutional; see Mollinga (2003) for a detailed discussion.

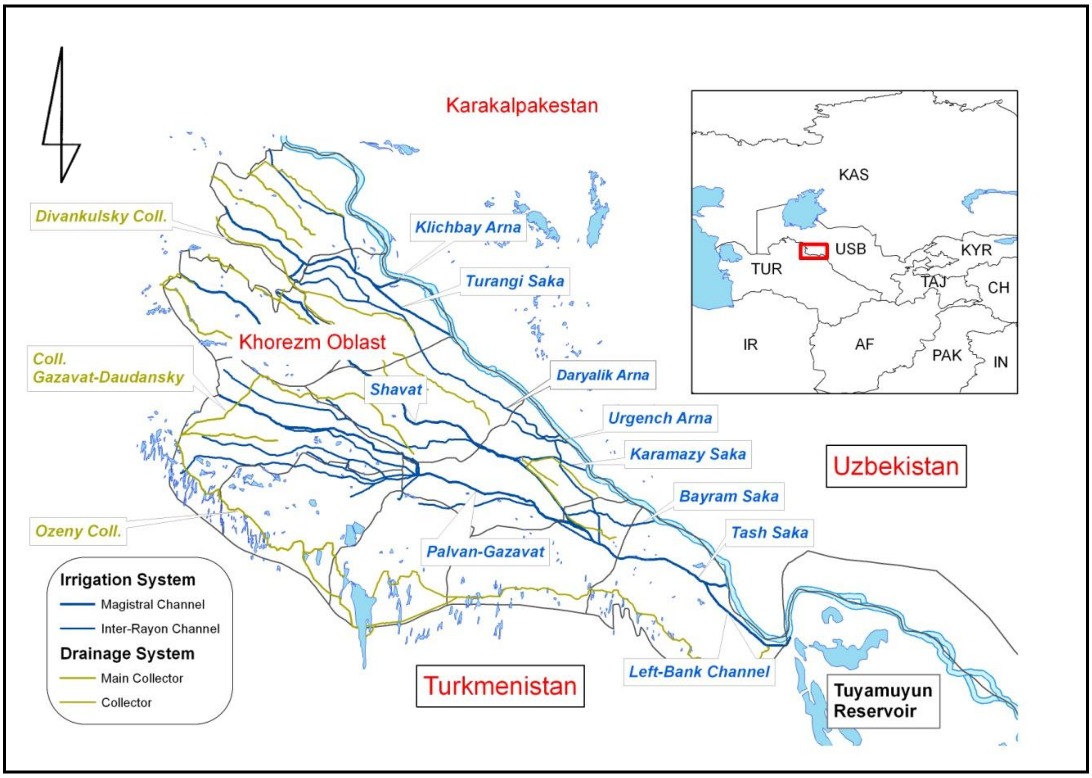
[18] Private groundwater use through tubewells is not common in this (black soil) region.

[19] Dzhabbarov (2005), for instance, reports the existence of an area of 148,000 irrigated hectares (ha) in 1926. This seems on the high side in comparison with other numbers, but does indicate that irrigation was then already practised on a large scale.

Table 1. Summary Tungabhadra LBC.

FIRST ANGLE: *The 'match' of governance regime and canal infrastructure*	**SECOND ANGLE:** *Canal infrastructure in water management and use*	**THIRD ANGLE:** *Canal infrastructure and the process of agrarian development*
- Contradiction in colonial state rule (revenue maximisation/ cash crop cultivation vs. political stability/famine) expressed in notions of productive and protective irrigation; reproduced after independence in market-based growth and accumulation vs. (national) rural development and poverty alleviation - Technical and institutional challenge of rationing water (or distributing scarcity) in protective systems, addressed differently in different regions; - Design for centralised control (reservoir-based, continuous flow; non-modular outlets, land use planning *avant la lettre* called localisation in South India) as state-led development representing 'modernity'.	- Attempted 'delegation' of water governance and management to canal infrastructure, but implementing rationing through localisation and scheduled supply are difficult to implement. - Division structures become sites of contestation and signposts of struggle; the system property of 'queuing' facilitates a 'classical' head-tail situation (concentrating over time). - State-citizen interface enacted on and through the canal infrastructure.	- Irrigation system as a government instrument for rural development under post-independent planned development. - Temporal reshaping of the agricultural seasons, spatial inversion of the landscape in terms of water availability and settlement. - Canal system as grid and vehicle for 'Green Revolution' agriculture from the late 1960s. - The spatiality of social differentiation of farmers with the canal infrastructure as grid and contested instrument.

Figure 2. The main irrigation and drainage network of Khorezm Province, Uzbekistan.



Source: Conrad (2006).

concerning further increase of cotton growing in Uzbekistan', which outlined a "tremendous program of irrigation construction" (Zonn, 1999: 159). By that time cotton production had become a crucial element in the relation between the centre and the periphery and the initial soft approach of decolonisation and transition toward socialism had been left behind (Zonn, 1999; Teichmann, 2007). The main expansion of the Khorezm irrigation network took place in the period from the 1950s to the 1980s, in steps of concentrated periods of time, always linked to the ever-rising political demand for cotton, which was expressed through central planning, production quotas and pledges to deliver (Obertreis, 2007).

Presently, water is used for irrigated agricultural production of cotton, wheat, rice and horticultural crops. In 2005-6 about a third of the consumed water was used for cotton production, about a third for commercial rice production and the remaining proportion (again, about a third) for household production of grains and horticultural crops (Veldwisch and Spoor, 2008). The production units have changed from large state and collective farms with typical sizes of 1000-2000 ha[20] to much smaller individually operated farms[21] through wide-scale land reforms in 2005-6 (Djanibekov, 2008;Veldwisch and Spoor, 2008; Trevisani, 2010).

The post-Soviet Uzbek state (1991-present) can be characterised as neo-patrimonial with an authoritarian regime and a strongly regulated agricultural sector that has maintained a state order system for the production of cotton. Notwithstanding the fact that state and collective farms have been dismantled into numerous smaller production units that are family managed, the state still controls cropping areas and many other aspects of agricultural production, including holding land rights.

