Creating a hydrosocial territory: water and agriculture in the Liwa Oasis

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Abstract

This article presents the Liwa Oasis as a hydrosocial territory defined by its natural resource, social, economic, and political context and how they manifest in policy and practice. The article identifies these components through analysis of the political economy of water management and agricultural production systems. Two distinct hydrosocial periods are defined: from independence in 1971 to the formation of agencies with water sustainability remits in 2006, and then from 2010 to the present, when subsidy regimes incentivized changes to cropping in existing agricultural production systems. The changes between these periods reflect alterations in the hydrosocial cycle stemming from natural resource degradation and how agriculture policy responded to it while still meeting social stability and food security objectives. In Liwa, water management and agricultural production regimes reflect the distributive nature of the state in that agricultural subsidies and payments are a significant source of supplementary income for UAE citizens. The current hydrosocial cycle leads to major groundwater resource degradation, which is beginning to pose a major challenge to the system. This disruption is at the heart of the hydrosocial dialectic playing out now in Liwa: resource degradation and depletion will ultimately require new patterns of resource utilisation, though arriving at new practices will require new laws, policies and modes of governance, which will alter the political, social, and economic context.

Keywords: Groundwater; hydrosocial; United Arab Emirates; governance; agriculture; political economy

Résumé

Cet article présente l'oasis de Liwa comme un territoire hydrosocial défini par ses ressources naturelles, son contexte social, économique et politique et la façon dont ils se manifestent dans les politiques et les pratiques. L'article identifie ces composantes à travers l'analyse de l'économie politique de la gestion de l'eau et des systèmes de production agricole. Deux périodes hydrosociales distinctes sont définies: de l'indépendance en 1971 à la formation d'agences chargées de la durabilité de l'eau en 2006, puis de 2010 à aujourd'hui, lorsque les régimes de subventions ont encouragé les changements de culture au sein des systèmes de production agricole existants. Les changements entre ces périodes reflètent les altérations du cycle hydrosocial résultant de la dégradation des ressources naturelles et la manière dont la politique agricole y a répondu tout en respectant les objectifs de stabilité sociale et de sécurité alimentaire. À Liwa, les régimes de gestion de l'eau et de

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production agricole reflètent la nature distributive de l'État dans la mesure où les subventions et les paiements agricoles sont une source importante de revenus supplémentaires pour les citoyens des EAU. Le cycle hydrosocial actuel entraîne une dégradation majeure des ressources en eaux souterraines, qui commence à poser un défi majeur au système. Cette perturbation est au cœur de la dialectique hydrosociale qui se déroule actuellement à Liwa: la dégradation et l'épuisement des ressources nécessiteront en fin de compte de nouveaux modèles d'utilisation des ressources, bien que pour parvenir à de nouvelles pratiques, il faudra de nouvelles lois, politiques et modes de gouvernance, qui modifieront le contexte politique, économique et social.

Mots-clés: eaux souterraines ; hydrosocial; Emirats Arabes Unis; gouvernance; agriculture; l'économie politique

Resumen

Este artículo presenta el acuífero de Liwa en los Emiratos Arabes Unidos (EAU) como un territorio hidrosocial definido por sus recursos naturales, sociales, económicos y políticos y cómo se manifiestan en la política y en la práctica. El artículo identifica estos componentes a través del análisis de la economía política de la gestión del agua y los sistemas de producción agrícola. Se definen dos períodos hidrosociales distintos: desde la independencia en 1971 hasta la formación de agencias con competencias de sostenibilidad i gestión del agua en 2006, y luego desde 2010 hasta el presente cuando los regímenes de subsidios incentivaron los cambios de cultivos dentro de los sistemas de producción agrícola existentes. Los cambios entre estos períodos reflejan alteraciones en el ciclo hidrosocial derivadas de la degradación de los recursos naturales y la forma en que la política agrícola respondió a este fenómeno al mismo tiempo que cumplía los objetivos de estabilidad social y seguridad alimentaria. En Liwa, la gestión del agua y los regímenes de producción agrícola reflejan la naturaleza distributiva del estado donde los subsidios y pagos agrícolas son una fuente importante de ingresos suplementarios para los ciudadanos de los EAU. El actual ciclo hidrosocial conduce a una importante degradación de las aguas subterráneas, que está comenzando a plantear un gran desafío para el sistema. Esta disrupción está en el centro de la dialéctica hidrosocial que se desarrolla ahora en Liwa: la degradación y el agotamiento de los recursos finalmente requerirán nuevos patrones de utilización de los recursos, aunque llegar a nuevas prácticas requerirá nuevas leyes, políticas y modos de gobierno que alterarán el contexto político, social y económico.

Palabras clave: las aguas subterráneas; hidrosocial; Emiratos Arabes Unidos; gobierno; agricultura; la economía política

1. Introduction

This article examines groundwater management and agriculture in the Liwa Oasis and their interactions with the wider political economy[2] of Abu Dhabi and the United Arab Emirates (UAE). The Liwa Oasis, which is in the Western Region of the emirate of Abu Dhabi, is crescent-shaped and sits on the edge of the Empty Quarter. It has supported permanent farming and seasonal settlement for centuries, and the Bani Yas tribe, the ruling tribe of Abu Dhabi today, began to occupy Liwa permanently from the late 16th century (Hellyer 2012).

The unconfined aquifer that underlies Liwa is the largest easily accessible freshwater resource in the UAE, and it is now used almost exclusively for irrigation (Pitman *et al*. 2009). It faces less precipitous over-abstraction and salinization challenges than other groundwater resources in the emirate that are more intensively utilized, such as the Al-Ain aquifer in the east of Abu Dhabi.

Water and food security are prominent concerns in the hyper-arid Persian Gulf states. Whilst the natural aridity and limited arable land are pre-eminent drivers of these issues, the geopolitical complexity of the region influences the political economy of water and food nexus issues (e.g. GEF 2016; Molle and Closas 2017; Wijnen *et al*. 2012). These factors make the case study self-contained and relevant for the UAE's long-term water security concerns.

The primary research underpinning this article was conducted for an applied research project on groundwater management in Abu Dhabi (Fragaszy and McDonnell 2016; McDonnell and Fragaszy 2016) that

[2] We use Wijnen *et al*.'s (2012) conceptual definition of political economy, "the way in which different stakeholders influence policy, governance and resource allocation, and thereby influence outcomes."

assessed the sources of groundwater resource management challenges. This article builds on these findings and highlights the interactions of water resource, agriculture, and political economy features within the specific milieu from which they emerge.

The study uses the theoretical lens of the hydrosocial cycle (Budds *et al*. 2014) and the concept of hydrosocial territory (Boelens *et al*. 2016) to explore how water management in Liwa has interacted with local, regional, and national political economy drivers. It is the first study to explore in depth the socio-economic drivers of groundwater and agricultural management in Liwa, and it builds on Cariou's (2013) work on their relation to the wider UAE political economy and water management issues.

In the Persian Gulf region, water resource management has always been paramount to community survival and livelihoods, with tribal territories, laws and customs partly defined by access to water and its governance (Lambert 2014). The discovery of oil in the 1950s, predominantly in what became the emirate of Abu Dhabi[3], and the independence of the UAE from Britain in 1971 changed the country's development path, water management regimes, and its hydrosocial cycle.

We describe two distinct periods in the modern hydrosocial cycle and their effects on Liwa as a hydrosocial territory: from independence in 1971 to about 2006, and then from 2010 to present. The first period witnessed major expansion of groundwater-dependent irrigation to meet political objectives of nation-building, modernization, and legitimization following independence. The second period witnessed shifts in existing agricultural production systems that reflect rulers' paramount prioritization of social stability, albeit with growing recognition of natural resource limitations. The current hydrosocial cycle results in major groundwater over-abstraction that, in turn, is challenging the very basis of the system.

Changes in each period were rapid in Liwa, and this Oasis serves as a microcosm to understand the manifestation of the UAE's state-centric, developmentalist and distributive objectives in agricultural and water resources policies and their influence on water users' practices (e.g. Krane 2010; McDonnell 2014; Woertz 2013).

