

GROUNDWATER GOVERNANCE IN ASIA AND THE PACIFIC

IWMI Project Report **No.4**

Groundwater governance in the Arab World

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December 2016



This is an IWMI project publication – "Groundwater governance in the Arab World – Taking stock and addressing the challenges"



This publication was made possible through support provided by the Middle East Bureau, U.S. Agency for International Development, under the terms of Award AID-263-IO-13-00005.



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Foreword

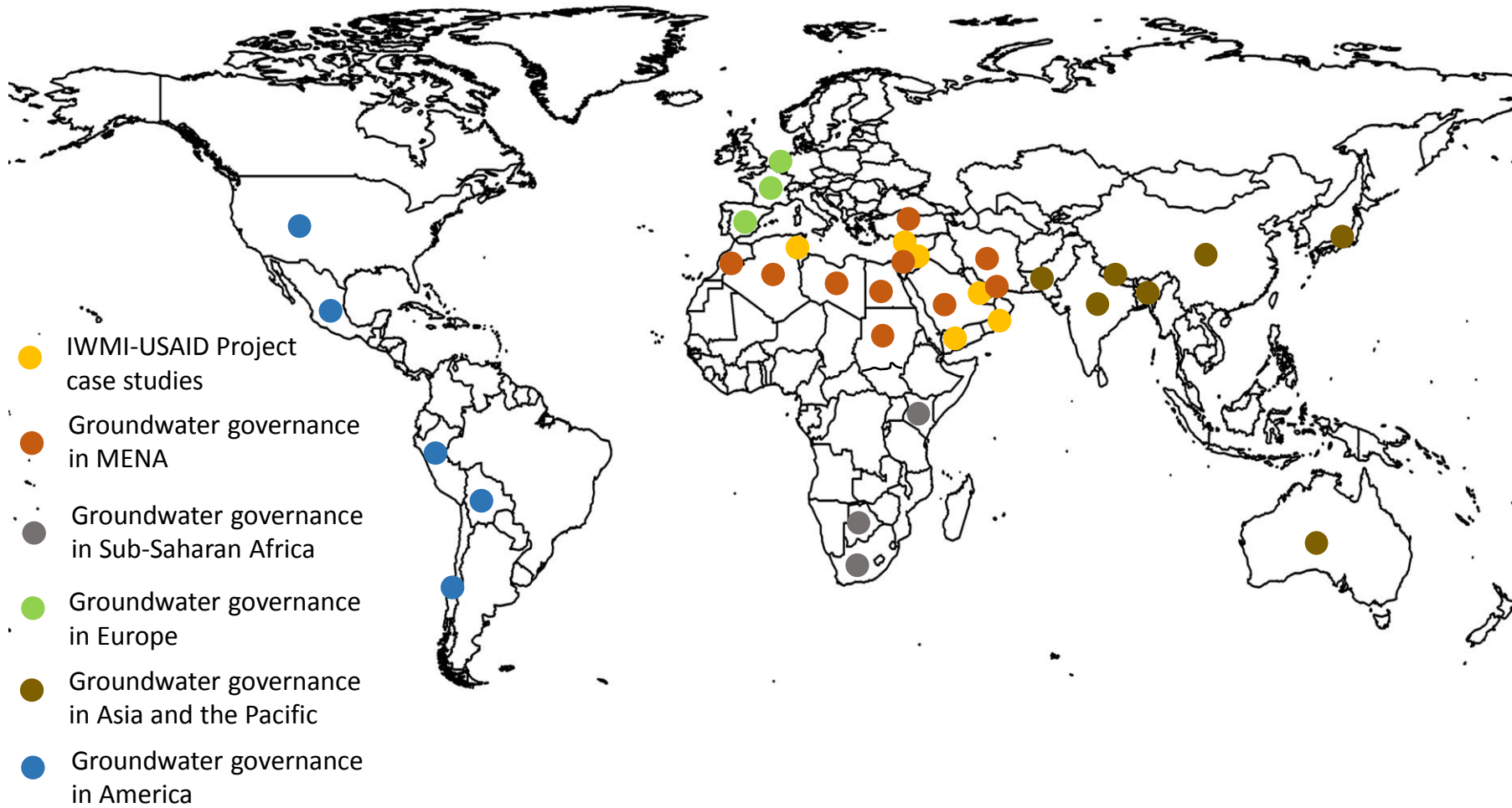
This report on groundwater governance in Asia and the Pacific is part of a series of five regional reports arising from a research initiative undertaken by the International Water Management Institute (IWMI) and funded by USAID aiming to address the challenges posed by the unsustainable use of groundwater in the Middle East and North Africa (MENA) region (Figure 1). Groundwater over-abstraction is a phenomenon threatening the sustainable economic and social development of the countries on the southern side of the Mediterranean and the control and management of over-abstraction has become a clear challenge for policy-makers, managers and academics in the region. This broader research exercise is aimed at presenting different governance problems and challenges that exist around the world regarding groundwater and inform potential future management and policy pathways in the MENA region.