Main design features

The Khorezm Province irrigation network has three main gated inlet canals (and several smaller ones which are only intermittently used) that are directly connected to the Amu Darya River. There are no diversion weirs in the river. Just a few kilometres upstream of the inlet there is a large artificial reservoir (Tuyamuyun Reservoir) which serves to stabilise river water supply. The irrigated area in Khorezm is about 275,000 ha. Water is distributed through an open canal network with a dendritic layout (see Figure 2).

Till 1939 all canals had been flowing below surface level which made them, in effect, function as drainage canals too. Moreover, lifting devices (first water wheels, but later also pumps) were needed to get the water from the canals onto the fields, which probably limited the amount of water being applied. The current main canals were built in the period 1939-1941. Various smaller canals connecting directly to the Amu Darya were merged into larger ones with a single intake. Three water division structures, which also functioned as check-structures were built at different distances from the river intake, at the 34 km, 47 km and 68 km km-posts, respectively (they are referred to as *Zaruzenya*). It is likely that the height of the canal bunds was also increased. As a result, the main system could now be operated to flow above surface level. Offtakes, either into branch canals or directly to fields, could now be operated by gravity. The diversion to tertiary canals is partly by gravity (if water levels permit it) and partly by pumps with a typical capacity of 500 l/s.[22]

[20] During the Soviet period these were the Sovkhozy and Kolkhozy, which after independence were transformed/renamed as Shirkats. Typically they had sizes of 1000-2000 ha.

[21] About 5-10% of the former workers of the collective farms were granted large portions of land, while the other 90-95% of the rural population was left with only very small home garden plots and the possibility to work on the fields of others. This land redistribution made the distinction between *fermers* (landlords) and *dehkans* (peasants). For a discussion on this emerging distinction see Veldwisch and Bock (2011).

[22] In normal years, about 40% of the area is supplied by using a pump; in dry years a larger area needs pumping as the water levels in the canals are lower.

As an effect of this technological change towards gravity supply, seepage levels rose and pushed up the ground water levels. In Khorezm the construction of drains on a local scale started in 1942 and in the period 1950-1960 this was further developed into a network that is referred to as the collector-drainage system (Dzhabbarov, 2005).

The change to above-surface canals was probably made (1) to increase control over flows, (2) be able to reach a larger area by maintaining a higher water level, and (3) to be able to irrigate fields by gravity. The implication of a much higher water table and the consequent need for a drainage system to lower it to avoid waterlogging and salinisation could have been (and probably were) understood beforehand, but it seems likely that under the pressure to increase cotton production these were either overlooked or chosen to be overlooked for as long as possible.

The expansion of the irrigation area in leaps and bounds in the Soviet period led to hydraulically interesting infrastructure solutions that are still visible in the main canal network. With the pressure to quickly expand on the one hand and the command and control mechanisms focussing mainly on cotton output, on the other, the development of the irrigation network lacked an overarching hydraulic design. In interviews with old people who had been workers of water management organisations in Khorezm they explained how new canal stretches and division points were mapped out and constructed 'on the eye' and with practical, on-the-job knowledge rather than on formal designs by trained engineers, similar to what Teichman (2007: 511) describes.

The 'bricolage' as for instance seen around the largest division structure (as depicted in Figure 3) is a nice example of improvisation in the context of quick expansion. When new land was being reclaimed the network of canals expanded dendritically and the trunk of the tree had to grow wider. The 'short-cuts' were probably made to be able to transfer the additional discharges without having to redesign and reconstruct the main division point. This was probably the easiest and cheapest way to quickly solve the issue. Hydraulically it is a complicated solution that leads to high operational demands on the basis of upstream and downstream measurements.

Figure 3. Division point from Palvan-Gazavat Canal into Palvan Canal and Gazavat Canal.

The irrigation system in use

In the Soviet period, state and collective farms were established as the production units. They were mostly established following administrative boundaries not linked to the hydraulic layout of the irrigation and drainage networks, with maybe the exception of areas reclaimed from the 1980s onwards. The "mental map" that state organisations had of districts and provinces consisted of LFEs (Large Farm Enterprises) as production units, not as hydraulic units.[23] Even though LFEs were also held accountable for their water use, the primary accounting was done through (cotton) production targets.

This also expresses, in practice, in the subordination of water management departments to district managers (*Hokim*) and their offices (*Hokimiyat*). The political position of the Hokims is closely tied to their ability to fulfil the production quotas allocated to their districts. Hokims are also said to frequently override decisions by the Water Distribution Department. What emerges is an image of a strong political leadership that aims to optimise water allocation and distribution within the boundaries of its area of jurisdiction. Hokims frequently ordered to let water pass to the next LFE if this was necessary for cotton production. Though it was not always effective, the fact that lines of command regarding water distribution ran along the same lines as those for cotton production targets and political legitimacy, is characteristic for the regime. In Khorezm, the idea seems to have been to create production units (the state and collective farms) that do not depend on their neighbours or compete with each other over water distribution.

Technically, the state authorities might have preferred to design a piped system in order to guarantee a free water delivery to each LFE unit. In practice, this was not necessary as, by means of political force, the state authorities managed to very much limit the competition between the LFEs.[24] This type of management is easier in a situation of water abundance – a situation that exists in Khorezm during most years and seems to have been created and maintained on purpose.

In the period 2004-6, it was found for Khorezm that around 50% of the water abstracted from the Amu Darya leaves the area as drainage water, of which only a small amount is reused while the rest flows to desert sinks (Conrad, 2006; Veldwisch, 2010). Water managers in Khorezm even actively aim for an outflow/inflow ratio of 50% or less (Veldwisch, 2010). The figure seems to be a structural element of large-scale irrigation in Uzbekistan; it is neither a recent management norm, nor specific to Khorezm. Dzhabbarov (2005) reports that in the period from 1970 to 1990 the outflow/inflow ratio for Khorezm fluctuated between 48 and 64%, with an average of 56%. Zonn (1999: 170-1) mentions similar supply ratios for the Navoi, Samarkand and Karakalpakstan regions in Uzbekistan and the Tashauz region in Turkmenistan.