2. Introducing the hydrosocial cycle and hydrosocial territory concepts

The majority of academic studies and government-developed strategies focusing on modern Persian Gulf water issues apply integrated water resource management frameworks or focus almost solely on evaluation of technical and engineering solutions to water issues (e.g. Al-Zubari *et al*. 2017; EAD 2014; Government of Qatar 2018). Such a monolithic approach points to extreme over-reliance on technological fixes such as water reuse and desalination as a general approach to water management, paving the way for a technologically deterministic developmental pathway (March *et al*. 2014; Williams and Swyngedouw 2018). This path has very specific water management outcomes – predominance of supply-side dominated discourses and capital- and technology-intensive solutions to issues that arise – but it misses vital socio-political aspects of resource management altogether, especially in the Gulf region (McDonnell 2014).

Recent studies (e.g. Cariou 2013; Hommes *et al*. 2016; Kim and van der Beek 2018; McDonnell 2014; Mustafa and Tillotson 2019; Zenko and Menga 2019) evaluate water management in Arab and other west Asian states through the assessment of resource mobilization drivers linked with the understanding of water as a biophysical resource as well as a socio-political construct (Swyngedouw 2007). These political ecology approaches incorporate the epistemology, if not always terminology or explicit frameworks, of hydrosocial territories (Boelens *et al*. 2016) and hydrosocial cycles (e.g. Budds *et al.* 2014; Linton and Budds 2014). These frameworks structure the analysis of water management in a socio-ecological fashion; water impacts societies and political systems, and human activities, while institutions and cultural contexts equally shape its material flows (Bakker 2003a, 2003b).

One of the underlying elements of the hydrosocial cycle is the 'hybridity' of nature, both biophysical and social (Budds 2008; Swyngedouw 1999). Such a conceptualization argues that nature is in constant flux,

[3] The United Arab Emirates is a federation of seven emirates, with Abu Dhabi the largest and the home of the President of the country. Other emirates include Dubai, Sharjah, Fujairah, Ajman, Ras al-Khaimah, and Umm al Quwain.

equally shaped and re-shaped by, on the one hand, socially constructed forms of resource control and appropriation within specific communities or political settings, and, on the other hand, the physical expressions of the hydrological cycle: the biophysical, material and technical constituents of water as a natural resource.

Boelens *et al.* (2016: 2) define a hydrosocial territory as:

> …the contested imaginary and socio-environmental materialization of a spatially bound multi-scalar network in which humans, water flows, ecological relations, hydraulic infrastructure, financial means, legal-administrative arrangements and cultural institutions and practices are interactively defined, aligned and mobilized through epistemological belief systems, political hierarchies and naturalizing discourses.

Further, they describe the conceptual themes inherently related to development of hydrosocial territories: hydrosocial networks, politics of scalar reconfiguration, governmentalization, and territorial pluralism. This article describes these components and their relation to the underlying political economy drivers and tensions within Liwa and Abu Dhabi that generate specific environmental outcomes: how are natural resources appropriated, by whom, why, and what are the effects of such appropriation.

Figure 1 attempts to summarize this political ecology conception of the hydrosocial cycle: the contextual milieu of social, economic, political, and natural resource characteristics interact with one another and ultimately have a dialectical relationship with the manifestations of the hydrosocial cycle – law, policy, governance[4], and practice.

The hydrosocial cycle and hydrosocial territory are concepts that emerge from the social-ecological systems and *territoire* traditions, both of which address the nature-society interface from slightly different angles. Combining these approaches for analytical purposes, as we have done here, helps to clarify the system components within their temporal and spatial dimensions (Barreteau *et al.* 2016).

3. Methods

The article employs critical textual analysis through the hydrosocial framework described above, and uses field research data consisting of key informant interviews focused on social, economic, and governance issues collected during two fieldwork campaigns in 2015-2016. Fragaszy and McDonnell (2016) provide more detailed descriptions of the interviewees and the interview process and focus. Here it suffices to provide an overview of the three sets of interviews undertaken.

The first set (Interviews A) consisted of interviews with farm managers and workers on 20 farms as well as two group discussions with farm owners and Liwa representatives of the Abu Dhabi Farmer' Services Centre (FSC), an agency offering extension services, input supply, and agricultural produce marketing. This set focused on agricultural water management practices and their business, social, and regulatory drivers, as well as changes in groundwater resources over time.

The second set (Interviews B) consisted of a group meeting with Liwa representatives of the FSC followed by individual interviews with nine FSC staff in various roles as well as one Liwa representative of the Abu Dhabi Food Control Authority (ADFCA[5]). The ADFCA, in relation to groundwater management, is primarily a policy implementation and regulatory compliance, monitoring, and enforcement agency. These interviews focused on local agricultural water management practices as influenced by water and agricultural law, policy, and governance regimes.

The third set (Interviews C) consisted of interviews with Abu Dhabi officials. They included six representatives from the Environment Agency Abu Dhabi (EAD), primarily a legal and policy development as

[4] Law structures what government can do while policies consist of what governments actually do (Lowi, 2003). Governance, then, is the modes of interaction between state and non-state actors in practice.

[5] In 2019, the ADFCA was agglomerated into the Abu Dhabi Agriculture and Food Safety Authority, but its website at time of writing still provides the ADFCA's policy guidelines and this article refers to the agency as the ADFCA.

well as environmental monitoring agency, four from the FSC, two from the ADFCA, and one from the Khalifa Fund, a government-linked organization that funds small- and medium-sized enterprises in the UAE including farm businesses through its *Zaarie* program. These interviews focused on the political and natural resource context as well as national-level policy and governance regimes.

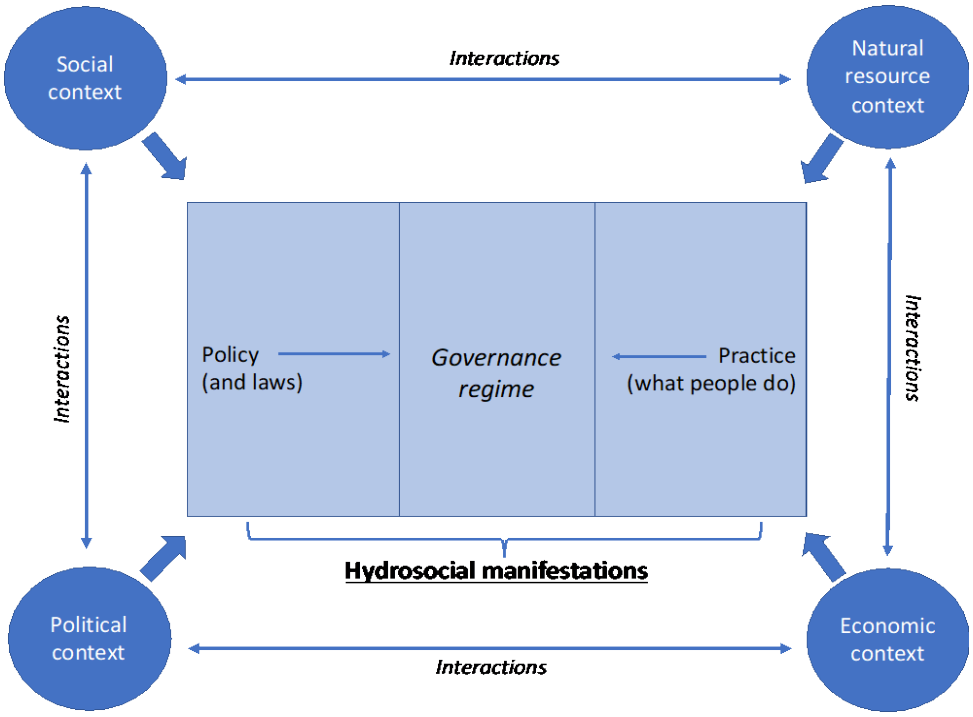

Figure 1. Conceptualizing the hydrosocial cycle. Source: Authors.