The reason for this report on groundwater governance in Asia and the Pacific arises out of the necessity to examine, at various scales, existing cases of groundwater regulation and management so that policy discussions, effective solutions, and mitigation measures to the groundwater crisis may be found. This report represents a compendium of cases aiming to bring to the attention of the MENA region the policy and regulatory experience of groundwater in a few selected countries in the Asian and Pacific region so that relevant policy and management lessons can be drawn from this case. The countries reviewed in this report are India, Pakistan, Nepal, Bangladesh, China, Japan, and Australia. The report analyses, through a political, regulatory, and historical lens, the different groundwater regulatory tools, reflecting on the different laws, regulations, community actions, and institutional structures found in the different countries in order to curb groundwater over-abstraction.

Although this report does not attempt to be exhaustive as it is based on existing and accessible literature, it aims to go further than what has been presented until now and address the intrinsic challenges faced by current groundwater policies whilst offering a number of analytical and factual elements on groundwater governance presented in an original way. Semi-arid and arid countries are understandably more likely to (over)exploit their groundwater resources and the lessons drawn from the situation in other arid areas with different political economies, can potentially be very relevant for the MENA region as they may indicate potential solutions or - more often than not- flag the dangers or irrelevance of certain standardized, or seemingly desirable, policies. Thus, the examples studied here can provide a deeper understanding of the challenges countries in the MENA region face when it comes to reducing groundwater abstraction, echoing some of the attempts to regulate groundwater abstraction made by states in Asia and the Pacific.

The results and failures faced by governments and communities can also represent relevant insights when it comes to enforcing regulation or understanding legal barriers to policy implementation, all relevant and important lessons for other countries. Reflecting on a wealth of background stories and experiences will also provide a richer understanding and diversity of insights to these problems, what worked and did not work. The gravity and complexity of the situation require a systematic and wide-ranging approach building on existing knowledge and practices in and beyond the region, so that innovations in groundwater regulation and legislation can be found and the groundwater depletion trend averted.

Figure 1. Project case studies and cases reviewed for the project



1 China

1.1 Groundwater resources and management in China

China has 8 hydro-geological regions (Figure 2) (1. Liao-Songhua Lowland; 2. North China Plain; 3. Coastal areas of the North China Plain, Shandong Peninsula, Huai River Floodplain and Yangtze River Estuary; 4. Huai River Floodplain; 5. Yangtze Floodplain and river valley; 6. South China Karst; 7. Sichuan Basin; 8. North-West Deserts) (COWI 2013a).¹ The main issues affecting groundwater resources in China summarized by COWI are a fragmented management of the resources; unsustainable abstraction in some areas (e.g. Northern China) causing declining yields and placing economic sectors at risk; salinity intrusion in coastal aquifers; pollution; low use of groundwater in karst areas in south-western China (ibid.).

Hydrologically China can be divided North-South into two regions following the Yellow and Yangtze River Basins: one in the north with relatively low rainfall (<650 mm) and one in the South (Figure 2) (COWI 2013a). In the north, the relative low rainfall reduces groundwater recharge and makes alluvial aquifers (predominant) vulnerable to over-abstraction (Cao et al. 2013; Qin et al. 2013). Incomplete groundwater estimates due to lack of data suggest that there are 840 Bm³ of available groundwater in China. Groundwater abstraction estimates at the country level indicate that 600 Bm³ are used every year, of which known abstraction constitutes only 110-150 Bm³ (2010 data) (COWI 2013a).² Groundwater abstraction mainly takes place in shallow aquifers in plains and inland deserts in North China. The main user of groundwater in the country is agriculture (60 percent used mainly for wheat, maize, cotton, and soya beans), with domestic and industrial uses each accounting for 20 percent. In some areas however, the importance of groundwater for urban use is strategic, as 400 out of 650 large cities in China use groundwater in their water supply (in the north and northwest regions, groundwater supplies 60-70 percent of urban water uses) (ibid.).