Partly these high losses are the result of the construction of unlined canals above ground level in combination with the construction of collector-drainage networks in response to rising ground water levels. However, water supply in Khorezm seems to be very high in the large majority of years. During fieldwork, irrigation water was frequently observed to flow directly from canals into drains when farmers did not need it right at that moment. Basins for rice growing were frequently continuously receiving and draining water. Farmers expressed that they could simply take the water from the canal when they needed it (Veldwisch, 2010). The latter makes clear that this situation of abundance makes water distribution a lot easier and irrigated farming less risky in comparison to irrigation systems that operate on a much smaller water allowance. This overallocation of water seems to be in line with an

[23] Water distribution in the main system is managed by a hierarchy of state agencies (Wegerich, 2005; Yalcin and Mollinga, 2007; Veldwisch, 2010). When collective farms were dissolved into individually operated farms water users associations (WUAs) were established with the same boundaries as the former collective farms (Veldwisch, 2007; Zavgorodnyaya, 2006; Abdullaev and Mollinga, 2010). These WUAs have remained under strong influence of state hierarchies, particularly the district governors (Veldwisch and Mollinga, 2013).

[24] Thurman (1999) reports, however, that competition was never fully gone.

historic attitude towards yield maximisation (production per ha) instead of profit maximisation (economic return per resource unit). Kienzler (2010) has shown this for Soviet and post-Soviet fertilizer norms in cotton production. The maximisation of the cotton yield was the objective and this should not be restricted by the available amount of fertilizer or water.

While easing the distribution of irrigation water by limiting the requirements for scheduling, the abundance of water also has associated costs in (1) overdesign of diversion structures and main canal system, (2) need for a larger drainage capacity and (3) less water available further downstream in the basin if the drainage water is diverted to desert sinks. The latter has contributed to the desiccation of the Aral Sea and the ecological and health problems associated with it. There are clear indications that the Soviet engineers did foresee the drying up of the inland water body, but considered it acceptable in comparison to the benefits of cotton cultivation (Micklin, 1985; Zonn, 1999; Peachey, 2004).

Irrigation infrastructure and agrarian development

The agricultural command and control mechanisms of the Soviet period focused around quotas, targets, pledges, 5-year plans, increased outputs, etc. Achieving cotton production was the highest goal and people's political careers were connected to it. The Uzbek cotton-scandal in which both regional and national production figures were systematically manipulated for a number of years (cf. Kandiyoti, 2003) indicates the importance of cotton production for political legitimacy. Also, the strong focus on cotton production has an ideological element with regard to the race against capitalism. Cotton produced in Uzbekistan was not only used within the USSR, but also served to supply other socialist nations around the world (Zonn, 1999: 161). The development of irrigation systems in Uzbekistan was only meant to facilitate cotton production. Irrigation was considered one of the necessary services for the higher goal of cotton production, and certainly not as a goal in itself.

Despite the USSR (and its successor regime in Uzbekistan) being known for their strong focus on planning, yet exactly under this governance regime we find an irrigation system that seems to be highly improvised in terms of layout, highly flexible in terms of management and shortsighted in postponing the construction of a drainage network. This paradox can be (partly) explained by the very quick, yet organic, expansion of the irrigation network under the economic and political pressure of a high demand for cotton. However, it could also be that this improvisation is the expression of a deeper systemic characteristic of the Soviet system of planned development.

A refined system of command and control in the production of cotton provided for a political force that guaranteed the stability of the irrigated production system, limiting the need to 'delegate' control to sturdy and sophisticated infrastructure. In terms of the 'politics of the irrigation artefacts' we infer that the overwhelming presence of strong mechanisms of political governance of agricultural production, and of Soviet and present Uzbek society in general, there was less need to mobilise infrastructure for this purpose. It seems plausible to us that the conscious use of a water allowance at least twice the amount required for cotton cultivation (see above), should be interpreted as a deliberate strategy to avoid constraints and conflict in relation to water availability/scarcity at the level of production units,[25] and perhaps more importantly, across production units. There is no sign of head-tail controversies like those described in the previous case of the Tungabhadra LBC, except in years with exceptionally low water supply.[26]

In SCOT and labour process terms, these specific design characteristics of water allowance and related infrastructure dimensions are part of the 'politics of production', centrally planned agricultural

[25] For example, the ditch networks within the 1000-2000 ha collective farms were managed highly flexibly as the competition over water was very limited, making water management at this scale level a rather pragmatic issue.

[26] In the early 2000s there were such years, and constraints and conflicts were indeed observed, both at the level of the river basin (a head tail pattern of provinces), and within the Khorezm region.

(cotton) production in this case (cf. Burawoy, 1985). We provisionally interpret them as a strategy of (political) control part of the broader mode of governance. Providing more conclusive direct evidence for this inference requires further research into the Soviet/Uzbek irrigation infrastructure design process in the 1950 to 1980 period. Some additional indirect evidence for the conscious aspect of this use of extremely high water allowances and related overdimensioned canals and structures, is that despite low levels of investment in maintenance of irrigation infrastructure since independence in most former Soviet Republics (Hannan and O'Hara, 1998; O'Hara and Hannan, 1999; O'Hara, 2000; Wegerich, 2003; UNDP, 2007; Thurman, 1999), in Khorezm, discharges are (still) well manageable and measurable (Veldwisch, 2010). There can be no doubt about the technical acumen of Soviet irrigation engineers, and it is difficult to believe that design decisions were in any sense 'whimsical'.

Our three-angled analysis of the Khorezm irrigation system is summarised in Table 2.

Table 2. Summary Khorezm irrigation system.