4. The Liwa Oasis

This Section sets the scene by describing the Liwa groundwater system, water use in the modern period, and Liwa as a hydrosocial territory in the pre-modern period up to 1971.

The Liwa Aquifer – groundwater characteristics and use

Groundwater is the sole significant natural freshwater resource in the UAE. As of 2005, the Liwa Aquifer held over 90% of the total freshwater[6] storage in Abu Dhabi, approximately 24Bm^3, as well as over 75 Bm^3 of brackish groundwater that can be used to irrigate specific crops (Brook 2006; Pitman *et al.* 2009).

Descriptions of groundwater in this article relate to the Quaternary age unconsolidated aquifer – underlying aquifers are either not productive, or highly saline, used in hydrocarbon production, or currently uneconomic for intensive abstraction (Alsharhan *et al*. 2001). The last period of significant recharge was from 9,000 to 6,000 years before present and so groundwater abstraction in Liwa is essentially mining fossil water (Wood and Imes 1995; Wood *et al*. 2003).

The freshwater lens of the Liwa Aquifer, with Total Dissolved Solids (TDS) less than 1,500 mg/l, extends over approximately 2,500km^2 and has an average saturated thickness of 25m, reaching a maximum of

[6] UAE definitions of fresh, brackish, and saline water are as follows: fresh < 1,500 mg/l TDS; brackish 1,500 – 15,000 mg/l TDS; saline > 15,000 mg/l TDS (Pitman *et al.* 2009). TDS=Total Dissolved Solids.

about 50m (USGS 1996). It becomes increasingly brackish, with TDS between 1,500 and 15,000 mg/l, for an average of 70m further into the aquifer. Saline zones with TDS greater than 15,000 mg/l extend to the bottom of the aquitard. In some areas, the freshwater lens is much shallower (Rizk and Al-Sharhan 2003).

Groundwater in Abu Dhabi is used almost entirely (about 80%) for agricultural irrigation and forestry (SCAD 2013). Official statistics (EAD 2013) show abstraction rates of 1.8 Bm^3/year for agriculture, but this should be considered a very rough estimate due to lack of flowmeters on wells (Interviews C). Groundwater was used for municipal drinking supply until the 1990s and was phased out because nitrate and boron levels exceeded health guidelines thresholds (Moreland *et al*. 2007).

Seawater desalination started with the oil era and now provides virtually all municipal water supplies. However, the Abu Dhabi Water and Electricity Authority (ADWEA) is implementing a major aquifer storage and recovery program in Liwa – but outside oil production and agricultural areas – that will result in ~26Mm^3 of desalinated water being injected and infiltrated into the Liwa Aquifer for later re-abstraction to supply the Emirate's drinking water supplies for about 90 days in case of emergency (Stuyfzand 2017).

Figure 2 shows relevant features of Liwa as a hydrosocial territory: it locates the Liwa Oasis and wider aquifer within the Western Region of Abu Dhabi, and it demarcates desalination infrastructure and the Liwa area's groundwater-dependent irrigation areas associated with recent agricultural development.

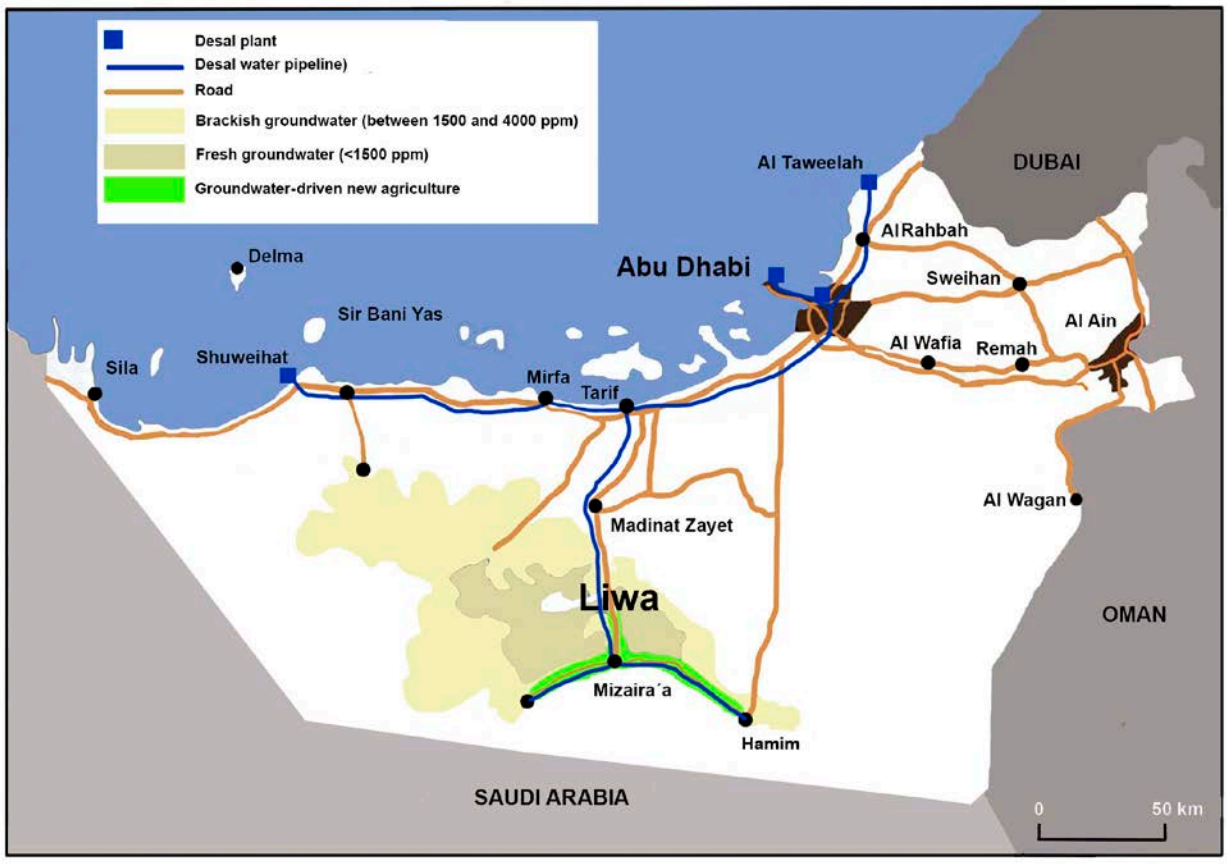

Figure 2: Liwa as a hydrosocial territory. Source: Authors.

Liwa as a hydrosocial territory in the pre-modern period

The Liwa Oasis has supported communities since the Late Stone Age, approximately 6,000 to 7,000 years before present (Adams 1991; Harris 1998). A historical record of continuous habitation exists from the late 16th century when members of the Bani Yas tribe began to occupy Liwa permanently (Hellyer 2012).

Liwa formed the central pillar of the Bani Yas' semi-nomadic lifestyle through the early 1900s. The Oasis provided an agricultural base via date and vegetable cultivation that underpinned seasonal camel herding across the Western Region and fishing and pearl diving on the Persian Gulf coast. The latter activity increased in importance as the territory entered the British imperial orbit from the 18th century (Heard-Bey 2005; Wilkinson 2009).

Historically, accessibility and quality of groundwater from the sand-dune aquifer was the limiting factor for population growth. The permanent community in Liwa was small – about 300 families in 1968 – but during the date harvest, it would swell considerably as temporary labor would move in for the harvest (Stevens 1970). In Liwa, people used shallow dug wells for potable and irrigation water until the salinity increased, and then they left individual wells to recover for several hours or days, which severely limited overall irrigation and drinking water potential (Heard-Bey 1974). Water governance followed Islamic and communalist tribal precepts and was predicated around demand-centered and careful management of the natural resource by families bound by kinship (Lambert 2013).

As a hydrosocial territory in the pre-modern period, Liwa was thus a central node for the community's political economy. Water governance employed and reflected religious precepts, and communal water and agricultural management practices required careful consideration of groundwater systems to avoid degradation of water resources (Lambert 2013).