Groundwater abstraction began to be actively exploited at the time of the foundation of the People's Republic of China in 1949 (Zhu et al. 2013). Between 1949 and 1980 the Chinese government invested heavily in irrigation infrastructure, building canals, reservoirs and wells. The effective irrigated area during this period increased from 15.9 million hectares in 1949 to 44.9 million in 1980 and the number of wells rose from 0.11 million in 1961 to 2.69 million in 1980 (ibid.). In 1972, "following several consecutive dry years (including 1969 when 80 percent of the more than 3,000 mechanized wells in the county ran dry), the government organized 114 drill rigs to construct 1,253 new wells in Luancheng County" alone (Kendy et al. 2003). A shift in political priorities in the 1980s led to a reduction of financial expenditures in irrigation development and management from the central government affecting the local management of resources (see below). The strategic direction by the government shifted from extensive to intensive management, with emphasis on water-saving irrigation technology, modernization and optimization of water use (ibid.).

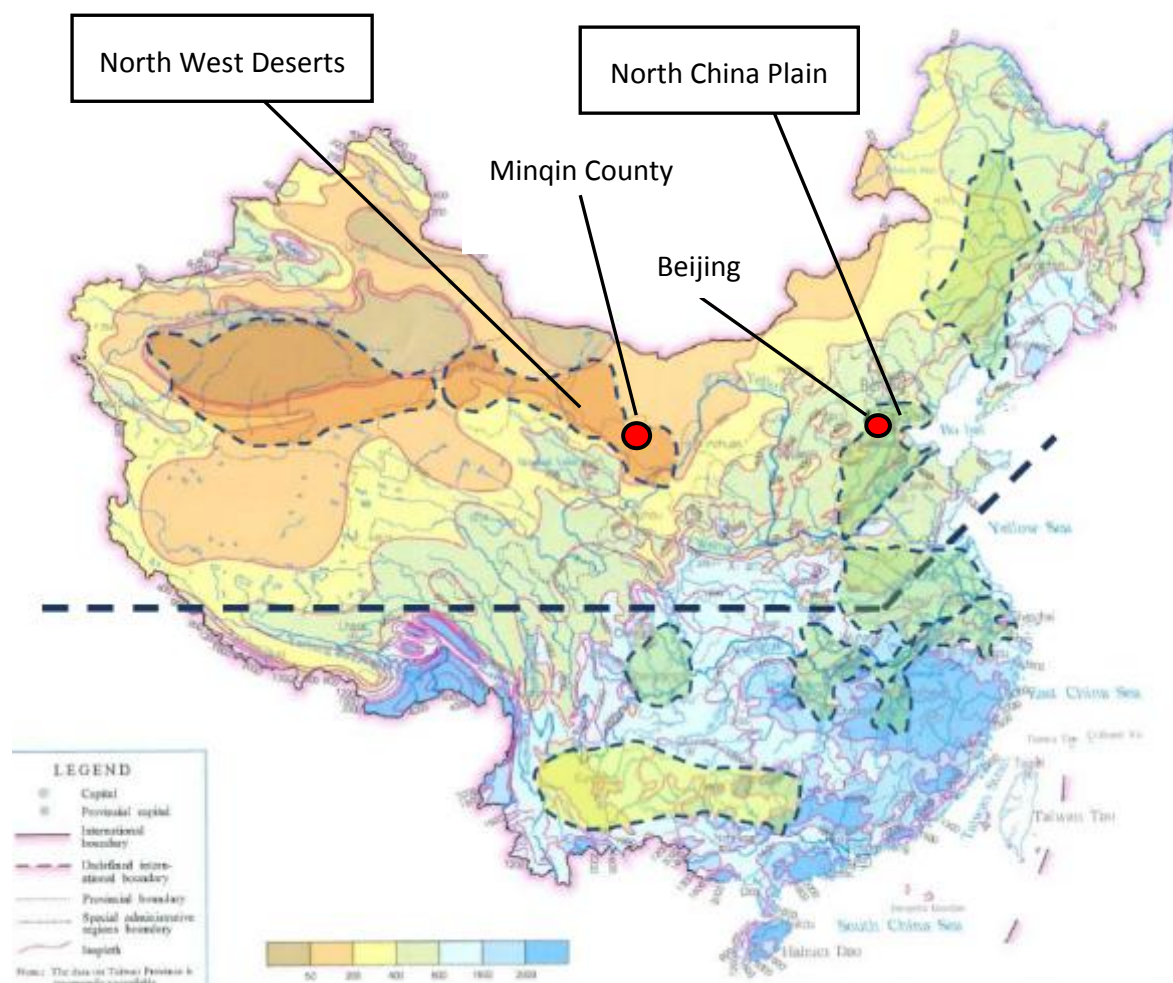
¹ In terms of groundwater use, the Liao-Songhua Lowland is the region with the highest groundwater use in China (23 percent of national resource use) followed by the Northwest Deserts (22 percent), the North China Plain and Huai River Floodplain (16 percent) (COWI 2013b).