FIRST ANGLE: *The 'match' of governance regime and canal infrastructure*	**SECOND ANGLE:** *Canal infrastructure in water management and use*	**THIRD ANGLE:** *Canal infrastructure and the process of agrarian development*
- Over-designed infrastructure deriving from high water allowances expressing overriding importance of maximising cotton production through centralised control as a key governance regime characteristic. - Each unit preferably independently supplied and managed. - Hurried and incremental construction in politically defined episodes of expansion. - Lifting canals above the surface allows canal network expansion (commanding of larger areas possible; constraints in lifting forms of irrigation – Persian wheels, pumps – reduced). - High water allowances help to avoid water distribution conflicts and are – thus – part of the 'politics of production' (inference to be further researched).	- The balance of technical and institutional/political control has been in favour of the institutional/political side: infrastructure is instrumental and pragmatic, not an 'interface' or 'arena of struggle'. - Lifting canals above the surface for the politically driven cotton expansion has produced a plethora of issues: increased seepage, need for drainage, ecological (waterlogging and salinity) damage. - Post-1991 agrarian (land)reform in principle allows increased individualisation of water control and, in principle, poses new challenges to within-LFE water management, now redefined as WUAs, but the continuation of centralised control of agricultural production implies limited expression of these potentialities.	- Irrigation as modernity: communities and farming systems were totally uprooted and fit into a concept of socialist/communist modernisation; the irrigation system was the physical grid for state-planned and controlled collective agriculture. - System (still) caught in a centralistic logic of planned cotton (and wheat) production by state order, coexisting with an 'informal' system of rice cultivation and need to allow diversion of water to individual plots for livelihood security of impoverished rural population. - Ecological effects have been – quite consciously – externalised (disappearance of the Aral Sea, Turkmenistan desert as a sink).

EXPERIMENTING WITH COMMERCIAL IRRIGATION DEVELOPMENT IN COLONIAL INDIA: THE KURNOOL-CUDDAPAH CANAL

The Kurnool-Cuddapah Canal (KC Canal) irrigation scheme is located in the present districts of Kurnool and Cuddapah in the State of Andhra Pradesh, India (see Figure 4).[27] It has a registered (planned) irrigated area of 110,482 ha (107,845 ha in a recent source). The canal takes water from the Tungabhadra River, a tributary of the Krishna River by means of a weir (the Sunkesula *anicut*) and takes the water over a watershed into the Pennar Basin. The main canal is about 300 km long. The canal was constructed between 1860 and 1871 by the Madras Irrigation and Canal Company,[28] the first and only effort at large-scale canal irrigation development in India through a private company (Atchi Reddy, 1990). The intention was that the company would raise the money for, build and operate canals. The MICC was incorporated in 1858 following the enormous financial success (in terms of revenue collection) expansion of the South Indian delta irrigation schemes (for the East India Company) by Sir Arthur Cotton, labelled by colleagues as 'the irrigation wizard of the South'. The KC canal was to be the first step in a master plan to link India's rivers for navigation, apart from supplying irrigation water. The KC Canal was a resounding failure in financial terms and had serious technical problems at completion. For one, it was unable to carry the design discharge, thus making navigation infeasible. The failure of the canal helped to tilt the debate on whether railways or canals should be preferred (and invested in) for improving colonial transportation infrastructure: the controversy was decided in favour of the railways. Also in terms of area irrigated (and therefore in terms of land revenue collection) the scheme was a disappointment: local farmers showed very little interest in using the irrigation water made available, except in drought years.

In several respects the KC Canal is a peculiar irrigation scheme, peculiarities that allow us to think through additional aspects of the technology-governance connection.

Main design features

The first peculiarity of the KC Canal is its location (see Figures 4 and 5), or more precisely the choice to construct a canal that diverts water from the Tungabhadra River to take it into the Pennar Basin (the KC Canal enters a subbasin and flows alongside the Galeru and Kundu rivers, tributaries of the Pennar). This choice was informed by the navigation objective and suggests that this was a dominant argument in choosing the location and main canal alignment of the system. A canal for irrigation could also have been built (and had been envisaged) in the neighbouring Bellary District, where more land was available also.[29] Sir Arthur Cotton was indeed envisaging connecting India from north to south by waterways, an idea that has remained part of the imagination of engineers and policy makers till today.

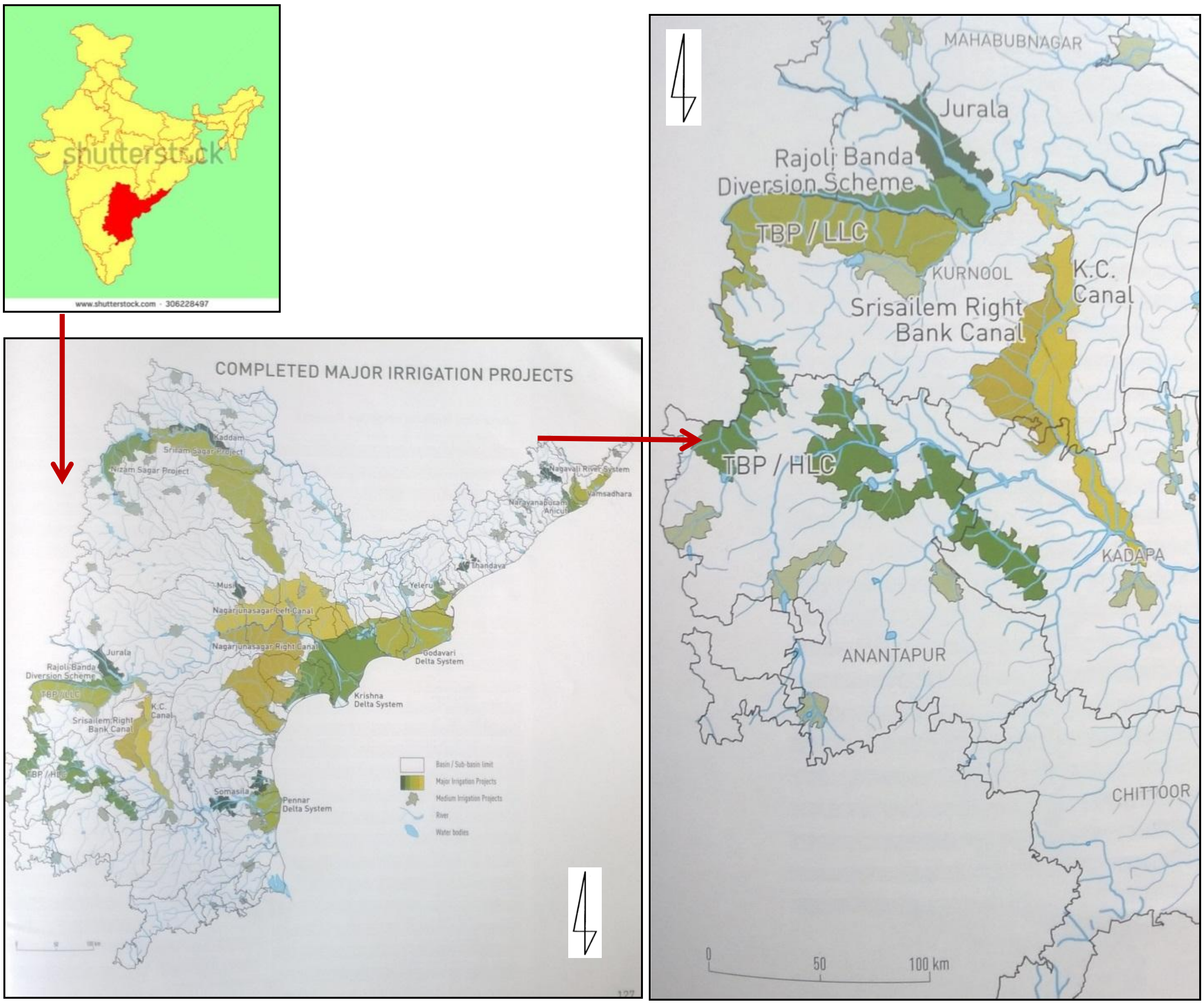
Taking the water over the watershed to a new basin meant that the canal was effectively a source of additional water at the top of a basin. This is unusual as diversion from rivers for large-scale irrigation schemes is usually done at downstream parts of the river, leaving the hydrology of the upper catchment untouched. The valley of the Galeru and Kundu rivers is also a narrow valley, making the KC Canal Irrigation Scheme a long and narrow scheme. Figure 5 (left) shows that the curvy canal touches and crosses the local rivers several times. A peculiarity of the design is that the river system is used as part of the conveyance system, not only at the main canal level drawn on the map, but also at lower canal levels not drawn on the map, where local natural drainage streams are integrated into a water conveyance.

