www.water-alternatives.org Volume 10 | Issue 1

Navarro-Navarro, L.A.; Moreno-Vazquez, J.L. and Scott, C.A. 2017.
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Evidence from the San Miguel Watershed, Sonora, Mexico.
Water Alternatives 10(1): 41-64

Social Networks for Management of Water Scarcity: Evidence from the San Miguel Watershed, Sonora, Mexico

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ABSTRACT: Pervasive social and ecological water crises in Mexico remain, despite over two decades of legal and institutional backing for Integrated Water Resources Management (IWRM) as a policy tenet. In this article we apply a socialshed analysis to uncover and understand the geographical and jurisdictional forces influencing the social construction and simultaneous fragmentation of the San Miguel Watershed (SMW) in the state of Sonora, in Mexico's water-scarcity bulls-eye. Specific insights derived from an empirical analysis include that water management (WM) is socially embedded in dense networks of family and friends, farmers and ranchers, citizens and local government – all to varying degrees sharing information about local water crises. Irrigation water user representatives (WUR) are connected across communities and within their own municipalities, but inter-watershed social links with other WUR are virtually nonexistent, despite high levels of awareness of cross-municipality WM problems. Implementation of IWRM as a federal policy by a single agency and the creation of basin councils and subsidiary technical committees for groundwater management have not been sufficient for technical – much less social – integration at the watershed level. This study shows that the SMW socialshed remains fragmented by local jurisdictions; without coordinated agency-jurisdiction-local action fomenting social connections, a socialshed will not emerge.

KEYWORDS: Socialshed, IWRM, watershed management, social networks, Sonora, Mexico

INTRODUCTION

Societies' capacity to control and divert water -- the social capacity of water appropriation -- has increased considerably (Aboites, 2009), to the point that no water is left for the ecosystems and new users. Droughts, floods, diversion, overgrazing, and discharge of polluted water are processes that are internalised within a watershed. Therefore, the watershed has become the arena for the emergence of 'social dilemmas'.[1]

[1] According to Ostrom (2001), "social dilemma refers to an extremely large number of settings in which individual humans make independent choices in an interdependent situation".

Social dilemmas exacerbate conflicts and might lead to new ones as water becomes scarcer and demand increases. Climate change scenarios predict drier and more variable conditions; population growth, economic expansion, and related global change go together with higher water demand. These scenarios require greater adaptability and improved policies for water security. Adaptation initiatives and policies applied independently without coordination in a watershed lack the systematic approach required to internalise positive and negative externalities for water users.

The most consistently advocated approach to address fragmentation is Integrated Water Resources Management (IWRM), defined as "a process which promotes the coordinated development and management of water, land and related resources, to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (GWP-TEC, 2000). IWRM relies on the watershed or river basin as the spatial unit to apply water policies and coordinated management. In Mexico, IWRM is mandated in the Law of the Nation's Waters (*Ley de Aguas Nacionales* [LAN] 1992 and amended in 2004); as a result, the Mexican territory was subdivided into 757 watersheds (DOF, 2016) and 653 aquifers. There is a single federal water agency – the National Water Commission (*Comisión Nacional del Agua* [CONAGUA]) and unified policy – which in theory should override jurisdictional fragmentation.

This article highlights, as a main challenge to IWRM, the social integration of local actors managing water – geographically distant, separated on the social map, and sometimes with rivalries and diametrically divergent interests. Taking as a starting point the concept of a 'socialshed', which relies on social capital theory operationalised through networks, we analyse a case study of the administratively delineated SMW in northwest Mexico. The institutional approach of watershed social integration is usually focused on watershed partnerships or councils (*consejos de cuenca*), which in Mexico were created top-down based on LAN and its amendments and regulations (LAN, 2004). By contrast, this paper addresses bottom-up sociospatial relations among leaders and representatives of local organisations managing water under the premise that coordination, cooperation, and co-management are grounded in social networks.

The approach takes as a point of departure that water is managed locally by actors embedded in dense clusters of multilayered social networks. Following the socialshed concept, these clusters should be connected to other broader networks of local networks. However, in the SMW the connectivity of local leaders with their peers outside their locale is virtually nonexistent, while links of local leaders with external agencies are also tenuous, as explored here. For example, only 11% of local residents rated the SMW watershed council favourably because other external agencies (e.g. the agricultural department) were better able to structurally and programmatically connect users within the watershed. Thus, a socialshed is unlikely to emerge by itself without an agency fomenting the creation of intra- and inter-watershed social connections.

SOCIALSHED THEORETICAL APPROACH

The concept of a 'socialshed' was reintroduced by Berg (2013) in the literature on bioregionalism.[2] Berg suggested the idea that individuals who identify with real places, engage with a local environment, and live in geographic closeness foment social interaction to form a 'socialshed'. He considered this group as a unit of bioregional political interaction; several of these units could join together to form an organisation for a broader community, which could eventually become a watershed council.

[2] McGinnis (1999: 2) mentioned that "bioregionalists believe that as members of distinct communities, human beings cannot avoid interacting with and being affected by their specific location, place and bioregion: despite modern technology, we are not insulated from nature". In this approach, a watershed is commonly treated as a bioregion (McGinnis, 1995; Nelson and Weschler, 2001). As Molle (2006: 20) explained "bioregionalism renews the old search for the organisation of societies according to 'ideal' or 'natural' boundaries".

A 'socialshed' is understood in what follows as the social connectedness of the watershed territory, a network formed by people sharing concerns, beliefs, awareness, and water management practices; such a network has the potential to exchange information, learn from experiences, and create agreements.

The general question addressed here is: *Is it possible to have social participation, cooperation, coordinated action, and agreements without social connection?* As suggested by Butterworth et al. (2010), local water users have traditionally made their day-to-day decision-making on water development and management with limited external assistance. At the local level resources management institutions (for irrigation, livestock, etc) are already quite integrated and have a relatively holistic outlook, which raises the question: could they not be flexibly interconnected to make a difference at higher scales? Atomised groups are often unaware of the water challenges experienced by other actors within the watershed, resulting in indifference over how their decisions might affect others and vice versa.[3] Bodin and Crona (2006) stressed the importance of linking different groups of stakeholders in communities for the joint management of resources. Individuals are influenced by people with whom they engage in frequent interactions, and are hence likely to develop an understanding of the status of natural resources like other members of the same group of stakeholders.

A socialshed describes here a watershed with substantial social capital (SC). Defined broadly, SC refers to features of social organisations such as networks, norms, and social trust that facilitate coordination and cooperation for mutual benefit (Putnam, 1995). SC is a multilevel concept, relying on individual relationships with the aggregated effect of producing benefits at higher scales such as communities or states, or as suggested in this study, at the watershed level. This research is based on grounded criteria seeking to explain the presence of SC at the watershed level. Falk and Kilpatrick (2000) point out that SC is the accumulation of micro-social interactions, which are in turn embedded in the macro-social order. The study of SC as networks is referred to as the structural dimension of SC. In this regard, Social Network Analysis (SNA) deals with the study of the social structure derived from social interactions. SNA depicts actors (individuals) as embedded in webs of connections, and the task of the researcher is to describe and explain the patterns exhibited in these connections (Scott, 1988).

This paper addresses two research questions in the context of the San Miguel Watershed: 1) what is the social network supporting water management of local organisations (social connectedness)? and 2) what is the actors' level of perception/awareness of water-related challenges beyond their local contexts?

To address these research questions the socialshed concept was broken down into four structural dimensions of social capital:

1. Bonding SC – represented as closed local networks of relations that engender robust individual and collective action (Coleman, 1990; Woolcock and Narayan, 2000).
2. Bridging SC – represented as horizontal boundary-spanning networks. This form of SC has the potential of integrating local jurisdictions operating within a geographically defined area (Ostrom, 1972). Closing the gap between different social arenas that transcend local boundaries – 'integrated management' (Grigg, 1999) – implies balancing the goals and views of interdependent players in a watershed.

[3] As an example of the power of social interaction for promoting mutual understanding and reaching agreements, Lejano and Ingram (2009) studied water organisations in California acting as mediators and coordinators for activities across a large set of water actors. The authors described the case of engineers operating river diversion works and fisheries managers demanding enough water for survival of fish. Through social interaction of both groups in regular meetings mutual understanding was developed, leading to shared attitudes and trust.

3. Linking Social Capital (LSC) – described by Stone (2003) as involving social relations with those in authority that might be used to gain resources or power. LSC is important for political influence, campaigning, wider social change (Muir, 2011), and providing access to external resources for strengthening physical infrastructure or investing in technological change (Scott and Silva-Ochoa, 2010).
4. Problemsheds – defined as a "geographic area that is large enough to encompass the issues but small enough to make implementation feasible" (Griffin, 1999). Problemsheds are represented as networks where persons are linked to water issues/places forming an 'issue network' (Mollinga et al., 2007); such connections are expected to create empathy and awareness among watershed inhabitants.

Because water management takes places through multiple social networks, the social integration of a watershed is an essential component of IWRM. In the next section, two important aspects preventing social integration of watershed are discussed: 1) the absence or weakness of an institution such as a watershed council promoting social participation; and 2) jurisdictional fragmentation that socially divides people and hence impedes water management.

SOCIAL PARTICIPATION AND JURISDICTIONAL FRAGMENTATION IN THE SAN MIGUEL WATERSHED

The LAN, first issued in 1992, was fully amended in 2004, and has been subject to further minor but important changes.[4] Despite the intent of reforms to improve the law, scholars agree that challenges remain, chiefly administrative decentralisation (Sanchez-Meza, 2008; Scott and Banister, 2008; OECD, 2013) and stakeholder participation[5] (Wester et al., 2003).