² This figure is 50 percent higher than recorded official statistics (COWI 2013b).

The current water law was passed in 2002 (China 2002), and was itself an amendment of the 1988 Law (Guisheng et al. 2013; Wang et al., 2014). Article 3 stipulates that "water resources shall be owned by the state. The State Council shall exercise ownership of water resources on behalf of the state". It indicates – among other things and rather at the level of principles - that water should be managed at the basin level; and administration and calls for watershed plans; allocation planning should be based on quotas. It also indicates that "those using the water supplied by water projects shall pay water fees", and that "the state shall require strict economy in the use of water, vigorously promote measures for water saving, spread new technology and techniques to conserve water, develop the water-conservation industry and agriculture and service industry, and establish a water-conservation society." Among the important ensuing decrees, the 2006 Regulation on the Administration of the License for Water Withdrawal and the Levy of Water Resource Fees strengthened the licensing process and pricing mechanisms (China, 2006).

The drilling industry in some places also been gradually controlled. Although in the early 1980s, "household enterprises specializing in well-drilling emerged to compete with government drilling teams" (Wang and Huang 2002), local administrations have issued regulations to license and train all companies equipped with drilling rigs, such as in Sanxi Province (Guisheng et al. 2013).

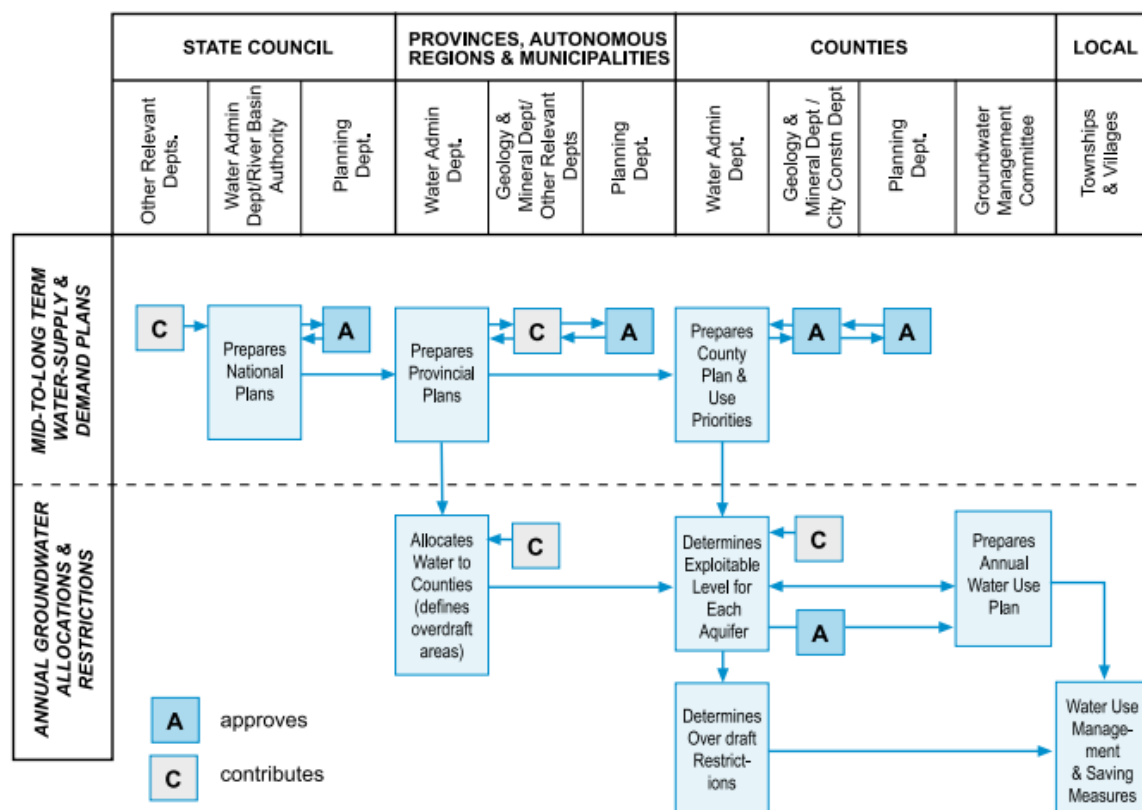
Figure 2. Main groundwater regions of China and the north-south rainfall divide



Source: map from COWI 2013a.