The formation of the UAE following independence from Great Britain in 1971 changed the hydrosocial context dramatically: a centralization of political authority, growing populations, introduction of desalination and motorized groundwater pumps, and integration with global markets all interacted to reshape Liwa and UAE society in fundamental ways. These changes left Liwa on the periphery, as the center of economic gravity shifted to Abu Dhabi (Cariou 2013). Still, Liwa remains prominent in the political imaginary as a key source of national identity, and it is a key location for the state to undertake legitimizing activities such as greening the desert, securing water for the city, and actively supporting social stability through agricultural policies.

5. Political economy of water management

This section describes general aspects of state formation and water management in the UAE before describing the current role of government agencies and water management regimes in Liwa. Government agencies with environmental and agricultural remits require special attention because the hydrosocial lens necessitates examination of the extent and limits of state power to facilitate and constrain access to, and use of, groundwater. Equally, in political economy terms, this article explores how state and private decision-making is affected by the political nature of the state (Drazen 2000).

General features of UAE state formation

The concept of 'the state' is associated with a specifically bounded territory over which a supra-individual apparatus exercises a monopoly of coercive authority, legitimacy via symbols, and shared history that provides an ideological rationalization and justification for this monopoly of coercion (Khoury and Costiner 1990). The formation and evolution of Arab states, in particular, has contended with three features that are at times oppositional and at other times mutually reinforcing: 1) formal and centralising structures of state power, regulation and control; 2) the role of informal linkages and institutions within society; and 3) the increasing role of the market and its impact on national and local economies (Ayubi 1995).

In the Persian Gulf region, the process of state formation has occurred incredibly rapidly; relatively loose and small tribal confederations became centralized nation-states within just a few generations, and the population of the UAE increased over 50 times in the fifty years between 1960 and 2010 (UN 2019).

In the UAE context, one can describe state formation as the hybridization of economic and bureaucratic modernization with "initial conditions" set by the British model – but subsequently modified by the national objectives of post-independence leaders and strongly influenced by: 1) traditional tribal forms of power and authority; and 2) the market forces unleashed by rapid economic development in a market system largely free from constraints, at least in relation to water management and agriculture, but with many state-supplied incentives.

These characteristics are borne out in the 'distributive' nature of the Abu Dhabi (and UAE) government, in which the social contract entails that citizens, who are less than 20% of the population, receive the benefits of oil wealth (Krane 2010). They are also borne out in water management and agricultural production regimes that reflect national development narratives, symbols, and governance frameworks, which have led to specific outcomes in Liwa.

Water management and UAE state formation

The developmentalist ideology of Sheikh Zayed al-Nahyan, regarded as the father of the nation, ensured that water infrastructure was prioritized and provided for within a statist framework. From the late 1960s, the strong centralization of authority, and creation of a technocratic bureaucracy in charge of water development, cemented new lines of power between citizen, ruler and state, and they resulted in new conceptualization of water resources. Whereas previously communities managed water and with rulers adjudicating disputes relatively directly, following independence and modernization, state agencies enabled individual and independent access to groundwater, which contributed to conceptualization of water as a private resource (Heard-Bey 2001; Lambert 2013; Fragaszy and McDonnell 2016).

The technical bureaucracy's oil-funded "hydraulic mission" has two core components that have endured and are integral to Emirati national identity narratives and the legitimacy of Abu Dhabi's rulers (Lambert 2013; Ouis 2002). Firstly to provide ample volumes of water, particularly for municipalities, and secondly to green the desert. Liwa has been prominent in the agro-forestry aspects of this vision, and with the initiation of the aquifer storage and recovery program, it is relevant for urban water security as well.

State centralization and post-independence agricultural development in Liwa followed Boelens *et al.*'s description of "territorial governmentalization projects" (2016: 6). National efforts sought to "alter local water users' identification with community, neighborhood, kinship or federative solidarity organization[s] in order to change water users' ways of belonging and behaving, according to new identity categories and hierarchies." This is most clearly reflected with regards to agriculture, and in Liwa, this occurred through policies that created a major groundwater-driven agricultural pioneer front (Trottier and Perrier 2018) through state provision of land and resources to citizens to undertake agricultural activities. This allocation to tribespeople and social communities existing as part of the proto-state played a major role unifying their allegiance to one flag and national identity (Khoury and Costiner 1990).

The hydraulic mission facilitated conspicuous water consumption, which is now a key component of Abu Dhabi's hydrosocial cycle. Its subsidized provision, and the state-led establishment of over 305,000 ha of irrigated forests, many of which are in or near Liwa (Barari 2015), are critical components of the governing regime's legitimacy (McDonnel 2014). This explains both why the UAE has among the highest per-capita water footprints in the world (Pitman *et al.* 2009) and why the continuity of this system has such symbolic importance (Amery 2017).

While aspects of the tribal order described briefly above, and particularly the participatory and consultative mechanisms of *majlis* and *shura*, still exist and are influential in policy considerations, it is no exaggeration to say that the shifts described in this section constitute a revolution, at least in water management (Lambert 2013). There was no serious or sustained opposition to this revolution, and relatively little discussion or commentary on how it has altered society, including humans' relationships with the natural environment of oases like Liwa, such as that described in Abdelrahman Munif's *Cities of Salt* (Nixon 2013).

Competing official mandates to manage natural resources

Current water governance structures in Abu Dhabi largely came into being in 2005 and 2006, following Sheikh Zayed's death in 2004, with the creation of the modern EAD, ADFCA, ADWEA, and the Regulation and Supervision Bureau (RSB). Collectively, these agencies have wide remits over water supply, groundwater resource management, and agriculture policy including regulatory roles and responsibilities. These agencies, and their modes of operation, reflect the general characteristics of UAE state formation described in Section 5: they have strong central government mandates, provide significant market incentives to shape practices, and, in theory, expansive powers to enforce regulatory compliance that in practice are strongly moderated by political concerns about whether and how citizens will accept them (Interviews C).

The EAD is the competent authority over natural water resources in Abu Dhabi, per Abu Dhabi Law No. 4 (1996) and Law No. 16 (2005). Its remit includes many aspects of land and water management including environmental regulation, licensing, monitoring, compliance, and enforcement of established standards.

The ADFCA develops agricultural policy and is responsible for providing water for agriculture (Decree No. (2) 2005; S5 Law No. (9) 2007). It is tasked with ensuring the vitality of the agriculture sector, preparing sustainable growth policies, and introducing regulation to mitigate negative agricultural impacts on the environment including groundwater resources.

The FSC was established in 2009 to improve agricultural production and marketing and to help bring greater water efficiency to the sector through technical support and advocacy (Law No. (4) 2009). It is responsible for implementing policies set by the ADFCA, but it is independent of it. The RSB is relevant to discussions of groundwater management because it sets electricity and desalinated water prices for consumers, both of which influence groundwater abstraction.

These agencies are challenging the predominant features of the UAE's hydraulic mission with a governing ethos that includes addressing the problematic of groundwater sustainability (McDonnell and Fragaszy 2016). For instance, in 2016 Abu Dhabi passed its groundwater law (Law No. 5, 2016) that, among other stipulations, reiterates that groundwater is government-owned and states that well owners must register them, install meters, and abide by prescribed permitted abstraction limits (EAD 2017). Ongoing efforts such as the national well inventory, which aims to create a GIS database of existing wells and farms, and ongoing testing of smart flowmeters for wells, are significant undertakings that aim to narrow the monitoring, compliance and enforcement gap. The well inventory was beginning in earnest during the fieldwork period and should conclude in the near future (*Ibid*.).

These competing and overlapping roles lead to political and inter-agency tensions because their focused remits can result in fragmented consideration of, and discordant views about, what constitutes "sustainable" groundwater management (Interviews B, C). In response, the state has increasingly deployed narratives and discourses on irrigation efficiency, and made linked investments in measures to increase irrigation efficiency – largely as defined by a "more crop per drop" productivity typology (Lankford 2013) – to reduce groundwater over-abstraction and salinization as described in Sections 6 and 7. They have also, at least on paper, increased state regulation of water management practices.