The delineation and public dissemination of watersheds and aquifers as water management units represent the most tangible advances in IWRM in Mexico. The national territory is hierarchically divided into 13 hydrologic-administrative regions, subdivided into 37 hydrological regions, and is further dissected into 757 watersheds and 653 aquifers (DOF, 2016). CONAGUA has regional headquarters in each of the 13 administrative regions, which are adjusted to match municipal borders (see Figure 1).

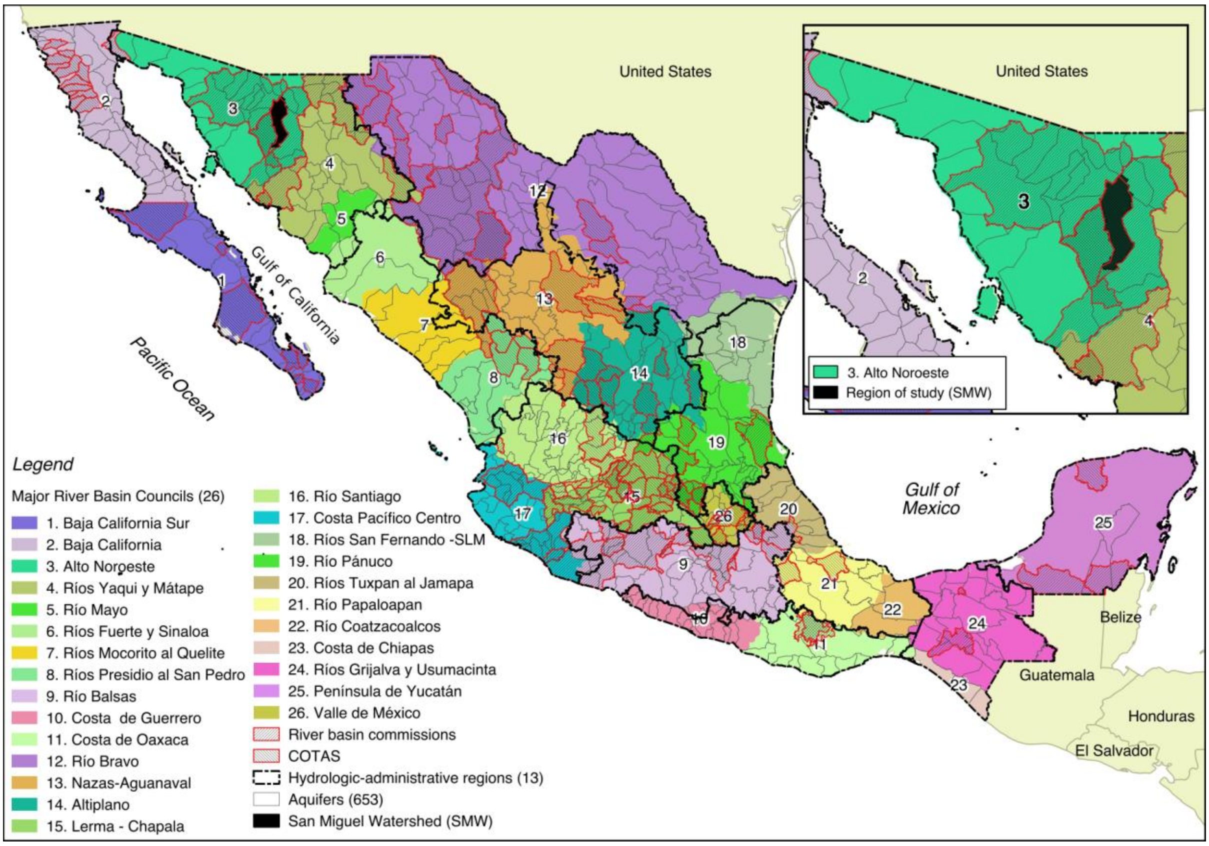
The aquifers and watersheds represent the administrative hydrological units through which CONAGUA implements water policy; all surface water and groundwater users are required to obtain a water concession,[6] and new concessions are conditioned on availability of water. By 2016, hydrological studies had been carried out for the 757 watersheds and the 653 aquifers, to assess water availability. LAN (1992) section 22 mandates that hydrological studies must be updated every three years and the latest assessments show that 250 watersheds and 223 aquifers were at balance or were over-allocated or in overdraft (DOF, 2016); as a result, no new concessions may be issued in these areas. Watersheds and aquifers function as jurisdictions where water is allocated and appropriated by users. CONAGUA has the power to grant or cancel water concessions, monitor water use, establish norms for water use and water quality (Wester et al., 2003), and levy taxes and fines.

[4] As published in the Diario Oficial de la Federación (Federal Official Gazette, Spanish acronym DOF): 18 April 2008, 20 June 2011, 08 June 2012, 07 June 2013, 11 August 2014, and 24 March 2016.

[5] OECD (2015) stated that "stakeholder engagement is a rising topic in the water agenda, because government and public governance are becoming increasing open, citizens demand to be more engaged in how public policy decisions are taken".

[6] Concessions are granted for water use and for discharge of wastewater; under Mexican law, concessions confer the right to use resources, but do not constitute ownership, despite the fact that water users consider them as property 'rights' (Hearne, 2004). The Public Registry of Water Rights (REPDA for the Spanish acronym), is maintained by CONAGUA and is available on the Internet, and lists names of all the concession holders.

Figure 1. Mexico hydrologic-administrative regions, major river basin councils, auxiliary organisations, and aquifers – with close-up of the San Miguel Watershed in Sonora.



All government responsibilities and powers related to water are vested in CONAGUA (Wester et al., 2003), a single federal agency exercising a common water policy that should in principle override the political and jurisdictional fragmentation complicating IWRM. For instance, 261 out of the 757 watersheds cross state borders. However, this institutional prerogative comes at a price: a centralised and inflexible water policy.

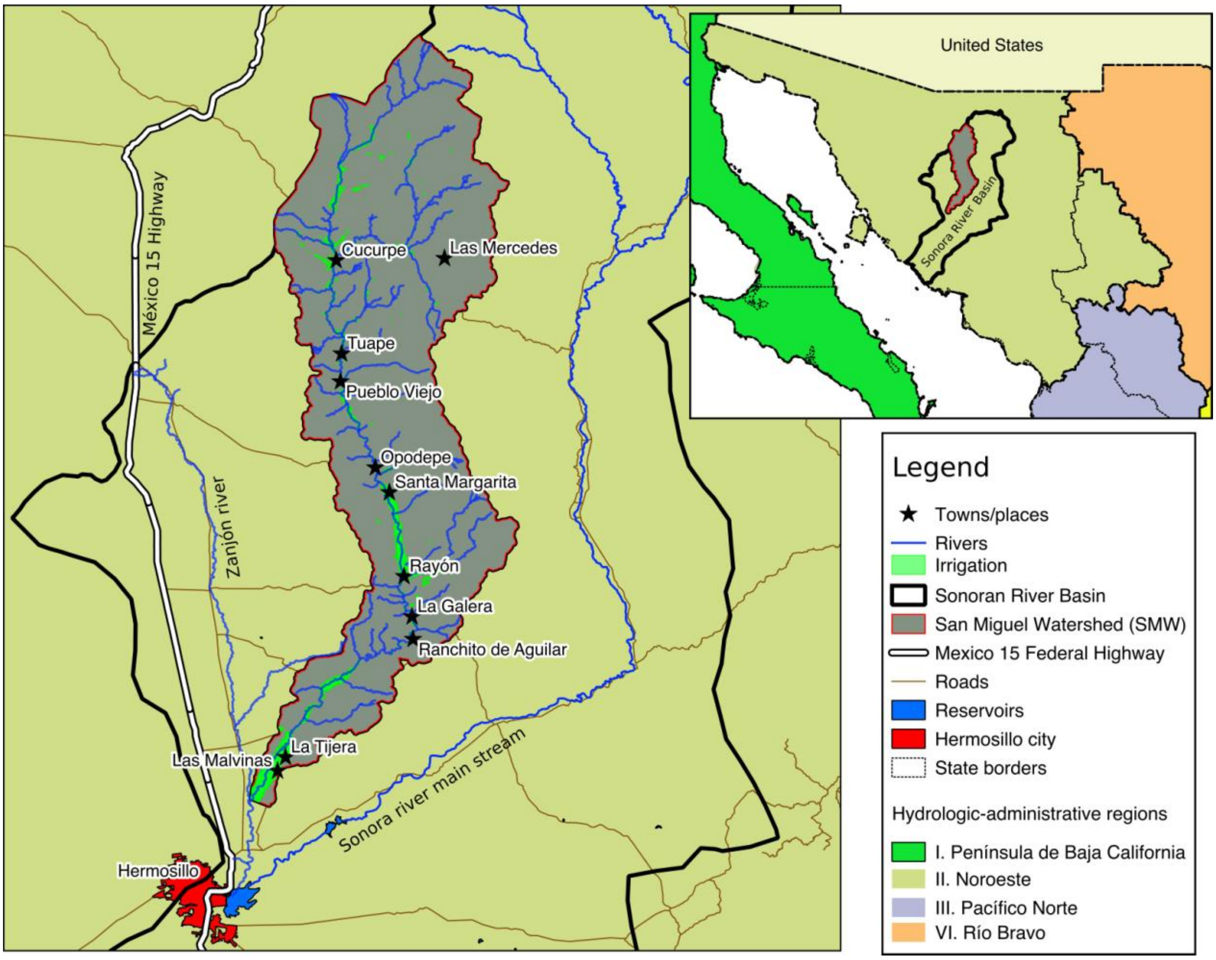
Decentralised governance of water resources was a centerpiece of the Mexico's neoliberal reform strategy (Wilder and Romero-Lankao, 2006). Water decentralisation efforts did not imply more 'federalism', but just a withdrawal of federal funding from the water sector with less federal spending on hydraulic infrastructure and the administration of the large irrigation districts along with reduced support for small rural irrigation systems and water utilities. Thus, provision and appropriation duties were 'returned' to users, under the broad regulatory and policy umbrella of CONAGUA, which Scott and Banister (2008) termed "water management decentralisation with centralised resource allocation".