[27] In the map we use the boundaries of Andhra Pradesh as before its division into Telengana and Andhra Pradesh in 2014.

[28] Madras is the present Chennai, the capital of the State of Tamil Nadu

[29] In this district the Tungabhadra Right Bank Low Level Canal and High Level Canal were later constructed (see Figure 4 for the location of these canals).

Figure 4. Location of the KC Canal in the State of Andhra Pradesh.

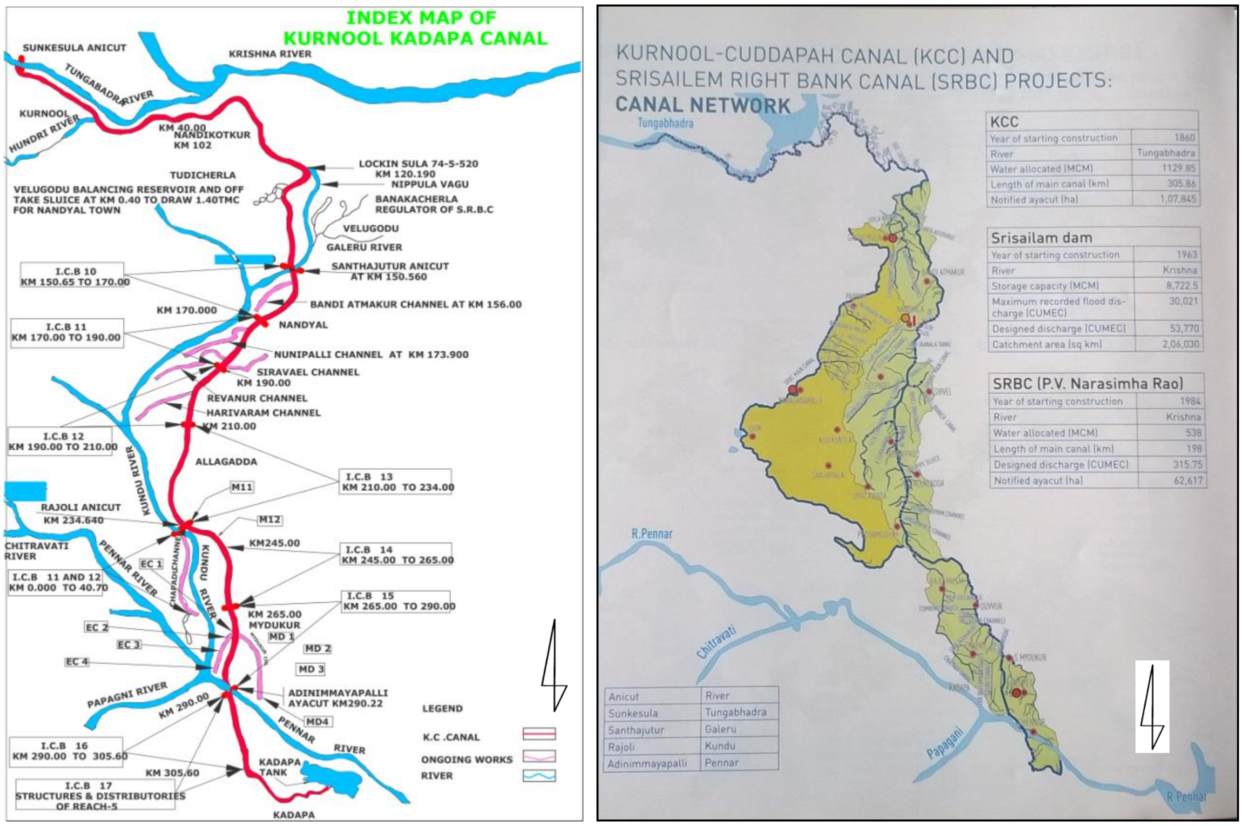


Source: wwww.shutterstock.com and Gupta et al. (2011: 189). Note: Andhra Pradesh state is now split into Andhra Pradesh and Telengana states.