On paper groundwater abstraction is subject to licensing by the Ministry of Water Resources and its line agencies at the province level and municipal level, but in reality this practice is incipient (COWI 2013a). The legal basis for regulating groundwater abstraction is the 2006 'Water licensing and water resources fee collection and management regulations' stemming from the 2002 Water Law (ibid.). Permits are issued, but with limited knowledge of groundwater resources (in Minqin Oasis in North-central China) it was found in 2010 that 10,000 wells had been registered with allowed abstraction volumes twice the estimated groundwater reserves; (see next section). Water abstraction permits are supposed to be issued based on total water allocations estimated at the provincial level by the Ministry of Water Resources. These quotas allocated to provinces responded to China's central policy, following the 12th Five Year Plan, (2011-2015) set a cap on total water abstraction of 635 Bm3 by 2015 and 670 Bm3 by 2020 (ibid.).

Figure 3. Planning procedures for groundwater allocation in China (in 2004)



Source: Foster and Garduño 2004.

Officially, water resource management in China is implemented by the 6-layered water bureaucracy in the country. This structure is presided at the top by the Ministry of Water Resources. Operating agencies are parts of the bureaucracy at provincial, prefecture, county, and township level. China's notorious bureaucracy employs large numbers of staff in its water

resource bureaus and other water organizations.³ County water bureaus have to raise some of its own budget via taxes, limiting its scope and activities. Kendy et al. (2003) found that the budget for the Luanheng country was enough to fund the bureau but not to finance water conservation across the county. Important budget deficits of local governments, with ambitious officials eager to spend money, could put the solvency of these projects⁴ at risk.

Fragmentation of ministerial roles and lack of cooperation increases competition for mandates over groundwater resource (there are 5 ministries with competencies over groundwater) (COWI 2013a) and according to the World Bank (2009), 10 ministries share competencies over water resource management. The Ministry of Land and Resources had the official mandate for groundwater until 2003, when the Ministry of Water Resources acquired part of the responsibility for groundwater regulation and abstraction. Prior to this reassignment, groundwater allocations following the river basin plan were supposed to be supervised by the Department of Land and Mineral Resources. This Department did not have groundwater specialists at the county level, so the provision and allocation plan was not fully consistent with the reality on the ground (Figure 3) (Foster and Garduño 2004). This could be a reason for the lack of relevant and accurate data and the gap between ministry estimates of groundwater abstraction and the reality. The Ministry of Housing (established in 2008) has also imposed bans on urban groundwater abstraction in Beijing and Shanghai (COWI 2013a). This fragmentation at the central level is reduced at the provincial and municipal level as local governments have authority over line agencies and can ensure cooperation (COWI 2013a; Foster and Garduño 2004).

Solutions put forward to counteract groundwater depletion include the large-scale South-to-North Water Transfer Project, conveying 28 Bm³ per year (when fully completed by 2020) of surface water from the Yangtze River to the North China Plain in order to secure water for the Beijing and Tianjin metropolitan regions (with 50 million inhabitants) and, according to the official version, relieve overexploited groundwater reserves⁵ (the current groundwater abstraction in the North China Plain is estimated at 18 Bm³ per year) (COWI 2013a; Crow-Miller 2015). The city of Beijing also relies on 6 emergency well fields which started to supply groundwater to the city during the long drought spell between 1999 and 2006 (Zhou et al. 2012). This led to further regional unsustainable levels of groundwater abstraction, impacting river discharges, drying up private wells, and causing land subsidence (of 0.1 m over 3,000 km²) and the accumulated groundwater level drawdown to more than 20 meters and a cone of depression of 1,100 km² (ibid.).

³ According to Shah et al. (2004), the province of Liaoning employs some 40,000 staff in water bureaus, excluding an equal number at village level. Gujarat, India, is bigger than Liaoning but has just around 11,000 public officials employed by water related departments.