Moreover, although not explicitly stated, stakeholder and intergovernmental participation was considered in the LAN (1992) as a formula to curb CONAGUA power and democratise water management. The LAN (1992) institutionalised water user participation through the creation of major river basin councils (MRBCs).

These councils, according to Wilder (2009), "are one of the major institutional changes associated with the IWRM paradigm of Mexico". Basin councils were defined as coordinating and consensus-building bodies between CONAGUA, federal, state and municipal governments as well as water user representatives (Wester et al., 2003).

In Mexico, there are 26 MRBCs. Ideally, each should be composed of auxiliary organisations such as river basin commissions (RBCs), subbasin committees, technical committees for groundwater management (COTAS as the Spanish acronym), and clean beach committees in coastal areas. Auxiliary organisations are required due the vast territories, diverse sectors, and often large populations, covered by each MRBCs. According to CONAGUA, by 2014 there were 35 RBCs, 47 subbasin committees, 87 COTAS, and 39 clean beach committees.

Figure 2. The San Miguel Watershed, the Sonora River Basin, and important towns and places.



MRBCs have received some critique. CONAGUA has been reluctant to endow MRBCs with sufficient power (Wester et al., 2003: 803; Scott and Banister, 2008: 72); therefore, participation has been centred on a core clientele. Wester et al. (2008: 281) studied the Lerma-Chapala council finding that representation of agricultural water users was dominated by farmers with large landholdings.[7] Sanchez-Meza (2008: 30) pointed out that CONAGUA has the discretionary power to consider or dismiss the

[7] The MRBCs have been improved ('perfeccionamiento' as known in Spanish) internally to balance stakeholder representation. Wester et al. (2003) noted that a challenge for the MRBCs had been ensuring effective user representation: "what was clear is that only water users with a water licence will be eligible to elect committee members, thus excluding the vast majority of the basin’s population". In 2004, LAN Article 13 was extended to mandate stakeholder representation of at least 50% of the council members, with 35% as state and municipal representatives. 'Perfeccionamiento' of MRBCs did not limit participation to concession holders, but also required the inclusion of environmental, indigenous, and other underrepresented groups.

agreements reached by the MRBCs which CONAGUA regards as consultative organisations. Finally, MRBCs are poorly funded, and the major (if not the only) contributor is CONAGUA, which also appoints the operational managers of MRBCs.

Institutionalized social participation in SMW

The SMW corresponds to an official CONAGUA watershed and aquifer, and is located in hydrological region 9 nested in the hydrologic-administrative region II Noroeste (see Figure 2). The SMW, covering 3999 km^2, is a tributary of the Sonora River. As Sheridan (1988) describes it: "the San Miguel River and its tributaries are typical intermittent streams of arid North America – shallow stretches of surface water alternating with expanses of river sand". Climate is semiarid with average annual rainfall of 421 mm and potential evaporation of 2400 mm (CNA, 2009). The population was approximately 5091 in 2010 (INEGI, 2010). Cattle ranching, the main economic activity in the watershed and a major water consumer, produces milk, cheese, and weaned calves. Total cropland is about 11,000 hectares (ha), of which 8266 ha are irrigated, with 75% of the cropland dedicated to fodder crops. There is no industrial activity in the area, other than a gold-silver mine ('Las Mercedes' see Figure 2) operating in the SMW headwaters.

The SMW belongs to the '3 Alto Noroeste' (AN) MRBCs formed in March 1999.[8] The AN has formalised just one RBC out of four; the Río Sonora RBC was created in December 2004 but has not yet been staffed. The Río Sonora RBC has nine aquifers, but just three operative COTAS -- one corresponding to the SMW. Therefore, SMW is at present part of two auxiliary organisations: Rio Sonora RBC and the San Miguel COTAS.

The San Miguel COTAS was created on 3 June 2001. The operational staff consists of a technical manager and office assistance; there is an honorary president, who must be a water user within the aquifer. Staff salaries and administrative expenses are partially covered by CONAGUA funds, and since 2006, as an alternative means of funding, the AN MRBC and local SAGARPA[9] District made an agreement (exclusively for the three COTAS of the Río Sonora) to allow the COTAS to issue an 'irrigation permit', which charges a fee depending on the diameter of the well.

The AN MRBC was studied by Sanchez-Meza (2008), who concluded that the council had a tendency to avoid and ignore relevant water issues. For instance, AN MRBC was not a forum for addressing the social unrest caused by the spill of a mine tailing pond that occurred on 4 August 2014 in the Sonora River headwaters, polluting 190 km of the main stream.[10]

The AN MRBC also did not serve as a forum for the main SMW problemsheds that required collective attention: 1) a multi-annual drought (2000-2015) that severely affected traditional irrigation systems, many of which changed from diverting surface water to extracting groundwater, which in turn raised the need for considerable outlay of funds beyond the means of the stakeholders; 2) in 2004, Las Malvinas scheme was built to transfer water from the San Miguel aquifer to the city of Hermosillo in the face of strong local protest demanding that water transfers be stopped under all circumstances (Scott and Pineda-Pablos, 2011); to date, the lower SMW is where groundwater abstractions are more

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[8] The AN MRBC operational budget provided by CONAGUA was $600,000 (Mexican pesos, or USD 27,650) in 2014; $630,000 in 2015; and $500,000 in 2016. This operational budget is for four important river basins (Sonoyta, Concepción, Sonora, and the Mexican portion of the San Pedro), covering 101,238 km^2

[9] SAGARPA is the Spanish acronym for Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food of the federal government. SAGARHPA is the state of Sonora counterpart, with the primary difference that the local secretariat includes the water sector, that is, the State Water Commission (CEA).

[10] Reviewing AN MRBC meeting minutes, the council held a meeting in May 2014, and did not meet again until December 2014, where the participants mentioned the Sonora river pollution issue as problem that required the 'council attention". To date, no auxiliary organizations of the AN MRBC have been reactivated or created to attend the issue.

concentrated (about 23 Mm^3), with small water users complaining that their wells are being affected by the two wells of the Hermosillo City: Las Malvinas and La Tijera (see Figure 2); and 3) inequitable surface water and groundwater allocation among users, for example, REPDA (1 April 2015) shows that the San Miguel Aquifer has 911 concession holders, 60% of whom had allocated volumes totalling 0.52 Mm^3 while the largest 20 held 13.56 Mm^3.[11]

Jurisdictional fragmentation in the SMW

According to Bakker and Cook (2011), "fragmentation occurs where responsibility for water governance is allocated amongst multiple actors and/or agencies, with relatively little or no coordination". According to Cook (2014), literature on the water resources has frequently lamented fragmentation in water governance and called for integration. Countries with a highly decentralised approach to water governance confront challenges of integration, coordination and data availability. This is the case of both Canada (Bakker and Cook, 2011) and the US (Grigg, 2008).

As is often the case, social and political formations of the territories do not match hydrological boundaries of the watershed. In Mexico, as suggested by Commons (2002), administrative boundaries have been demarcated in response to political forces, without considering 'natural' territorial delineations. Social and political formations of the territories do not match hydrological boundaries of the watershed.

In this regard, the SMW is a patchwork of 15 municipalities, much of it corresponding to land located in the high mountains and private ranches socially linked to adjacent watersheds but not to the San Miguel River (SMR). There are only four municipalities with local governments within the SMW (see Figure 3 map A).

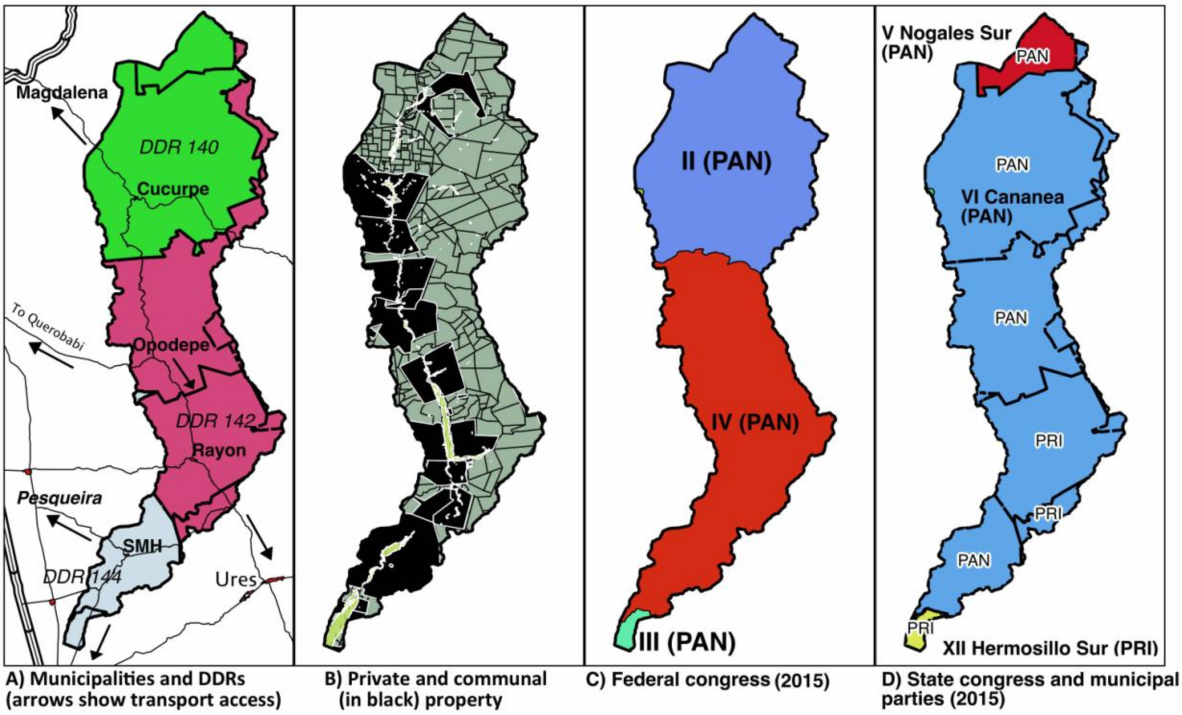
Property regimes can be divided as communal (or '*ejidos*') and private land (see Figure 3 map B). There are 23 communal landholdings encompassing 1842 stakeholders[12] managing over a third of the SMW. Most of these landholdings are located along the SMR stream and around the main towns. On the other hand, private property (mostly extensive ranching operations) is the basis for exploitation of rangelands by landowners who do not necessarily live in the SMW.