The exact considerations for this integration of canal and river, and of irrigation and drainage functions can only be speculated about, as there is, to our knowledge, no detailed record of them. Cost reduction is a likely reason, particularly given the financial strain the MICC very quickly found itself experiencing. The design discharge for a canal reach between two 'pick up' points where the canal touched or crossed the river was calculated based on only the area to be irrigated in that reach. Water for lower reaches moved through the river, to be diverted into the canal at the next 'pick up' point. This saved on canal size and thus constriction costs. Another possible reason is that it is a translation of how canals were constructed in the delta areas shortly before – as extensions of natural streams to a large extent. An effect is that the water use efficiency at scheme level is likely to be high – water 'lost' in drainage canals actually remains within the system – a significant contrast with both the Tungabhadra and Khorezm systems.[30]

[30] The consequences for river ecology can only be speculated about. We know of no publications documenting the hydro-ecological changes and the impacts resulting from the KC Canal diversion and the later building of the Tungabhadra Dam.

Figure 5. Layout of the KC Canal.



Sources: Field office KC Canal (left; redrawn; no scale); Gupta et al. (2011: 284) (right; no scale).

An important managerial implication is that the KC Canal is effectively compartmentalised. The irrigation water entering the subbasin at the top does not have to pass through the whole irrigated area to reach the lower, downstream part of the irrigation scheme. Irrigation water is conveyed through the river bypassing irrigated areas from the Lockin Sula diversion indicated on the map (Figure 4, left). This allows a level of managerial flexibility that does not exist in a system like the Tungabhadra Left Bank Canal or the Khorezm systems discussed above. To the best of our knowledge, the KC Canal is the only system in India constructed in this manner.[31] The concept, if it was that, has not been repeated. Rather than a conscious concept, the peculiar design may have been the unintended consequence of a series of other considerations and conditions: the navigation imperative, cost reduction, and the narrowness of the valley.[32]

The irrigation system in use

Very little is documented of the irrigation practices in the KC Canal till well after Indian independence. Wade's work, with fieldwork starting in the 1970s is the first comprehensive account of contemporary

[31] The closest similarity are the chains of tank cascades (interlinked small reservoirs along a (network of) streams) in present Tamil Nadu (formerly Madras Presidency), dating from precolonial times, particularly when these get linked to additional 'external' water supply created through river diversion and large reservoir building, as sometimes happened in colonial and independent times. We have no indication that the tank cascades directly inspired the KC Canal design. It seems unlikely as there is no intermediate storage component part of the KC Canal design.

[32] Plus, more speculatively, that 'irrigation science' was still a very experimental affair in the 1860s.

scheme use (Wade, 1979, 1988). What is known of the colonial period is that local farmers were hardly interested in using the canal water for irrigation, not only with the high revenue rates of the MICC, but not even with the lower government rates after the scheme had been taken over by the government in 1882. In 1913, about 10,000 ha of the envisaged area was irrigated, which is less than 10%.

The reasons for this lack of interest are now well known. The soils in this region are so-called 'black soils', vertisols that are extremely water-retentive. Under average or above-average rainfall conditions no additional water is needed to mature the rain-fed crops that were grown by local farmers. In fact, when rain falls after a field is irrigated such crops may drown. Farmers thus considered irrigation of rain-fed crops a risky affair, and also envisaged damage to soil structure in the longer term. For Maharashtra (Bombay Presidency) it has been documented that local grain crops like sorghum responded to irrigation primarily through stronger vegetative growth and hardly by higher grain yields. The plants became taller and more easily fell over (Attwood, 1985, 1987; Wallach 1985). Farmers only rushed to the irrigation agency for water in drought years – in such years irrigated area expanded.

Moreover, the KC Canal region was an interior region with very little transport and market infrastructure – the lack of transport infrastructure being one of the rationales for navigation. The region is also known for strongly unequal and violent social relations among different caste/class groups. Till today, this region has been considered a 'wild' area. Villages negotiate deals with forest communities to avoid raids on their crops and cattle to this day (Wade, 1988; 2009 fieldwork Rahul Pillai).

In the recent 'modernisation' of the KC Canal scheme (started 1994, completed 2012, the latter phase with Japanese assistance) repairs of structures and canal lining have been implemented, considerably reducing losses and enhancing the actual discharge capacity of the canals.[33] Furthermore, the construction of the parallel Srisailam RBC to the west of the KC Canal (see Figure 4) and the Telugu Ganga Canal project on the east side (not on the map) in the same valley, produces 'regenerated water' (drainage losses) that flow into the river, and can be picked up for KC Canal irrigation. The inefficiencies of these newly constructed canals thus provide additional water to the old, now modernised, canal. The 'pick up' system has been maintained in modernisation, which has been limited to repairs of weirs and other structures and upgrading of canals through lining. The engineering discourse on modernisation is about water losses and savings and technical quality and efficiency. In management terms the system is treated as any other large-scale irrigation system (as regards establishment and functioning of WUAs, and 'pushing water to the tail' for instance), with no apparent reflection on the special possibilities of the system.

Irrigation infrastructure and agrarian development

A central feature of British colonial rule was the creation of individual private property in land, through the so-called land settlement process. This process undermined the power of landlords controlling feudalistic land relations, and created a large group of individual, potentially entrepreneurial farmers, who could pay tax directly to the British government. The creation of government canal irrigation systems was meant to further enhance revenue collection through increased crop production (increased yields, area expansion by double cropping). However, in South India's 'black soil areas' the colonial attempt to bring large numbers of smallholders into the fold of state-led canal irrigation development failed overall, as discussed above. The crops and soils issue was only really solved with the advent of the green revolution in the 1960s, while transport and market facilities also improved

[33] The design discharge capacity of the first canal stretch up to Lockin Sula has also been structurally enhanced from 3050 to 3850 cusecs cubic feet per second) under modernisation. This and other information is based on field visits in 2007 and 2009, and one in May 2016, including two interviews with retired Executive Engineer K. Amarnath, whose contribution is gratefully acknowledged here.

considerably in the decades after independence in the KC Canal region, as elsewhere. The construction of the Tungabhadra Dam allowed stronger control of water releases into the KC Canal, and supplying water from storage in the second, dry season, after the monsoonal season. The main irrigation season is still July-December (the *kharif*, monsoon season*)*, but there is major localisation for the second season (*rabi*) also since the 1960s.[34]

Table 3. Summary KC Canal.