⁴ According to The Economist (January 4th 2014), China's local government debt was found to be up to a third of China's GDP (including investments, guaranteed debt, and implicit obligations). However, local governments will only have to directly bear a fraction of these liabilities which reduces the local debt to 22 percent of the GDP. Local governments are also diversifying the type of lending they request, turning to bond markets, trust companies, and securities firms. Traditional banks now account for only half of the lenders of local governments.

⁵ According to Crow-Miller (2015), the official environmental narrative states that the project will benefit groundwater resources as it will relieve some of the over-pumping with additional surface water from the south. However, according to research by Ye et al. (2014) and Crow-Miller (2015), this argument remains an 'official distraction' as the region of the North China Plain as a whole will continue to experience groundwater problems as the benefits will be concentrated around the immediate periphery of the project.

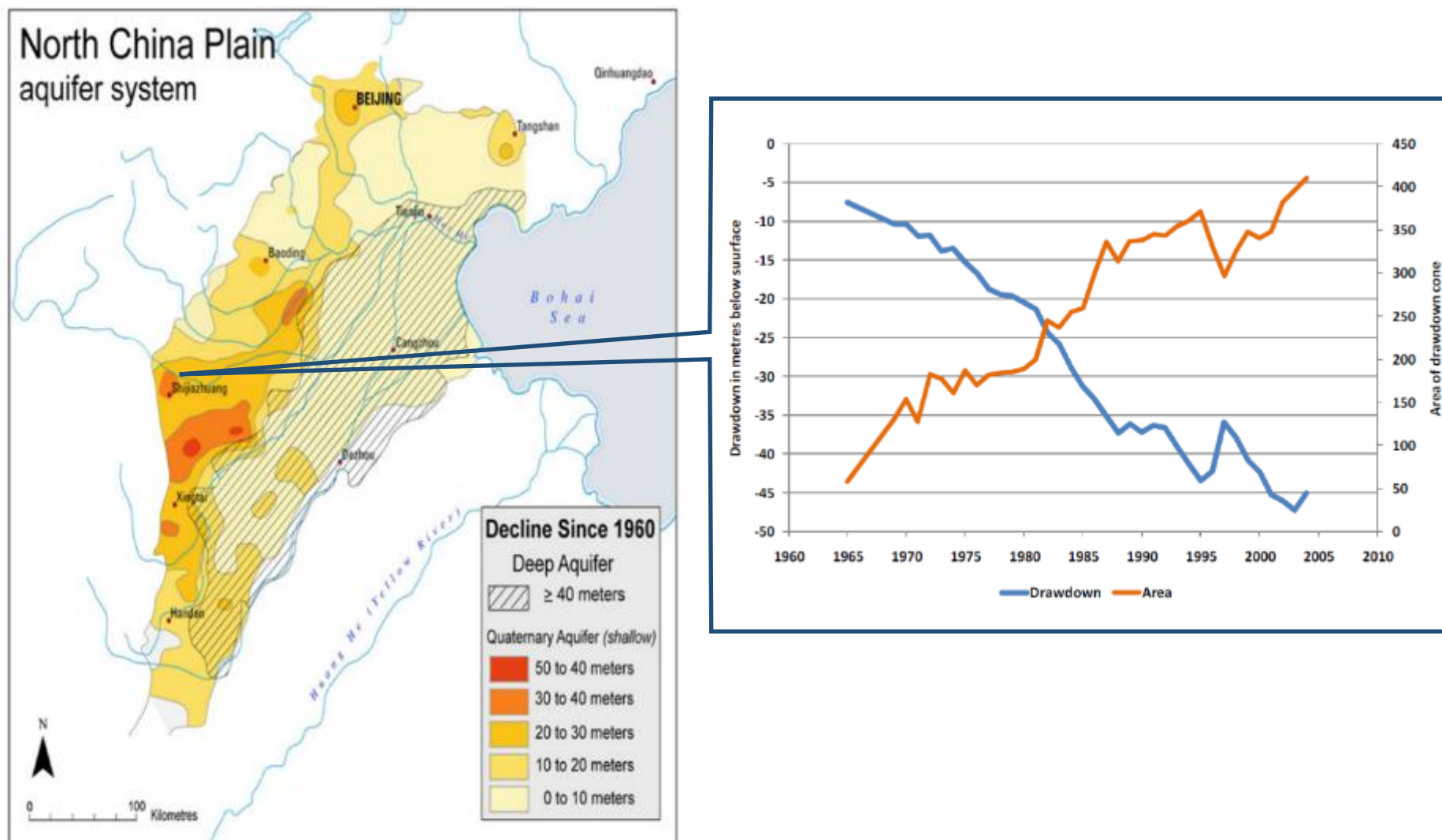
1.2 Groundwater use in the North China Plain