Irrigation is extremely important for the cattle industry, the main economic activity in the SMW. Irrigated land is located along the banks of the SMR. Irrigation systems use dikes to divert water to acequias, while groundwater extraction has increased rapidly. Single users may manage some systems privately, but the most consolidated and representative irrigation systems are referred to as irrigation units (IU, *unidades de riego* in Spanish). In these, a group of irrigators rely on the same source(s) of water and infrastructure; IUs usually consist of a combination of private and communal (*ejido*) property regimes.

[11] The latest geohydrological study for the San Miguel Aquifer was conducted in October 2013 (CNA 2013); it assessed and estimated a recharge of 68.7 Mm^3/year; the total volume granted in concessions to 31 March 2013 was 48.9 Mm^3/year and, thus, the volume available was 17.5 Mm^3 with 2.3 Mm^3 flowing out of the aquifer. Reviewing the REPDA, and inquiring from local authorities and stakeholders in the San Miguel, did not provide information on the allocation of this water surplus and the beneficiaries.

[12] Compared to the SMW population (5,091) the number of communal stakeholders might seem out of proportion (1,847); this number represents the rightful stakeholders not necessarily living in the SMW.

Figure 3. Maps showing the political fragmentation of the SMW.



In addition to jurisdictions, there are physical barriers preventing communication and socialisation. Stakeholders travel away from SMW using their own, separate direct routes to main highways (see Figure 3 and the arrows in map A). For instance, a paved road from Hermosillo directly reaches SMH;[13] Rayon, another important town, is accessed through Ures. Cucurpe has its own commercial and business relations with Magdalena. The middle part of the SMW, Opodepe, is the most disconnected, with dirt roads and no cellphone signal; these residents go down to Rayon, and eventually to Ures. Probably the jurisdictional boundary that most closely resembles the physical circulation of people, goods, and services along transportation routes is the Rural Development Districts[14] (see Figure 3, map A) or DDRs in Spanish.

Last but not least, the effect of jurisdictional fragmentation is accentuated by politics. Mexico's drive toward democratisation has empowered people and their social demands. Politics enhances differences between two municipalities with presidents from opposite political parties, but softens relations when both share the same affiliation. This fragmentation is derived from the political race (Kloster and De Alba, 2007). For example, Figure 3 map C shows that the PAN (National Action Party) won all the seats for the Federal Congress in 2015; figure 3 map D shows that PAN also won most of the territory for the State Congress. Rayon was won by PRI (Institutional Revolution Party). Hence, Rayon has an advantage

[13] Some roads were recently built (paved): Hermosillo-SMH in 2009, Rayon-Ures in 2011, and Carbo-Rayon in 2002; before 1990 there were no paved roads in the watershed. Even these days, during the rainy season there are a lot of river crossings that isolate towns for days, for example: Cucurpe-Magdalena.

[14] SAGARPA has 33 regional offices (32 corresponding to each state and one for the Región Lagunera in Durango and Coahuila). Each state is further subdivided into Rural Development Districts (in Spanish 'Distritos de Desarrollo Rural' or DDR). There are 192 DDRs in the entire country of Mexico.

with the federal and state governments (from PRI), but a not so easy relationship with the federal congressional leaders.[15]

METHODS

Boundaries of the network

The initial step to design social network studies is to define the population integrating the network. This study did not include the full spectrum of water users because it was centred on the rural watershed inhabitants. The universe of actors considered was defined based on representatives of irrigation units (n=24), communal landholdings (n=17), local elected authorities (n=4), local livestock associations (n=4), livestock inspectors (n=6), and public water utilities (n=5), as well as key stakeholders (n=5) totalling a potential network of 65 actors. Particularly, the interviewees were previously recognised and selected though multiple visits to the communities, conducted from November 2012 to August 2015.

Egocentric networks

An egocentric or ego-network is defined as a network on a specific individual (Newman, 2003) whom we call ego; in this study, ego refers to the interviewed stakeholder who was asked to nominate up to five peers with whom he held a type of relationship regarding water management. The ego also explained the nominate-to-nominate relationships. Thus, an ego-network is made up of six stakeholders and the relationships among them. Stakeholder-to-stakeholder networks are considered one-mode, and stakeholders to organisations, issues or places are considered two-mode networks.

Data collection and analysis

The questionnaire asked respondents first about their perceptions of water scarcity and also aimed to identify the type of water user (domestic, agriculture, livestock, services, industry, and/or other). Relational data were gathered to allow the mapping of four structure-based elements of social capital:

1. Bonding SC was assessed through a set of name-generating questions that asked respondents to identify the five most important stakeholders with whom they deal with and discuss water management issues.
2. Bridging SC was mapped providing a roster of previously identified leaders and representatives (within the municipality and the rest of the watershed) presented to the respondents (egos), as suggested by Marsden (1990) allowing them to recognise rather than recall their relationships. Respondents were asked to identify those actors with whom they also had discussed and collaborated on water-related projects.
3. The methodology applied for LSC was intended to capture the whole spectrum of external contacts, regardless of the type of agency. This technique was adapted from Stone and Hughes (2001). The survey listed, as a reminder, a series of 30 external agencies and asked respondents, for each one, whether they personally knew someone in the agency with whom they had a tie, confirmed by having either: a) received a visit from the agency in the community as part of his work; b) contacted the agency for information or to initiate an administrative procedure; or c) worked in a project/ programme run by the agency.

[15] Federal congressmen have access to funds earmarked (out of the executive branch programmes) for regional and municipal infrastructure (for more information search 'Ramo 23' of the Mexican Federal budget). As an example, the VI Cananea congressman promoted the formation of a special commission in May 2016 to oversee remediation actions to alleviate the pollution caused by a mine tailing pond breach in the Sonora River in 2014.

4. LSC was also captured through narratives[16] of sociability[17] method to elicit actors' names where the respondent was asked to narrate a recent experience in which they had participated in solving a case-specific water-related problem.
5. Problemsheds or issue networks were assessed by encouraging respondents to speak about the local water-related problems (water crisis) and if they knew about problems in other communities beyond their municipalities (boundary spanning networks).

Several network analysis tools and techniques were used in data analyses as described and referenced in the next section.

DATA ANALYSIS

In this section we provide the results of the quantitative analyses that were essential for robust assessment of the SMW socialshed. As described above, four elements of social capital are of particular interest: bonding, bridging, linking social capital, and problemsheds (or issue networks).

Descriptive statistics of ego sample

We interviewed 37 social actors, all of whom are currently living within SMW (see Figure 4). Most of the interviewees occupy multiple roles in their communities (e.g. a municipal representative might be also a rancher, an irrigator, and so on); therefore, they were knowledgeable about a greater array of local water issues. It was possible to interview representatives of 12 communal landholdings, five irrigation units, five key informants, three livestock local associations, six livestock inspectors, and six local government representatives (municipality staff). Overall, 86% were communal landholders (*ejidatarios*), 76% had irrigated land, and 73% were ranchers.

As mentioned earlier, a multi-year drought was identified as a problemshed in the SMW. Social actors' water management struggles play out in a complicated and challenging environment. This fact was evidenced in the respondents' water scarcity perception. Results showed that 62% were reported to have had problems meeting livestock drinking demands (e.g. 68% hauled water during the dry season); 70% had experienced shortages in water for irrigation; and only 11% of respondents had experienced scarcity in water for domestic household use.

Bonding SC

The ego-centric network metrics used to describe the properties of bonding SC were: density, multiplexity, and the volume of social interaction of ego with his nominates. These metrics estimate the strength of the ego-network.

Additionally, ego-networks are expected to be independent (no members in common). This expected property along with the fact that the place of residence of ego and his nominates were also asked, and the addition of a physical space dimension to the analysis was permitted.