FIRST ANGLE: *The 'match' of governance regime and canal infrastructure*	**SECOND ANGLE:** *Canal infrastructure in water management and use*	**THIRD ANGLE:** *Canal infrastructure and the process of agrarian development*
- Designed as an effort, and at a location, to enhance navigation, revenue collection and crop protection, expressing colonial governance priorities. - Unique design, combining rivers and canals for conveyance, thus integrating drainage/re-use into the design, with partial 'compartmentalisation' allowing flexible management – in principle. - Peculiar design features result from 'interlinking of rivers'/navigation and cost concerns, and valley features – not likely to have been a conscious 'concept'. - 'Echo' of canal/system design from southern deltas: enhancing the river; curvy canals. - Peculiarity remains unrecognised to date.	- Farmers were hardly interested in irrigation of 'black soils' except in drought years – combined soil and agronomic characteristics provide the explanation. - Navigation proved impossible – railways became the main mode of transport. - In the post-independent period, it became more a system like the Tungabhadra LBC: reservoir changed water supply schedule/seasons; in recent 'rehabilitation' work, extra water supplies provided through connections with other schemes/new reservoirs. - Within units/compartments similar head-tail issues as in the Tungabhadra LBC, particularly in the dry season and in dry years.	- The MICC (the company that constructed the system) went bankrupt very soon – failed attempt at private irrigation development. - Effort at rural and agricultural modernisation under colonialism that largely failed. - Agricultural innovation (in the form of 'Green Revolution' agriculture) overcomes this. - Subsequently shows a pattern of agrarian development similar to that of the Tungabhadra LBC, but with a localisation allowing much more rice cultivation. - Rice localisation and related canal capacities and water supply make 'head/tail' issues less pertinent in principle, but system supply in general is vulnerable, and regional agrarian relations are highly polarised.

When sufficient water is available (normal rainfall, normal reservoir filling) the KC Canal is a rice-growing system in the monsoonal season, with little 'scarcity by design' overall, though not without distribution problems (Wade, 1979, 1988, 2009 fieldwork Rahul Pillai). However, water distribution in the second, rabi season faces similar challenges as in the Tungabhadra LBC. In dry years, and tendentially because of increasing upstream allocation commitments, these challenges intensify.

DISCUSSION AND CONCLUSION

In this section we first discuss, in summary, the system-level design characteristics of the three examples of large-scale canal irrigation infrastructure in relation to the governance regimes within

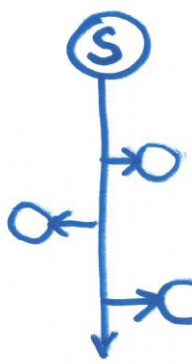
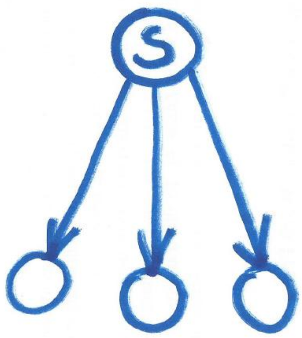
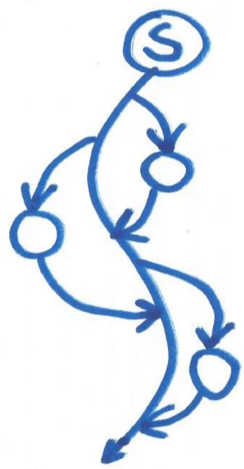
[34] Kharif localisation has 154,899 acres of single wet (rice), and 2814 acres of irrigated dry crops. Rabi has 87,604 acres of irrigated dry crops. In addition, 13,982 acres are localised for sugarcane and 9940 acres for double wet (rice), both covering two seasons (information acquired from EE office Nandyal, 2009).

which they were conceived. We subsequently discuss the implications of our findings for research and policy.

System-level design characteristics and governance

Table 4 depicts the 'basic' system-level structural characteristics of each of the three irrigation infrastructure systems graphically, with a short explanatory description. These representations of the design logic and the technical *assemblage* of the systems capture, we propose, those system-level structural properties that are relevant for the systems' 'social' dynamics.[35]

Table 4. Stylised graphical representation of the system-level design principle of the Tungabhadra LBC, Khorezm and KC Canal irrigation system canal infrastructures

	Tungabhadra LBC	Khorezm	KC Canal
Desired/ designed water distribution principle *S = source* *0 = unit*	*Irrigation units supplied in a queue* 	*Independent supply of units* 	*Hydraulically flexible supply to semi-autonomous units* 

The Tungabhadra LBC and Khorezm systems both express and facilitate the centralised rule through centralised control of water supply, though in qualitatively different ways. The Tungabhadra LBC reservoir-supplied, protective, continuous flow, (and?) queuing design fit a state effort at enrolling (private propertied) farmers as subjects into the modernisation projects of colonial and independent planned (rural) development. The assumption of the 1950s that technical control through hierarchically sequenced canals and structures combined with institutional control through land use planning in the form of gazetted 'localisation' could actually be achieved, is, with hindsight, quite startling. It was, however, attempted, in the Tungabhadra LBC as elsewhere. In practice, the emergent process of agrarian development has been production increase in a techno-spatially specific pattern of social

[35] The systems also vary qualitatively in their drainage infrastructure characteristics. Tungabhadra LBC has no constructed drainage; natural streams are used for this. Khorezm includes very significant drainage infrastructure construction. KC Canal has an integrated form of irrigation supply and drainage. We understand these as a consequences of the irrigation supply design (rather than the inverse) and thus a 'second order' structural characteristics. However, the question of drainage infrastructure merits further research.

differentiation of agrarian producers shaped by the canal infrastructure's hierarchical layout, 'protective' canal capacities, and non modular division structure design.