The North China Plain consists of the overlapping flood plains of the Hai, Yellow, and Huai River. They appeared as alluvial cones of gravel, clay, and sand deposited by these rivers. Coarser deposits of gravels and sands dominate towards the western border with the Taihang Mountains and the Loess Plateau and where large aquifers can be found (COWI 2013a). High abstraction in the North Plains, with mechanized groundwater abstraction, which allowed double-cropping growing wheat in the winter and maize in the summer, led to groundwater level declines of up to one metre per year already, back in the 1960s (Figure 4) (COWI 2013a; Xu et al. 2005; Zhen et al. 2002). In the alluvial plain towards the coast where aquifers are thinner and produce lower yields, groundwater drawdown has been between 0.3 and 0.5 meters per year since 1965 on average (COWI 2013a). The area with water table decreases of 10 meters and more represents 67,000 km² (one half of the North China Plain) (Cao et al. 2013).

Supplying 70 percent of the total water needs of the region, the North China Plain groundwater use represents 16 percent of all groundwater use in China (COWI 2013b). Groundwater abstraction for irrigation represents 70 percent of all water uses for agriculture in the Plain (Cao et al. 2013). Population in counties overlying the aquifer system was expected to reach 100 million in 2015 (UNEP 2012). Groundwater pumping in the plain is however uneven due to the high urban density of some areas and the still remaining agricultural activities in others (variations in density of grain crop cultivation explain differences in pumping and drawdown rates) (Cao et al. 2013).

In North China, the control over groundwater is done by using a combination of direct and indirect demand management instruments such as the promotion of water saving approaches, implementation of withdrawal permits, water pricing as well as the enforcement of water withdrawal quotas, replacing urban tube wells by surface water imports (Zhen and Routray 2002). These official measures, more effective in urban areas, seem to have created growing confidence on the effectiveness of China's experience with direct management according to Zhen and Routray (*ibid.*). The results in practice however, are mixed. Withdrawal permits can be issued by water bureaus at various government levels and since 2002 with the Water Law, old and new tubewells are required to have withdrawal permits by paying an annual fee (Wang and Huang 2002 in Shah et al. 2004). The results of this policy are mixed and the implementation of this plan claimed by some researchers is far from achieved (Shah et al. 2004). Withdrawal fees are difficult to collect and due to the financial burden of farmers, the application of this measure was upheld by the central government. The allocation of withdrawal permits was done by village at the village committee level (one for each committee) and not one for each tubewell. The general picture is therefore one in which tubewell and water withdrawal permits have not brought significant regulation of groundwater demand for irrigation and experiments such as the regulation of tubewells via cards and quotas in Shaanxi, remain exceptions (see below).

Figure 4. Groundwater table depletion in the North China Plain aquifer system and drawdown of shallow groundwater and surface affected by depletion (1960-2004)



Source: Foster and Garduño 2004 in UNEP (2012) and COWI 2013a.

Zhen and Routray (2002) indicate how, in Northern China, agricultural activities will have to face the severe consequences of groundwater depletion if the current pattern of groundwater use continues. The improper implementation of policies and regulations also contributes to declining groundwater levels. In Ningjin County (Hebei Province, North China Plain), administrative reform and reduced budget have affected the capacities of the two organizations responsible for the implementation of local groundwater management laws and the monitoring of farmers' practices (ibid.). Additionally, there seems to be no clear indication of where the responsibility and right for groundwater utilization and conservation duties lie. General strategies, monitoring and reporting are also missing, making it difficult for local organizations to implement groundwater regulations (Zhen and Routray 2002).

1.3 Local management of groundwater in China

China shows various hybrid forms of community involvement, state rule and the use of market mechanisms to locally manage groundwater. The strong local authority structure maintains a degree of control over the different institutional arrangements. While in the 1960s and 1970s most of the wells were funded by Village committees (or 'councils'), in the past two decades new wells have been largely the result of individual or collective investments. The change was spurred by a reduction in the financial capacity of public institutions, water scarcity faced by farmers, a decrease in the yield of public wells and poor maintenance, and was facilitated by a changing political environment as well as state loans and subsidies (Wang et al. 2005).