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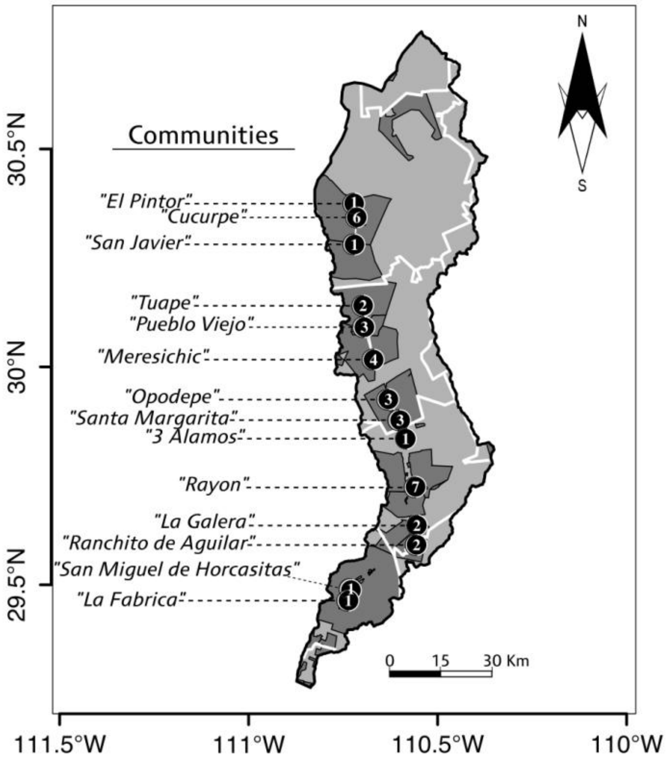
[16] Ingram et al. (2014) stated the importance of narratives (story-telling); identifying elements and events of a narrative, allows mapping and identifying actors, events, and objects. The authors used the concept 'narrative-network' to explore whether these networks exhibited a holistic sense of the relationships connecting people with each other and with their environment.

[17] Daniel Chamberlain (no date) Narratives of Sociability and Personal Networks. School of Arts, Griffith University (consulted online 20 November 2015).

Figure 4. Location of the respondents' node label displays the number of interviewees per community (Darker polygons are communal land).



Density

Ego-network density, sometimes also called clustering, is the proportion of ties present to the maximum possible number of ties in the ego-network (Wasserman and Faust, 1994: 101). Dense ego-networks are usually composed of strong ties (Granovetter, 1972: 1370; Marsden, 1987). In this study, each of the 37 egos interviewed occurred as a 'clique', meaning that every person in the ego-network had ties with everyone else.

In addition, the volume of social interaction was high; in 91% of the cases, respondents rated their frequency of contact with their network members as 'almost daily' or 'at least once a week'.

Multiplexity

Along with density, multiplex relationships between two stakeholders have the potential to enhance the strength of ego-networks. A relation is multiplex if it transacts several kinds of exchanges concurrently (e.g. co-workers who are also relatives, friends, etc) (Degenne and Forse, 1999: 46). Each type of relation is considered a network layer. In the survey, respondents were asked to mention any additional relationship they held with each stakeholder; categories were 1) 'acquaintances', 2) 'work', 3) 'friends', 4) 'in-laws', and 5) 'immediate family'.

The questionnaire did not strictly permit disentangling friendship from the interaction content of the study: "someone with whom one discusses and/or jointly manages water", that is, all nominates were considered as good friends and, therefore, friendship was taken as a baseline to estimate multiplexity.[18]

[18] Burt's (1980) formula for multiplexity was used: ∑i Zij(m)/n-1 where there are 'I' actors in 'J's' ego-network, Zij(m) is zero when 'J' has more than one type of relation to 'I', whereupon it equals one.

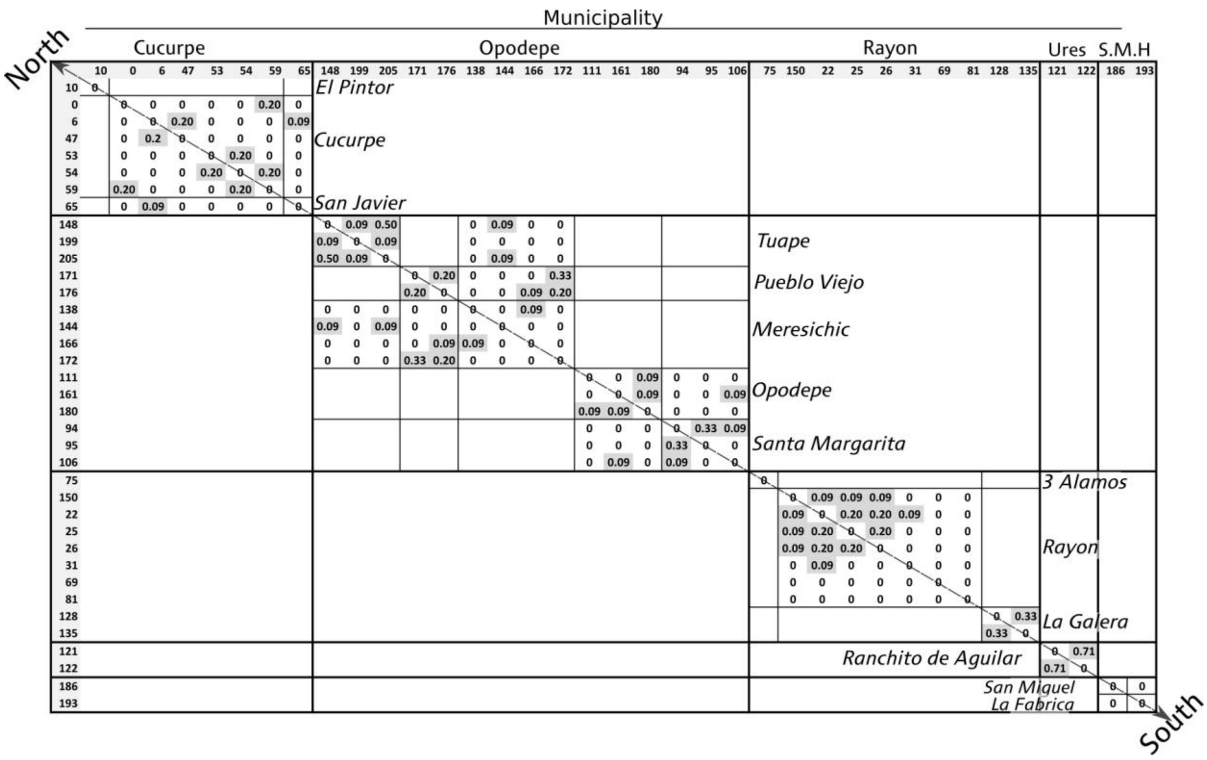
The results showed that, on average 48% (range 0-100) of the ties had multiple contents. The ego interpersonal environment is dominated by: 'in-laws' or 'immediate family' (46%) and 'work' (2%). Overall, 75% of the observed ego-networks had a percentage of multiplexity greater than 20, only 6 networks (out of 37) were uniplex (one type of relationship).

Ego-network overlap

The Jaccard coefficient (JC) (Jaccard, 1901) is a measure of the percentage of overlap between sets defined as: J(E1, E2) = |E1∩E2|/|E1∪E2| where E1 and E2 are two sets of ego-networks. The JC can be a value between 0 and 1, with zero indicating no overlap and '1' indicating complete overlap between the sets. A high JC indicates that two stakeholders share the same group of peers with whom water management issues are dealt with.

Figure 5 shows a 37-by-37 matrix of ego-networks (i.e. respondents), in which entries are the JC row and column names are the coded ego-networks, and the diagonal of the matrix is disregarded. To identify ties that extend across communities, the matrix was divided into regions or blocks by permutating rows and columns to group respondents by community, and communities by municipality; the upper-left corner of the matrix has the northernmost community, and the lower-right the southernmost one. Off-diagonal blocks were left blank if all JC entries were equal to zero; blocks with nonzero values indicate that there is an ego-network overlapping between these communities (or municipalities).

Figure 5. Matrix of ego-networks geographically ordered.



Note: Row and column names are ego codes; entries filled with the JC of ego-network overlap; blocked by municipality and by communities (labels within the matrix). Blocks between municipalities completely filled with zeros indicate that respondents did not nominate stakeholders living out of their municipality within the watershed. For instance, the block for 'Opodepe' off-diagonal nonzero blocks show ego-network overlapping between 'Tuape' and 'Meresichic', and 'Pueblo Viejo' and 'Meresichic'; and then, between the community of 'Opodepe' and 'Santa Margarita'. The interpretation of JC is as follows; for instance, respondent 176's ego-network (from Pueblo Viejo) has 20% of persons in common with respondent 172's ego-network (from Meresichic).