Groundwater management and its regulatory oversight in Liwa

Current Liwa farms typically have multiple wells with various license conditions including volumetric abstraction limits, pump power limitations, and specific operation restrictions dependent on farm type, such as limits on summer water usage for vegetable crops. EAD has the authority to issue fines for non-compliance (Interviews B). However, present EAD monitoring, compliance and enforcement systems do not enable active oversight. As of 2016, the EAD had no field staff based in Liwa, and their monitoring and compliance team had five staff for the entire Western Region of Abu Dhabi (Interviews B, C). In 2011 this area had an estimated 20,000 wells and over 8,500 farms, of which about 7,100 were in Liwa (National Bureau of Statistics 2011, 2011a, 2013).

Farmers frequently install pumps far more powerful than well licenses permit, and no interviewee had heard of fines given to farm owners for such violations (Interviews A, B). Government officials stated that recently groundwater regulation enforcement has focused more on illegal groundwater well operations that sell

water to labor camps and for industrial usage, and several punishments have indeed been given in for those issues (Interviews C). Overall, farmers and government officials in the Liwa area described EAD as distant and not involved on the ground, which EAD staff echoed. Only one person interviewed during farm visits recalled seeing EAD personnel, and that was when his well was first drilled. Farm managers and workers interact far more regularly with the FSC and the ADFCA than EAD. The characteristics described here indicate the strong role of agricultural policy, and its implementing agencies, in shaping groundwater governance and practice on the ground, and it also hints at the underlying dynamics of water use and appropriation by citizens *vis-à-vis* the state apparatus. While legal authority clearly rests with the state, political desire for social stability is paramount, and informal governance mechanisms such as the *majlis*, in which citizens can openly discuss concerns over governmentalization, are very powerful drivers promulgating the status quo hydrosocial cycle (Interviews B, C; McDonnell and Fragaszy 2018).

Thus, between the former (1971-2006) and current hydrosocial period, we see a significant shift in rhetorical aspects of water governance towards discourses, and slowly but surely regulation, of groundwater sustainability characteristics. This shift reflects

1) changing political objectives of the state and resulting changes to the legal regime through which those political objectives are implemented;
2) rulers' recognition of natural resource limitations, and
3) market drivers.

From Sheikh Zayed's stated desire to develop an agricultural civilisation, the current government is focused more on social stability and some aspects of food security. As will be shown in Section 6, this new rhetoric has been supported by major financial incentives, and as discussed in Section 7, it has major limitations due to fundamental characteristics of the current hydrosocial cycle.

6. Political economy of agriculture in Liwa

This section describes the objectives of Abu Dhabi agricultural policy, discourses that agencies deploy in the service of those objectives, mechanisms to deliver those policy objectives, and how those policies drive (and fail to drive) agricultural production regimes in Liwa.

From state-building to 'social policies with agricultural components'

From independence, the ruling family, through the state, granted titles to land in Liwa for citizens to establish farms, and this was the genesis of the modern hydrosocial territory. Politically, the objective was to gain support for the ruler and the nation, to ground nomads to one territory and prevent them from leaving the new nation, and instil a sense of citizenship and loyalty to the regime; socio-economically the goal was to lay the foundation for an agricultural society and narrow the rapidly-widening food import gap (AlShamry 1994; Lambert 2013).

Until the mid-1980s, the state provided plots of 5-10 hectares, and afterwards 2-4 hectares, to citizens in Liwa. The state also provided services to facilitate agricultural land development: land levelling, well-drilling, interest-free loans, free provision of, or subsidized, production inputs, price supports and guaranteed purchase of outputs, and subsidized or free electricity (AlShamry 1994; EAD 2009; Shihab 2001). Guaranteed government purchase of output ensured rapid farmland expansion and maximum cultivation intensity even though over 50% of produce was classified as wastage and much of the rest could not be sold for human consumption due to excessive pesticide residues (AlShamry 1994; Shihab 2001).

A brief chronology (see also Figure 4) highlights the scale of the resultant groundwater-driven pioneer front in Liwa. In the mid-1980s, farmland covered just over 1,000 hectares and about 125 wells were dug each year; by 1990, there were about 3,400 farms in Liwa (about ten times more than at independence) and nearly 900 wells were dug per year (AlShamry 1994). By 2002, agricultural area peaked at 21,000 hectares and has

since dropped to about 17,000 hectares on 7,000 farms by 2018, at which time there were about 11,500 working wells and 7,600 abandoned wells (ERWDA 2004; SCAD 2018).

Agriculture in Abu Dhabi's overall economy remains marginal: in 2012 the entire sector – including forestry and fisheries – was valued at US$1.45 billion, less than 1% of GDP. In Liwa it is a significant activity, though, with 70% of the population employed in agriculture-related sectors compared to the national proportion of just 5% (Oxford Business Group 2014; FAO 2015).

Despite the agriculture sector's marginal role in the economy, agricultural subsidies and payments are a significant source of supplementary income for UAE citizens since virtually all farm owners are employed outside of the agriculture sector (Interviews A). Also, farm rental, mainly to non-citizens who cannot own farmland, is lucrative. While it is illegal, there is little to no legal enforcement (interviews A, B).

The government-owned dates company, Al-Foah, is the primary purchaser of dates in the UAE. In 2014 it paid ~US$190 million to over 18,000 farmers nationwide (Al-Foah 2014). Locally grown vegetables sold by the FSC had a market value of US$45 million in 2013 with rapid year-on-year expansion. Livestock and date cultivation also have high symbolic currency given their connection to national heritage and identity (Interviews A, B, C). Liwa hosts the annual date festival that the royal family patronizes.

The discourse of food security is ever-present in agricultural production policies. The ADFCA increased attention on the issue following food price spikes and sourcing difficulties in the 2008-2013 period (Woertz 2013), and since 2017 the UAE has had a Minister of Food Security. The UAE imports over 95% of food by volume and all wheat and rice, the two largest sources of calories (National Bureau of Statistics 2013), and as such, it is fundamentally reliant on global markets for food security and food price hedging (World Bank/FAO 2012; Fragaszy 2015).

The food security theme combines neatly with increased market and cultural interest in locally grown agricultural products, especially vegetables, to shape the future direction of agricultural production in Liwa. FSC targets for self-sufficiency are defined by market share of a range of locally grown vegetables. They aim for these to reach over 40%, which in a few cases it has surpassed (FSC 2014).

As a result of these changes in the hydrosocial context – policy and market shifts – new farms are increasingly devoted to vegetable production and developed in areas with fresher groundwater rather than traditional cultivation areas, which are increasingly shifting to date production (Interviews A, B). The number of greenhouses nearly quadrupled between 2010 and 2018 to reach about 4,000, and hydroponic systems are increasingly being introduced (SCAD 2018).

Maintaining agricultural production systems, and the subsidies and government facilitation that underpin them, connects strongly to the state's wealth distribution and related social stability objectives. Multiple government officials described agricultural programmes as "social policies with agricultural components" or very similar formulations. This theme has become far more important following the outbreak of the Arab Spring (Interviews C), and it dovetails very neatly with food security narratives, which became increasingly prominent after the food price shocks in the 2008-2013 period (Woertz 2013). Promoting economically productive and sustainable farming methods – as defined by the state-deployed discourses of irrigation efficiency and crop water productivity – are important legitimizing narratives, but ultimately secondary objectives (Koch 2019).

This distinct hierarchy of objectives has critical ramifications for the current hydrosocial cycle and the flexibility of its manifestations to adjust to new contexts.

Agricultural subsidies

Agricultural subsidies drive local agricultural production patterns and reflect national political agendas the world over, and that holds true in Liwa and the UAE. They reflect the hydrosocial cycle and influence the long-term development of the hydrosocial territory. As described above, current direct and indirect subsidies emphasise wealth distribution and rationalisation of irrigation water use. They also facilitate livestock rearing, particularly camels, which is a status symbol and primary feature of tribal identity (Interviews B, C).