The Soviet regime was more singular in its centralised pursuit of production increase in the Khorezm case. It did not face the protective contradiction of rule as in India, and went all out in uprooting and reorganising rural communities, through collectivisation, to achieve maximum production of particularly cotton, as part of the broader Soviet regional specialisation approach to agrarian development. The collective and state farms created were configured as independent production units, all directly governed by the political authorities responsible for cotton production. Water supply and distribution were configured as practical services, not to disturb or constrain cotton production in any way. The 'bricolage' leaps-and-bounds way through which the expansion of the Khorezm irrigation network was implemented in the 1950s-1980s period illustrates the subservient instrumentality of water and canal design in the Soviet paradigm. Independence and no constraints in terms of water supply were achieved technically by very high water allowances and an overdesigned canal system. We have suggested that this design choice was conscious and informed by considerations of 'political control' rather than considerations of techno-economic efficiency of resource use. More direct evidence for this will hopefully be collected in subsequent research.

Factors potentially undermining and changing the functioning of the system were externalised by the governance regime and 'absorbed' by the design. A major contradiction of expanded cotton cultivation was its negative ecological impact. This was politically and physically externalised to the (disappearing) Aral Sea and the Turkmenistan desert sink. The present changes in local water management dynamics as a result of the formally largely illegal cultivation of rice as a cash crop by the new rural elite created through 'land reform', plus the need to divert water to large numbers of household plots for food security of the newly created, through the same 'land reform', rural proletariat, are absorbed by the over-design/high allowance and the canals being in working shape.

Lastly, the KC Canal provides an example of a design with the common centralising ambitions of colonial rule of enrolling agricultural producers and collecting land revenue, but which technically took on an unusual form that implied a potential flexibility in management and the possibility of more decentralised water supply. Paradoxically, the oldest of our three systems is in some respects the most modern, in terms of an 'integrated' approach to water management through its combination of canal and river/stream conveyance and compartmentalisation. In our present understanding, the design seems to have emerged by circumstance and default rather than as a specific 'concept'. The resounding failure that the KC Canal was in agricultural and revenue terms is perhaps the reason that the unusual features of the canal system have remained largely unnoticed.

Implications for research and policy

The findings of the paper confirm the SCOT perspective that the social logics in technical choice making before artefacts reach 'closure' lead to infrastructures shaped by and involved in the reproduction of the social order in which they emerged. The close study of histories of emergence and of use of large-scale canal irrigation infrastructure easily avoids Wittfogelian deterministic and functionalist tendencies. In addition to the structural configurations of rule that shaped the infrastructures in the three situations studied, there was material and social contingency in the genesis and evolution of each of them, including landscape features, the nonlinearity of social process, and the irreducible presence of agency. At the same time, the physical construction of a large-scale irrigation system is a moment of closure. The physical infrastructure is not immutable in use, and is subject to remodelling over time, as the three case studies have illustrated, but nevertheless, some systemic features remain. In the Tungabhadra LBC it is the protective design and in Khorezm the over-design that exemplify system characteristics that remain and have to be dealt with no matter what when broader changes in governance occur. The KC Canal 'modernisation' shows that the presence of systemic features conducive to decentralised management and governance may go unnoticed when a different paradigm is strong enough.

Beyond the point that infrastructures have non-trivial histories of emergence, our analysis also suggests a beginning of the specification of complex systems characteristics of large-scale canal irrigation infrastructure, for which Horst (1998) made the general case in an engineering idiom. The three characterisations of Table 4 are by no means a comprehensive typology. The already mentioned Balinese *subak* irrigation provides a further type for its, dendritically aligned, proportional division design characteristic layout. Tamil Nadu's briefly referred to tank cascades provide food for thought on the relevance of 'intermediate storage' for structural diversity in canal irrigation infrastructure design, and the potential of decentralised governance. The proposal by Paranjape and Joy (1995) for an alternative design of the Sardar Sarovar project provides another variant on this – using large-scale infrastructure to supply local storages and water user communities through existing drainage pathways, rather than through 'commanding' the landscape from the ridges. However, this is a hypothetical design, which fell victim to the big vs. small binary (Mollinga, 2010). The specific analysis of the three systems in this paper may be used to develop thinking along these lines further and more systematically.[36]

In governance reform terms the different system-level design principles have strong implications. Without technical redesign (introducing balancing reservoirs for instance) the complexity of managing rationing in the Tungabhadra LBC's complex queueing system is perhaps insurmountable for a government agency. Radical transfers of financial and water allocation control to irrigators may be prospective, but are untested in the Indian context.[37] The Khorezm irrigation system has been designed in such a way that it would allow contractual relations between the water supply agency and units/groups of users, relatively independent of other users/groups, a trajectory not (yet) fitting in the present governance regime. We read the KC Canal history as a missed opportunity of creatively experimenting with alternative governance arrangements in large-scale canal irrigation. The design allows a form of decentralised management and governance that sits in between the Tungabhadra and Khorezm systems in terms of the interdependence of subunits. It would also seem to be a system where 'integrated water resources management' is more in-built technically than in the other two systems, and therefore more feasible.

For us, the most reassuring finding of this paper is that the graphical representation of system characteristics as given in Table 4 is possible, and that the representation is different for each of the systems studied. This lends support to the hypothesis that large-scale canal irrigation infrastructure can be designed in qualitatively different ways, ways that matter for their functioning, effects, and for reform strategies. Rethinking the role of canal irrigation in development thus also requires rethinking infrastructural design. Particularly encouraging is the finding that large-scale irrigation infrastructure can be designed in more or less (de)centralised ways – as the KC Canal shows. The identification of qualitatively different systems may assist thinking beyond the 'big is beautiful *vs.* small is beautiful' binaries that characterise debates on irrigation development.

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[36] Further possibilities of extension of research and comparison include the warabandi systems in North India and Pakistan, and large-scale irrigation in Mexico, Egypt, Indonesia, the Philippines and Morocco – all of which have been investigated from social science angles by researchers with an engineering background.

[37] A policy measure outside the realm of water distribution with possibly huge effects would be market incentives and other production factors favouring irrigated dry crops. This is not the case at the moment, crops like rice and sugarcane, high water consumers, are the 'protected' crops.

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