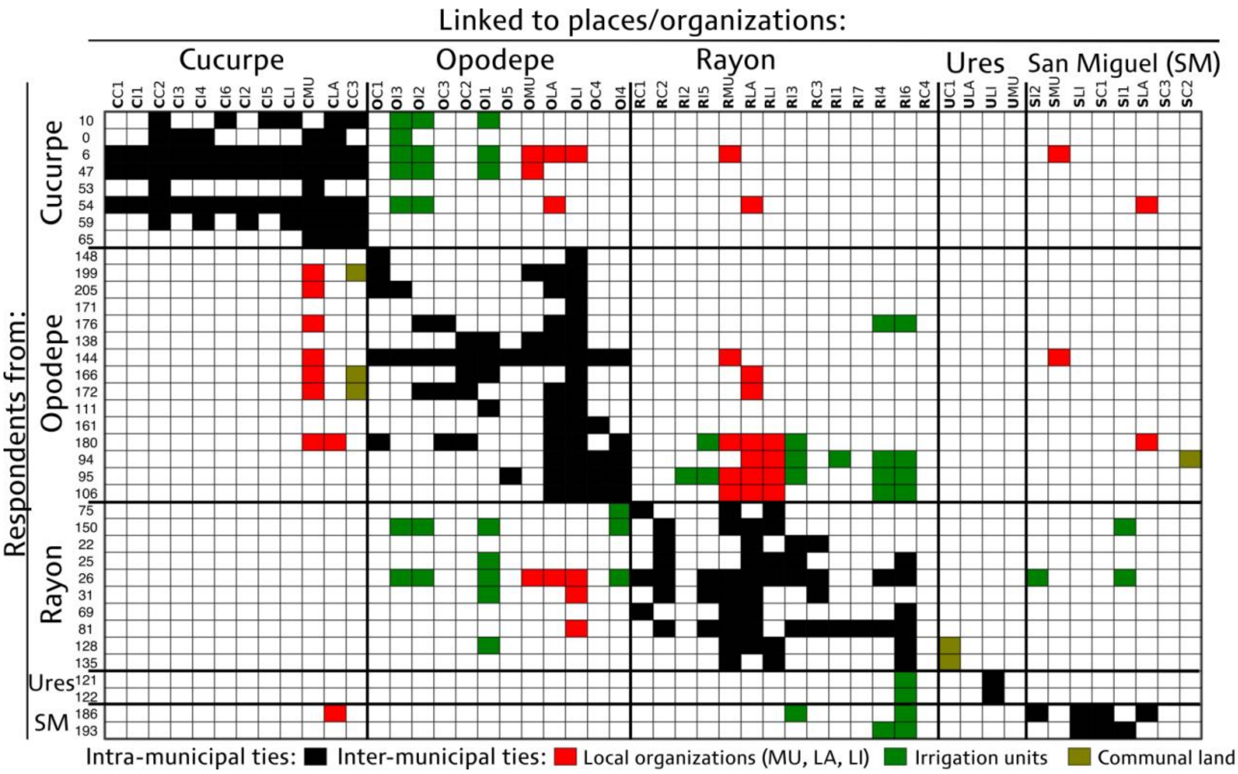
These findings inform the first research question suggesting that the social network supporting water management is locally embedded in dense social networks, but geographically bounded at the community level.

Bridging SC

In the analysis of ego-network overlapping it was possible to test watershed intra-municipal and inter-municipal connectivity, but the survey directly asked about these external ties. Respondents rated as 'yes/no' if they knew about the existence of places within their municipalities. The 'involvement' with these communities was defined in the same terms if respondents: a) have had discussion of water issues, b) jointly manage water, or c) have worked on or lobbied for a common water-related project.

Results showed that, except for municipal representatives, most of the shared experiences were limited to casual discussion and information exchanges. Common statements were: "I personally met him in a meeting (in the town hall) and we discussed drought (and other water-related topics)". The results for this section were stored in a two-mode matrix (Figure 6).

Figure 6. Two-mode matrix plot in which row names were coded respondents and column names represent coded places/local organisations.



Note: First letter for the municipality, 'MU' stands for president or administrative staff of the municipality, 'LI' livestock inspector, 'LA' for livestock association, second letter, 'C' indicates a communal land, 'I' irrigation unit. Blank-filled entries indicate no tie.

The fact that stakeholders are more connected within their municipality and sparsely or not connected to places/organisations of other municipalities of the watershed strongly indicates that bridging SC diffuses as it is scaled up geographically; that is, densely connected communities ('archipelagos') are poorly connected.

As suggested by the red-filled entries located off main diagonal blocks in Figure 6, the local organisations with the capacity of interconnecting the watershed are the municipalities, livestock associations, and livestock inspectors. The President of the municipalities and their staff usually attend the same meetings; also, presidents of the local livestock associations have an annual meeting, where they have the chance to discuss and exchange information; finally, livestock inspectors are aware of each other and have many chances to meet, because their duties include issuing livestock transportation permits.

This section’s main findings also give an idea of the scope of the 'problemsheds', i.e. in the SMW a very limited geographical span of connections exists (see matrix in Figures 5 and 6), to both other stakeholders and places/organisations. This makes it very unlikely that a high level of awareness of water challenges transcends multiple places across the watershed.

Linking social capital

It may be considered that every single stakeholder owns some form of linking social capital. A long trajectory occupying positions as representatives in local government and organisations give the respondents a broader and more heterogeneous portfolio of contacts, as was the case of former presidents of the municipality. The data show an average number of contacts per respondent of 8 (range 1-20), a mode of four, with 70% having 10 or fewer contacts. Conversely, Figure 7 shows the nominations received by agencies.

Figure 7. External agencies nominated by the respondents (maximum possible number of nominations = 37).

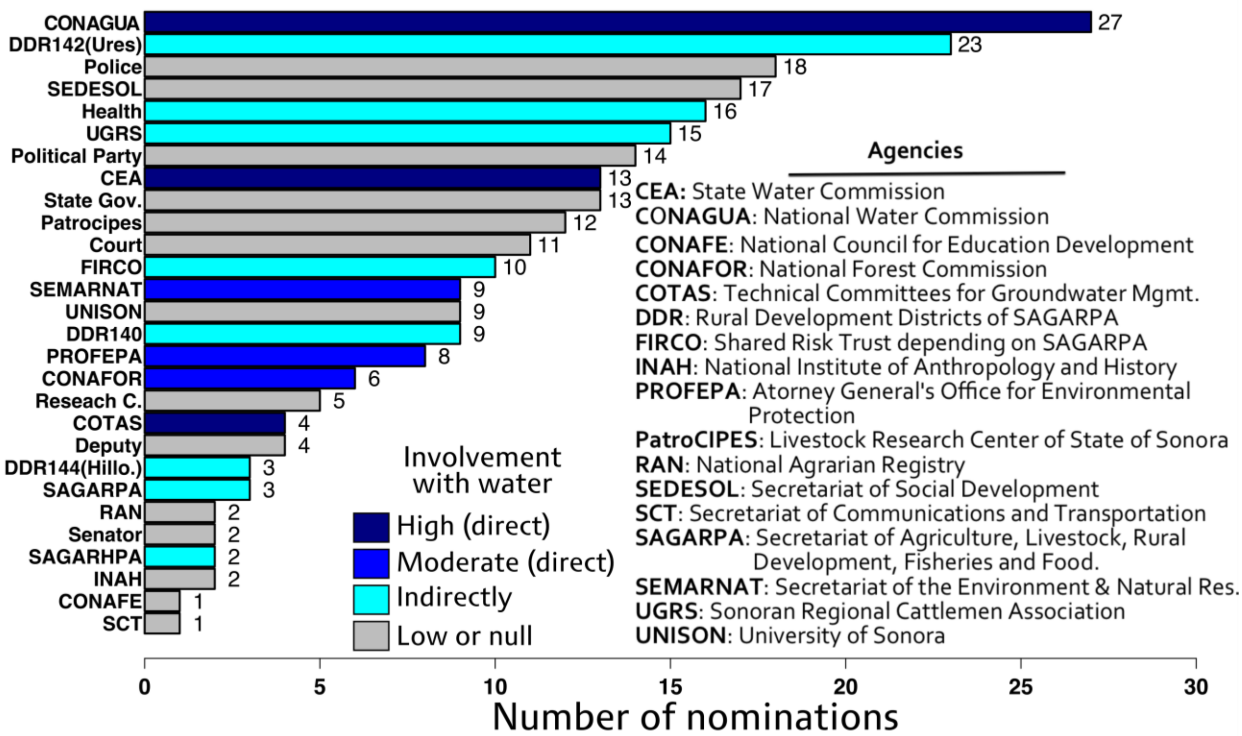


Figure 8. Two-mode network graph (nodes with numeric labels are the respondents and node size is a function of the number of nominations received for agencies and the number of agencies nominated for respondents).