Major current subsidies are described in Table 1. Other indirect subsidies include provision of soft loans from government-run and government-affiliated institutions, and services from the FSC including farm advisors, treatments, and marketing support. For example, ADFCA provides soft loans covering up to 50% of greenhouse establishment costs (ADFCA 2015).

Type	Quantity	Stipulations
Fodder crops	US$24,500/year	For growing fodder crops on less than 10% of farm area if farm owner has less than US$32,700 of real estate income per year[7]
Livestock feed provision	US$82/ton; US$136/ton; ~US$435/ton	Up to 10 tons per month; Between 10 and 20 tons per month; Above 20 tons per month
Date palms	US$2,724/year Free provision of young date palms	If farm has 60 or more date palms
Electricity	US$0.008/kWh (cost-reflective tariff US$0.08/kWh)	Excluding aquaculture and feedlots
Water rates	US$0.6/m3 (cost-reflective tariff US$2.87/m3)	When supplied by ADWEA and in some cases ADFCA and excluding aquaculture and feedlots

Table 1: Types of subsidies for agriculture in Liwa. (Source: ADFCA 2013; ADDC 2017; Interviews B, C)

The first three subsidies merit close attention because they were explicitly introduced around 2010 to decrease water consumption in agriculture while maintaining generous pay-outs to farmers, and linked policies were established to maintain herds despite drastic reductions in local fodder production (Interviews B, C). Roughly 66% of farm owners receive the fodder crop and date palm subsidies (Interviews C), and therefore a rough calculation based on the number of farms in Liwa (7,100) shows this subsidy alone to be worth approximately US$100 million/year to Liwa farm owners.

Prior to 2010, the cultivation of fodder crops, particularly the moderately salinity-tolerant Rhodes Grass (Chloris gayana), was incentivized through guaranteed purchase prices of US$450/fresh ton. Dried feed (3 tons fresh to 1 ton dry) was sold to livestock farmers for US$82/ton (Pitman *et al.* 2009). Rhodes grass in desert environments has irrigation requirements up to 48,000m^3/ha/year (El-Keblawy and Ibrahim 2006).

Between 2005 and 2010 field crops, predominantly Rhodes Grass and alfalfa, were grown on 22,000-34,000ha annually in Abu Dhabi (National Bureau of Statistics 2011). During 2010-2012 the guaranteed purchase price was phased out and replaced by the three subsidies mentioned above. The government-linked Al-Dahra Holdings purchased farmland abroad, especially in the United States, and made up for local production drops by importing massive quantities of fodder (Al-Dahra 2016). Indeed, UAE imports of alfalfa hay from the United States were 33 million tons in 2007 and 250 million tons in 2017 (Putnam *et al.* 2019). As a result of these policies, Rhodes Grass cultivation in Abu Dhabi (disaggregated statistics are not available for Liwa), dropped by approximately 90%, and alfalfa by approximately 75% by 2013 in relation to 2010 figures (National Bureau of Statistics 2013). These field crops were replaced primarily by date palms (Phoenix dactylifera L.), which have far lower crop water requirements and far greater tolerance for salinity (Figure 3).

The shift in subsidy regimes from 2010 demarcates the beginning of the current hydrosocial period. Through these policies, the government incentivized existing farms to shift to less water-intensive crops

[7] With few exceptions, only UAE citizens may own real estate; property rental is highly lucrative in a population that is ~80% expatriate.

without compromising either the social objectives of agricultural policy that are met by subsidies and payments, or, in the case of livestock-rearing, the symbolic currency of the practices they underpin.

This adjustment within the existing hydrosocial cycle reflects state actors' realization that groundwater depletion is challenging the status quo, and it implicitly indicates that more substantial depletion would entail a hydrosocial revolution. Rulers are delaying that negative eventuality by to reduce total groundwater drawdown rates through crop substitution using market incentives to retain existing production systems, shifting local cropping from fodder grasses to dates (Lankford 2013).

Figure 3: Irrigated date production in Liwa. Source: Wikimedia Commons (greeeen2008, CC BY 3.0)

Agricultural finance

There is no dedicated agricultural bank in the UAE, and private lenders are not deeply involved with the smallholder farmers who cultivate the vast majority of land. Direct government loans for agriculture – all of which are soft loans that have principal forgiveness components – in the Western Region and capital district of Abu Dhabi shrunk from US$1.55 million in 2005 to US$226,000 in 2014 (SCAD 2015). Still, substantial financial resources have been available for farm owners, but they have been scattered amongst varying institutions with varying objectives, and, until recently, few have focused on water management and sustainability of any sort (Interviews B, C).

Farm owners primarily rely on a mix of government agencies, pseudo-public institutions such as the Khalifa Fund (a government-linked enterprise development agency), and patronage networks such as the Crown Prince's Court (Interviews A, B, C). For example, the Khalifa Fund disbursed nearly US$27 million through its *Zaarie* program in 2012-2016 for the development of greenhouses, hydroponics and aquaculture (both inland and sea-based). It focuses primarily on new and recently-developed farms whereas the Crown Prince's Court provides grants or subsidies up to US$27,000/year to improve operations on existing farms (Interviews C). In both cases, most funding goes towards vegetable production (Interviews B, C).

In 2019, the Abu Dhabi Investment Office, a newly-created government agency that promotes foreign investment, launched an approximately US$250 million "AgTech" financing mechanism to support novel capital – and knowledge-intensive agricultural production technologies (Townsend 2019). Project recipients will primarily be centered near the capital and reliant on desalinated water.

State subsidy regimes and state-backed agricultural finance therefore have very different but not yet competing objectives. Subsidies, which clearly represent a far greater share of state expenditure, prop up existing agricultural systems that grow products with relatively low market value but very high symbolic value: livestock and dates. It is no coincidence that these formed the main part of the pre-modern diet. Active state support, on the other hand, focuses on the market-oriented and rapidly-growing commercial vegetable sector. Fiscal or natural resource shocks to the hydrosocial context could very well change the balance of the state's overall agricultural "investment" profile.

Farm structure and management in Liwa

Because of the land granting system described above, 97% of cultivated area in Liwa is on farms between two to six hectares (National Bureau of Statistics 2011). Few large landholdings or extensive agribusinesses exist, though some highly capital-intensive but there are some small footprint producers (e.g. fish farms or hydroponic greenhouses).

As of 2011, the most recent year for which locally disaggregated statistics were available, Liwa's cultivated area of 10,000 ha had dates on over 6,500 ha, fields crops - primarily Rhodes grass and alfalfa – on 1,700 ha, forests nearly 1,000 ha, and the remaining area was used for vegetables, greenhouses, and non-date fruits (ADFCA 2011). In the 2016 agricultural census, field crops area had declined to approximately 1,000 hectares across the entire Western Region (ADFCA 2017).

Farm owners in almost all cases are absentee landholders who employ laborers and, in a minority of cases, trained farm managers to run operations (Interviews A). Laborers are typically paid ~US$220/month and most come from South Asia. Interviews (A) indicate that the level of engagement between farm owners and workers varies, but that generally communications are less than once per month, and visits are rarer.

Farm managers suggest that guaranteed profits for farm-owners, whether from subsidies or via purchase price supports and guaranteed purchase from government-owned firms and agencies, provide disincentives for investment in agricultural equipment and human resources for all but the most enterprising farmers (Interviews A). As a result, careful water management is rare on farms, as described in depth in Fragaszy and McDonnell (2016).

Liwa farm owners have a very strong perception that groundwater from their wells belongs to them and its management is their own affair (Interviews A). Though legally this is untrue, regulatory agencies have been reluctant to push the issue. Wells are now required to have flowmeters, but interviews (B, C) indicate that there has been little enforcement of this yet because of the anticipated political backlash from owners who would see such a move as the beginning of state encroachment on their abstraction rights.