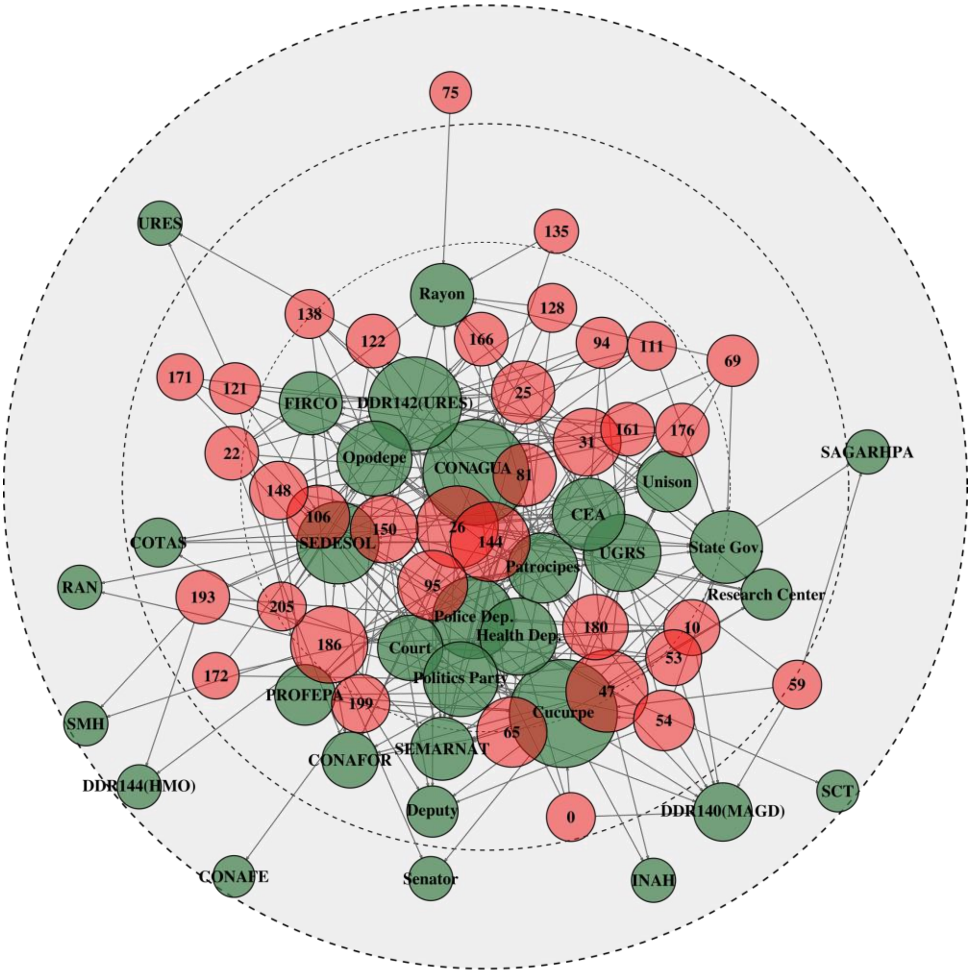


Figure 8 displays a two-mode network for LSC data; visual interpretation immediately reveals a core-periphery structure in which more densely connected nodes are located at the centre and relatively disconnected ones at the periphery. There are some important things to note about Figure 8. First, CONAGUA and SAGARPA (through the DDRs) – both federal agencies -- are the most central agencies. Second, the role of COTAS as the agency mandated to integrate social participation in water-related issues was lower than expected. Apparently, COTAS have very limited extension roles and received four nominations out of 37 (11%), and were mentioned only once as actively involved in any project. In addition, farmers rarely related the irrigation permit fee as a contribution made for sustaining the COTAS.

Narratives of sociability

Asking the respondent to narrate a story or experience where he had participated in tapping government funds for water-related infrastructure or gone through the procedures of any water-related permitting process, offered a vivid illustration of how the LSC works. These narratives also described individuals' connections and interactions with places, water issues, and local and external agencies.

Figure 9 describes a respondent who participated in a project for building farm ponds[19] in the Cucurpe communal rangeland with the external involvement of SAGARPA (which also used funds form PROGAN[20]), the local livestock association, and the municipality.

Most of the respondents successfully remembered having participated in a project to improve or solve a water-management problem; 86% had been involved in projects related with 'physical' infrastructure, and 43% in 'soft' activities such as lobbying and administrative procedures mainly with CONAGUA.

Interestingly, the narratives revealed how stakeholders intend to solve local water issues (some also considered as problemsheds) through LSC. Figure 10 displays a treemap divided into two blocks (categories) depending on the type of project (block 1 for 'physical' and block 2 for 'soft'). Within each block, rectangles represent a specific type of project as labelled; the size and colour darkness are a function of the frequency of mentioning in the narratives. For instance, the change by traditional irrigation systems from diverting surface water to extracting groundwater during the multi-annual drought (2000-2015) increased the demand for 'canal-lining' and 'auxiliary well' projects. In the 'soft' category, 'water-concessions' (i.e. projects to obtain and/or renew water concessions issued by CONAGUA) were popular; without their concession titles, stakeholders have no access to subsidies to build hydraulic infrastructure.

As was the case in the previous survey section, CONAGUA was also the most mentioned agency (70%) in the narratives, related mostly with 'soft' activities. Only 24% of the respondents linked the agency to physical infrastructure projects. Narratives also made explicit the struggle of stakeholders to comply with CONAGUA regulations and the feeling of disempowerment to influence official decisions.

Despite the fact that this agency was well known among the stakeholders, there was a lot of disinformation[21] and a gap in regularisation of water users, especially in the issuing of water concessions to irrigation units. Limited staff was the most frequently cited complaint followed by the regulatory power of this agency to cancel concessions and apply onerous fines. Based on limited scope for negotiation or trust-building, in general, water users view CONAGUA as a distant, disinterested agency that they have few incentives to contact.

The dual nature of this agency as both promoter and regulator of water development eclipses the important role of CONAGUA as a source of funding of infrastructure for small irrigation systems (i.e. irrigation units). SAGARPA was still remembered as being involved in canal-lining, dike building, and even as an organiser of irrigation units, suggesting that personal contact via institutional and social networks and lasting physical legacy are more important features of agency involvement than funding per se.

On the other hand, more physical-infrastructure centred agencies were SAGARPA (51% of nominations), followed by CEA (13%) and FIRCO (11%). PROGAN was frequently mentioned as a source of financing. COTAS was mentioned once as advisor in an administrative procedure being conducted with CONAGUA.

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[19] Also known as earthen embankments, ponds serve as a source of water supply for livestock and store runoff; they rarely hold water year-round. A photo interpretation of the Google Earth images (accessed in December 2012) revealed 387 ponds covering 184 ha.

[20] The PROGAN programme to improve livestock productivity gives a direct payment per cow (USD 14-17); communal landholders (ejidatarios) receive a consolidated group payment, and this money is usually invested in infrastructure such as ponds.

[21] The administrative procedure to obtain or regularise water concessions was not clear for most of the respondents; most of them were unaware if the aquifer and watershed were already closed for new water concessions, and if this were the case, their applications to regularise concessions might be denied.

Figure 9. Example of information elicited from narrative of sociability of respondent 54.

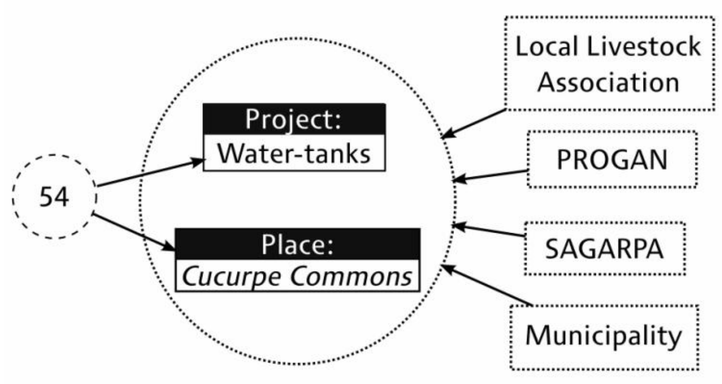
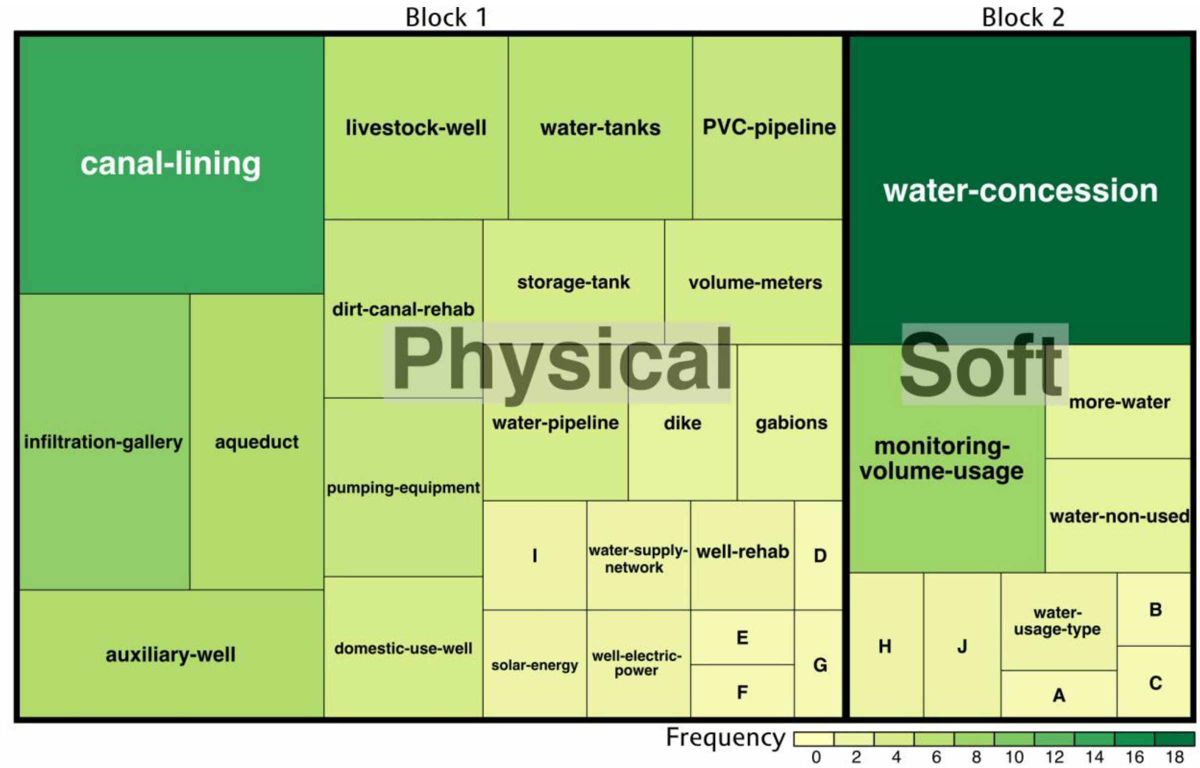


Figure 10. Tree map of water-related projects mentioned during the narratives.



Note: *A*: irrigation-unit-organisation; *B*: electricity-subsidy; *C*: water-fee-enforcement; *D*: power-lines; *E*: replace-asbestos-main; *F*: sewage-network; *G*: chlorination of water; *H*: reduce-domestic-water-use; *I*: new-irrigation-systems; and *J*: metering-domestic.

In 62% of the narratives the municipality appeared as a relevant actor, followed by the local livestock association (10%). An illustrative example of the role of municipalities was found in the communal landholding Ranchito de Aguilar, split in two by the Rayon-Ures municipality border. The two towns of La Galera in Rayon and Ranchito de Aguilar in Ures each has irrigated land; however, La Galera irrigation system remained idle for more than 10 years, because water was not enough to be diverted though the earthen acequia canals (and over time, the canals eroded away). In 2015, an extraordinary wet year, they asked for help from one of the candidates running for presidency of Rayon; borrowing machinery from him, the irrigators covered just the operator and diesel expenses, so it was possible for them to rebuild the IU. By contrast, in the immediately adjacent Ranchito de Aguilar (located in Ures municipality) irrigators complained that they did not receive proper attention from the authorities.

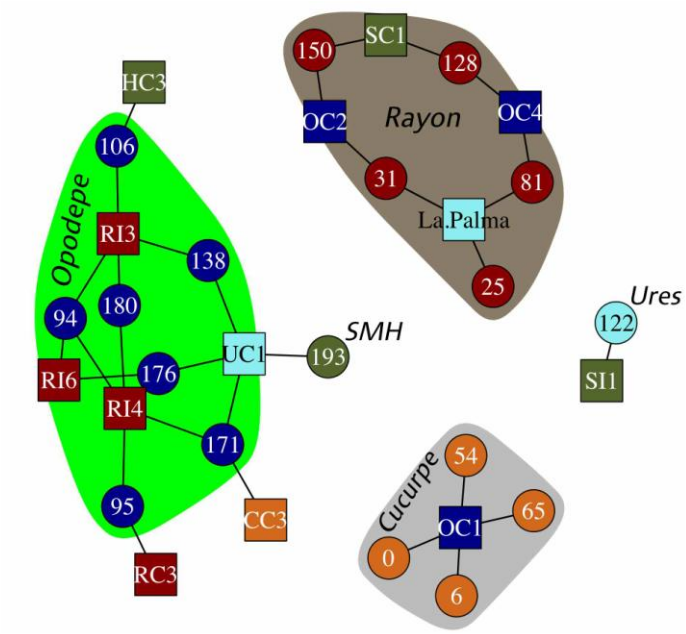
SAGARPA was the agency with more 'boots on the ground' presence, and because ranching and fodder production on irrigated land are the main water users in the watershed, this agency has a wide array of subsides related with water usage. All of them require presenting a water concession title issued by CONAGUA to be eligible for support (and the 'irrigation permit' issued by AN MRBC for PROAGRO[22]).

Finally, 49 and 84%, respectively, of the respondents mentioned having pending water-related necessities/issues to solve with external agencies, for 'soft' and physical-infrastructure. As suggested by many scholars (Woolcock, 2002; Stone, 2003; Muir, 2011), LSC has the capacity to leverage resources from external institutions beyond the communities. Evidently, our findings suggest the important role of resorting to external agencies with the resources needed for improving hydraulic infrastructure as a principal strategy for strengthening water management adaptive capacity.

Problemsheds

Knowledge about other places of water problems is important since, as mentioned earlier, water interconnects the watershed; therefore, people connected with information have the potential for creating coalitions or advocacy groups to deal with problemsheds. To unveil this connectivity along the SMW, stakeholders were asked about water issues occurring outside the borders of their municipalities.

Figure 11. Two-mode network graph.



Note: Squares are places (coded as in Figure 6) and circles respondents; labels start with the letter of the municipality: 'R': Rayon; 'O': Opodepe; 'S': San Miguel; 'C': Cucurpe; and 'U': Ures.

[22] PROAGRO is an agricultural subsidy from SAGARPA aimed to relieve the production costs of crops. In 2016, PROAGRO supports were $1,500 pesos/ha per agricultural cycle (USD 69) to farmers with less than 3 ha and up to $800 (USD 37) to commercial farmers.

Figure 11 displays a dimensionless two-mode network, which also reveals respondents connected to immediately neighbouring communities, e.g. Cucurpe to Tuape (coded 'OC1'), Opodepe to Rayon, and Rayon to Opodepe, Ures and San Miguel de Horcasitas. This information suggested a limited geographic span of the awareness of water-related issues.

Around 54% of the respondents acknowledged not having information about any water issue outside the municipality borders. The rest provided vague and obscure comments about the water-related issues of the places mentioned, all of them related to drought and water scarcity. This indicates a lack of information about the extent to which water-related issues are shared by others in the SMW.

The most acknowledged problemshed was drought; for instance, nominations to sections of the river that never dry out seem to suggest that severe drought and extensive drying are acute but generalised problems. Other problemsheds were not addressed; for instance, even stakeholders located in the lower SMW did not mention the Las Malvinas conflict that occurred in 2004 or the ongoing water transfer to the city of Hermosillo.

DISCUSSION

Bonding SC

This study demonstrates that, locally, water management is socially embedded in dense, multilayered networks. The social environment in which water management is carried out is dominated by strong family and friendship ties, closely connected geographically, and with a high volume of social interaction. Nevertheless, in general, these local networks are isolated. The metaphor of 'archipelagos' was used to refer to these densely connected clusters. IWRM requires a greater degree of connectivity between these clusters – a dimension captured by bridging SC.

Socialshed

The idealised watershed council described by Berg (2013) resembles densely connected clusters of people, in close contact with a local environment, eventually connected to other clusters to create a socialshed. In the SMW, despite the federal and centralised water policy overriding local jurisdictions, the social construction of the SMW, as idealised by Berg (2013), is far from being a reality.

Social fragmentation seems to be the normal state in river basin IWRM. The connectivity of local leaders or representatives with their peers elsewhere out of the municipality was almost nonexistent. Intra-municipal bridging of SC was significant; within a municipality representatives recognised each other and had an acceptable level of awareness of the water problems of their own communities.

This study reveals how water management takes place through various forms of social networking. Watershed social connectivity is a necessary condition for co-management, participatory decision-making, coordinated action, cooperation, and ultimately IWRM or some variant; the alternative is centralised management.

Problemsheds

In this research the concept of problemshed is generalised to connote a bottom-up approach, allowing the respondents to mention locally perceived problems and, in a fewer instances, problems outside the borders of their municipalities.

Moreover, in this study, social construction of territories is a structural dimension, i.e. places connected through people. In this regard, half of the respondents acknowledged they had no information about water-related issues occurring in the watershed outside their municipalities. The other half had a very shallow knowledge of a few places within the watershed. This very sparse knowledge-based network (see figure 11) severely limits the social integration of the watershed.

A commonly perceived struggle, risk, or threat can offer enormous potential for building social capital through feelings of empathy and solidarity, leading to the emergence of advocacy and coalition groups.

Linking social capital

In this study the connectivity with external agencies was measured by the LSC. As was described in the narratives of sociability, most of the local leaders and representatives sourced external funds through agencies such as CONAGUA, CEA, SAGARPA, and FIRCO and were supported by local institutions such as the municipality and the local livestock associations. For instance, for the case of irrigation units evolving from surface water diversion to groundwater extraction, the latter require more investment and formalisation (e.g. water concessions).

The requirement for external connectivity goes hand-in-hand with the necessity of external recognition and formalisation of local organisations; this forces social actors to agree with CONAGUA water policy and regulations.

CONCLUSIONS AND NEXT STEPS

Analysis of the spatial structure of social networks for water management can enhance understanding of socialsheds in drylands, and more generally, in water-scarce regions. The present study represented a bottom-up approach to the social connectivity dimension of IWRM and corroborated that it is not possible to have integrated management with unconnected social actors within a watershed. That is, coordination and participation assume social contact. Unveiling the pattern of social ties made explicit the social construction of the watershed territory, still dominated by social fragmentation, political jurisdictions, and physical barriers to communication.

The social integration of the watershed is unlikely to emerge considering the current institutional arena in which private, mostly individual users interface with monolithic, often unresponsive agencies. There is no agency or organisation purposefully promoting social connectivity at the watershed scale, despite IWRM principles enshrined in national law and agencies empowered with corresponding mandates and endowed with material, human, and financial resources. It is evident that central agencies such as CONAGUA, SAGARPA, and others not related with the water sector, play the role of structural connectors of otherwise disconnected groups, but this role is an unnoticed by-product of their case-by-case intervention in the watershed.

The role of the MRBC and its auxiliary organisations should serve as the fabric or connective tissue promoting social integration of local leaders and representatives dealing with water management. As suggested by Falk and Kilpatrick (2000) the construction of social capital requires: a) creating links and opportunities for interactions; b) these interactions must have a purposeful objective (in this case, to discuss and reach agreements over problemsheds) in line with IWRM; and c) the resulting experience must be positive.

In addition to the formation of new social capital, the MRBC and its auxiliary organisations also need to play an important role in levelling the playing field for social actors. As was demonstrated in the case of LSC, social capital, as any other asset, is unevenly distributed at both the personal and community levels. This situation skews access with some individuals and communities having more access to external resources than others. The MRBC and its auxiliary organisations do not explicitly have such goals; social connections tend to be created as vertical ties, one-by-one, in a case-specific manner -- a process that relies on, and often reinforces, centralised administrative and political structures.

ACKNOWLEDGEMENTS

Funding for this research was provided by National Science Foundation (NSF) grant DEB-1010495, Strengthening Resilience of Arid Region Riparian Corridors: Ecohydrology and Decision Making in the Sonoran and San Pedro Watersheds.

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