Most farms in Liwa are along the transition zone between brackish and saline zones (along the crescent itself as shown in Figure 2) due to historical cultivation patterns. However, the newest farms are located north of the crescent along the Liwa to Madinat Zayed road because it has groundwater with lower TDS better suited for vegetable cultivation. This is evident in the ratio of working-wells to abandoned-wells in the Liwa sub-districts: the ratio in the more recently-developed district of Seih al-Kheir (north of the crescent) is nearly 4:1 whereas in older districts it approaches 1:1; Seih al-Kheir also has nearly half of Liwa's greenhouses.

Farm-level cultivation patterns depend highly on groundwater salinity: all farms have some date palms and farms with high salinity (over 15,000ppm TDS) cultivate solely date palms; most farms have about 10% of their area in Rhodes grass or alfalfa, and vegetables cultivation is usually limited to farms with TDS<5,000 unless they have reverse osmosis systems, which are increasingly common on vegetable farms (Interviews A).

Agricultural production has led to long-term salinization and groundwater depletion in the Liwa Aquifer. Pitman *et al.* (2009) estimate that from 1971 to 2005, reductions in fresh groundwater storage in the whole Western Region (of which Liwa is a part) were less than 5% whereas they were over 47% in eastern portions of Abu Dhabi including the Al-Ain area. However, they also show that at current rates of abstraction, fresh and brackish groundwater could be exhausted within 55 years.

EAD State of the Environment (SOE) reporting shows that by 2008, the freshwater mound in Liwa significantly increased in salinity, with the lowest TDS regions (200-500mg/l) disappearing entirely, and higher

salinity zones spreading throughout agricultural areas (EAD 2015). Far more significant localized changes can occur (EAD 2017) and individual farms can face severe water quality degradation in a short period. For instance, one farm manager stated that his groundwater had increased in salinity from 2,000TDS to 7,000TDS in a period of about five years (Interviews A).

Faced with these challenges, farm-owners in Liwa typically adopt the following alterations to farm management. In the **first** instance, they may attempt to improve irrigation efficiency at the same time as they increase proportional area of date palm cultivation, and/or by investing in small-scale reverse osmosis desalination units. FSC officials estimated that only 1% of farms have desalination units, but the number is climbing steadily (Interviews B). This can further exacerbate groundwater degradation as brine reject water is rarely treated or disposed of properly, and in some cases, it is simply pumped into abandoned wells or those that already have saline groundwater (Interviews B).

Secondly, they respond by well-deepening or drilling new wells in different locations on the farm. As a **last** resort, they abandon land and make requests for new land from state agencies (Interviews A, B). In Al-Ain and other areas of Abu Dhabi, farmers have increasingly turned to desalinated seawater and recently have begun re-use of treated wastewater, though both would be more difficult in Liwa given present infrastructure and distribution networks (Interviews B).

Farm structure and management in Liwa directly reflects the hydrosocial cycle in Abu Dhabi and how it has changed over time. The predominance of smallholder farms is a result of the land-granting system, which had explicit political objectives. The profitability of absentee ownership, even without trained workers in most cases, is a result of the social stability objectives as borne out through subsidy regimes. However, we observe a markedly distinct shift in approach in recent years: this is borne out by the fact that most new farms, which by definition must be approved by the state since land must be granted by the state, produce vegetables and therefore have much more direct oversight by the FSC. The political economy of this system, though, relies on relatively unconstrained individual access to water resources, which, in turn, contributes to farm owners' conceptions of water as a private resource largely outside the bounds of governmentalization. This is a primary tension in the hydrosocial cycle.

7. The hydrosocial cycle – how the contextual milieu and hydrosocial manifestations interact

In the Liwa Oasis, the government subsidized, rapid agricultural expansion from 1971-2001 resulted in groundwater level declines and salinization. In the face of natural resource challenges, and in response to changing political drivers, from 2010 onwards government reforms sought to alter cropping patterns in order to reduce groundwater use without fundamentally upending agricultural production systems, because of their role in delivering social policy objectives. Figure 4 traces this history and illustrates the key events and drivers discussed in this article.

Farmers as well as local and central government officials describe improving irrigation efficiency as the low-hanging fruit for reduction of groundwater abstraction in Liwa, and therefore prolonging the viability of existing systems (Interviews B, C). They base this argument on the fact that irrigation application is frequently several times higher than actual crop water requirements. For example, anecdotal evidence from Alhammadi and Kurup (2013) suggests farmers in the UAE typically apply ~150l of water per date palm per day in the summer and ~50l per palm in the winter, and water consumption statistics from farms participating in ADFCA's well-monitoring program suggest in some areas it may be much higher (ADFCA 2016). These volumes, varying by palm type, are at least two and a half times greater than plant requirements as determined through sap flow studies (Alyamani *et al.* 2014). However, changing water management behavior and practice at the farm scale, and law, policy, and governance regimes that support and require that behavior change at the Emirate-level, present major difficulties. This would be the case even if clear alternatives that delivered on socio-economic objectives were available. Fragaszy and McDonnell (2016) summarize several key challenges related to on-farm improvement of water management that directly relate to hydrosocial manifestations. These stem from human resource barriers, particularly around farm laborers; perceptions of farm owners and

government officials; water management agencies' institutional structures and capacities, especially in regulatory compliance monitoring and enforcement; and structural issues in agricultural production systems, particularly the prevalence of small farms that provide supplementary income to largely absentee owners, and the absence of groundwater valuation.

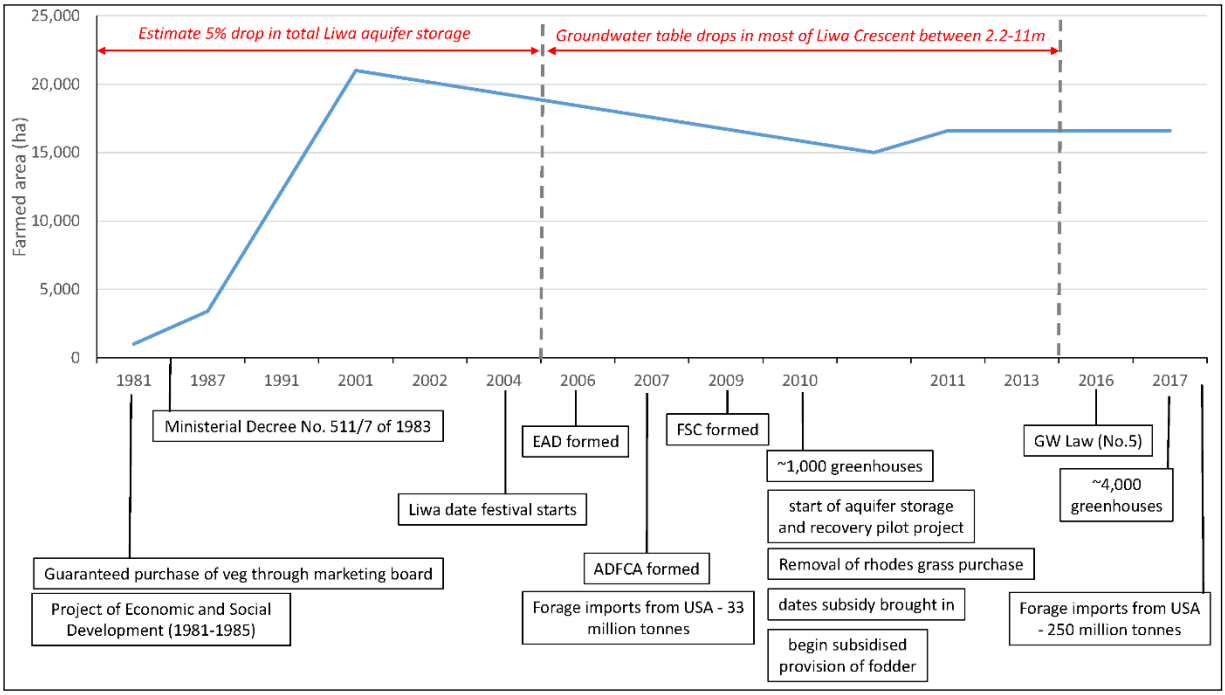

Figure 4: Liwa's hydrosocial history. Source: Author's elaboration.[8]

These issues are direct products of the hydrosocial cycle, and they illustrate clearly that attempts to address groundwater sustainability or to otherwise amend extant production systems would have major repercussions for the political, economic, and social underpinnings of the status quo. Given that agriculture in Liwa is dependent on mining a fossil aquifer, the prevalence of supply-side interventions undertaken by individuals (e.g. groundwater desalination) and the state (e.g. shifting areas of cultivation) is striking. Demand-side interventions within the existing hydrosocial cycle would increase demands on water users, something that is politically difficult.

Fundamentally upending the current hydrosocial cycle – for example, through direct state control of water resources and provision to farms, reversion to communal management, or market mechanisms like groundwater pricing – would require major shifts in relations between citizens and the state and their perceived roles and responsibilities. Although the scale of agricultural water use now threatens the long-term sustainability of water resources, both the social contract and social conceptions of water ownership and custodianship make their alteration an incredibly delicate political matter. It is difficult to imagine anything providing the impetus to overcome the inertia of the current hydrosocial cycle other than a great fiscal shock –

[8] This is an illustrative figure only due to data characteristics and limitations. For instance, data series on farmed area are incomplete prior to 2011, and the trend line only connects datapoints from approximately 1985, 1990, 2002, 2011, and 2018. Other statistics such those presented on groundwater represent different spatial scales and consist of different indicators. As such, the Figure is intended to identify key features of Liwa's hydrosocial cycle and resultant effects on its political economy. It was developed by the authors and all datapoints are cited elsewhere in the article.

which could alter the logic of subsidy and payout regimes and more general citizen-state relations – or a serious decline in water availability and quality over the next generation.

Partially as a result of this dialectic, the Abu Dhabi government over the past decade has gradually begun to incentivize a 'pioneer front' closer to urban centres driven by seawater desalination (Trottier and Perrier 2018). This new direction dos not challenge vested interests or the pre-existing socio-economic order; it is politically safe. Also, it fits with the dominant narratives of agricultural modernization and market-oriented development that the state has mobilized since its inception (Koch 2019).

The state has by no means abandoned the widespread and older groundwater-dependent systems for a variety of reasons articulated in this article, but it has shifted its predominant public discourse to focus on the newer systems for market-oriented as well as social narrative objectives. The market orientation relates to fresh vegetable production described above, and the narrative aspect reflects the role of modernization as a core component in the Abu Dhabi government's legitimacy. Indeed, as Koch (2019) shows, cyclical interest in high-tech agricultural modernism is a recurrent feature in Emirati national narratives and political technologies. Despite these narrative shifts and recent, highly publicized, investment in high-tech farms, state expenditure on agriculture is clearly dominated by subsidies that perpetuate the extant hydrosocial cycle and the agricultural production systems it supports.

8. Conclusions: Liwa as a hydrosocial territory

This article defines Liwa as a hydrosocial territory, one in which the natural resource, and the social, political, and economic context has undergone incredibly rapid changes over the past fifty years. Post-independence population growth, economic development, and state formation – and the politics attendant to these factors – revolutionized the hydrosocial cycle in Liwa and Abu Dhabi more broadly. The Liwa Oasis was a key site of, and contributor to, these undertakings.

The manifestations of the post-independence hydrosocial cycle in Liwa – water law, policy, governance, and practice – strongly reflect the ethos of Abu Dhabi agencies through administrative relations, political discourses, and national narratives (Mollinga 2013; Swyngedouw 2015; Koch 2020). They also reflect market structures, particularly for subsidies, and economic forces that have shaped water management practices in Liwa.

Figure 4 provides a general timeline of this transformation in the hydrosocial cycle and its effects on Liwa as a hydrosocial territory. It begins with the rupture of independence in 1971 and shows the expansion of the groundwater-driven pioneer front until about 2006. Then from 2010 onwards, it illustrates shifts in governance and their effects on agricultural production systems. These initially consist of shifting crop patterns within existing systems, and more recently, state support for developing entirely new agricultural water sources and production systems. It also traces, to the extent feasible, groundwater resource status using relatively course metrics of drawdown and salinization. Finally, it incorporates other specific features that, while not the focus of this article because of its focus on agriculture, are relevant for the overall characterization of Liwa as a hydrosocial territory: such as the initiation of the aquifer storage and recovery project, and the dates festival.

As part of the existing hydrosocial cycle, agricultural policy that aims for social stability and wealth distribution as well as production maximization and water supply provision is logical; however, it is fundamentally at odds with the technical bureaucracy whose remit now includes sustainability of resources (McDonnell and Fragaszy 2016). Although agencies now have groundwater sustainability as core objectives, the social acceptability (and therefore political risk) of policy changes to realize that objective poses major barriers to their implementation.

Farm owners fundamentally conceive of groundwater as their property and consider it the government's duty to ensure irrigation water availability (Fragaszy and McDonnell 2016). Indeed, the lack of regulatory enforcement personnel and uneven implementation of current policies in Liwa reflects this political context. More insidiously, there is a widespread perception amongst farm-owners and officials that groundwater drawdown and salinity rise is entirely inevitable, which has increased apathy in the face of that particular natural resource challenge (Interviews A and B).

Likewise, the economic context of agriculture production – that it is primarily landowners' second source of income, and they have guaranteed purchase of produce at favorable prices, and significant subsidies for production – precludes and disincentivizes changes in practice. The human resource issues noted by Fragaszy and McDonnell (2016) reflect this same general structure of production systems and are direct (as well as secondary) products of the "distributive state." There is high turnover and language barriers in the primarily unskilled labor force, and hiring untrained workers to manage several farms is common practice.

Liwa's trajectory and place in the national schema become evident through this summary of the constituent elements of its status as a hydrosocial territory. Liwa illustrates complex hydrosocial networks, a politics of scalar reconfiguration, governmentalization, and territorial pluralism (Boelens *et al.* 2016). The state and landowners – both categories of actors that have largely arisen since independence – created new hydrosocial networks to replace the pre-existing order. Government agencies have mobilized water resources in Liwa for the creation of a specific national identity. Over time, and as mediated by the state, the populace, and by market drivers, the purpose has expanded to include wealth distribution, the maintenance of built loyalties to the state, and, secondarily, vegetable production for the purpose of maintaining some elements of food security.

This process has resulted in a scalar reconfiguration of Liwa's place in Abu Dhabi from a position of centrality in a nomadic order. Government policies and market drivers have led to it having a peripheral but symbolically important role, in which those who profit from the land are virtually all absentee landowners (Cariou 2013). Now, with the development of aquifer storage and recovery and a greater need to maintain water quality (Stufzand 2017), control of Liwa's space is increasingly constrained, and its water will serve the capital.

Agricultural production in Liwa is increasingly the subject of governmentalization. Slowly but surely, regulatory oversight of groundwater use is expanding, and FSC quality controls for guaranteed purchase of vegetables drive on-farm practices (Interviews A, B, C). Market factors and government policies are generating a new system of territorial pluralism whereby the large majority farms that emerged first on the historical groundwater-driven pioneer front remain the recipients of state *largesse*, but only if they follow state-defined constraints on cropping patterns. In contrast, the few but increasing number of capital-intensive, high-tech and desalination-dependent farms elsewhere are front and center in the government's investment decisions, future-oriented narrative, and deployment of human resources as shown by the FSC focus on vegetable production (Koch 2019; Interviews B, C).

In Liwa and the UAE more broadly, groundwater abstraction enabled nation-building policies that sought to create a national identity by transcending tribal politics and nomadism, and it enabled agricultural subsidy regimes that facilitated oil wealth distribution and maintenance of social stability and security. However, groundwater resource degradation poses a major challenge to this hydrosocial context. This disruption is at the heart of the hydrosocial dialectic playing out now in Liwa. Resource degradation and depletion will ultimately require new patterns of resource utilization, though arriving at new practices will require new laws, policies and new modes of governance, which will alter the political, social, and economic context. This dialectical interaction will shape the next stage, whatever it may be, of Liwa's hydrosocial cycle and its character as a hydrosocial territory.

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