The diversity of institutional arrangements and property rights therefore include (Shah et al. 2004; Bluemling et al. 2010; Wang et al. 2005, 2006, 2013):

- The Village Committee keeps control of the (public) well, and funds O&M through different sources (farmers and others);
- The service of the well is contracted out by the Village Committee to contractors (often the earlier technicians running it or a specific farmer), who pay a fee against delivery of electricity;
- Former public wells put under the responsibility of the farmers using it (often the 'production team' associated with the well in the past); this is tantamount to shared ownership;
- Shared ownership of new privately-owned wells (a group of farmers pooling resources for this investment), or of a formerly public well (sold to the group); the government has extended special loans and subsidies for such investments;
- Individual ownership (one individual alone investing in his own well).

Following Shah et al. (2004), the evolution of this system originated in the Maoist era, where irrigation tubewells were directly managed by salaried operators of the village collective. Increasingly however, operation and maintenance tasks started to be contracted out to 'service providing entrepreneurs' as a kind of franchise model with a variety of contracting arrangements (ibid.). Typically, these service providers are amongst the more entrepreneurial members of each village community. Usually the service provider would be appointed via informal negotiation by the village community and/or the township water bureau although in some instances a five to thirty-year 'management contract' was auctioned to the highest bidder (ibid.). In these cases, village committees levied an annual fee on the contractors – responsible only for water distribution and fee collection – and retained management and repair responsibilities. Responsibilities for the contractor would typically include the operation and maintenance of the system; water distribution to farmers; collection of irrigation fees; and

payment of electricity fees to the village electrician or township electricity bureau. The irrigation fee however was determined by the village committee and/or the township water bureau (Shah et al. 2004).

For systems built, owned, and operated solely by private farmers, the village committee had little or no say at all in determining irrigation fees. In Shaanxi province, irrigation systems where contractors had shared the capital costs of the investment (for new drip and sprinkler systems for instance), the village authorities had retained the power to fix irrigation fees but allowed liberal margins and gave long-term contracts with varying management contract lengths (depending on how long the contractor had contributed to the capital cost of the investment, from a 5-year contract with a 10 percent capital cost investment to a 30-year management contract for a 25 percent share in the investment) (ibid.).

1.3.1 Management of groundwater resources in the North China Plain

In the North China plains, where one quarter of the country's total grain yield is produced, the increase in population and food demand has led farmers to turn to groundwater after having exhausted surface water resources (Zhen and Routray 2002). The deficit between supply and demand was estimated at 7.9 Bm³ in 2010 and water shortages have serious impacts: "Most rivers have been drying up or been changed to seasonal rivers. The groundwater table declines continuously and brings a series of adverse consequences – land subsidence, seawater intrusion, wetland loss, and pumping cost increase. Competition for water resources among different water-use sectors becomes more and more intense. Besides the challenges in finite water quantity, water quality degradation is another important issue" (Liu et al. 2011).

Joint irrigation wells and the rules in place to access and allocate groundwater in the North China Plain have been studied by Bluemling et al. (2010). Focusing on three villages in the Hai River Basin, renowned for its rapid groundwater depletion, the authors studied institutional change in the existing arrangements used to share groundwater amongst users. These wells went through a process of 'privatization' producing 'shareholder wells' where a small group of farmers took possession of public wells. Following the de-collectivization in China in 1979, the fiscal reforms affected village finances with smaller budgets for irrigation. Up until the 1980s farmers mostly accessed groundwater through collective tubewells but increasing groundwater depletion and irrigation reforms triggered the development of private wells (reaching 70 percent in 2004 in the North China Plain) (Zhang et al. 2010). Economic reforms forced village governments to become financially more independent, eventually creating serious financial shortfalls in those villages without lucrative non-agricultural enterprises (Bluemling et al. 2010; Wang et al. 2014). Because of this, these villages were unable to invest in agriculture, maintain state-managed and owned collective wells (Wang et al. 2014). The relaxation of constraints on private activities and investments also facilitated the development of private wells (ibid.).

Each one of the villages studied by Bluemling et al. (2010) opted for different strategies to cope with budget cuts resulting in different 'stakeholder constellations' to manage groundwater wells for irrigation, exemplifying significant levels of collective organization in rural China (Muldavin 2000 in Bluemling et al. 2010). A caveat however has to be added: devolution has only taken place in better endowed groundwater areas. In the more problematic resource-limited villages (1 and 2), the local public authority is still responsible for irrigation water management (Bluemling et al. 2010).

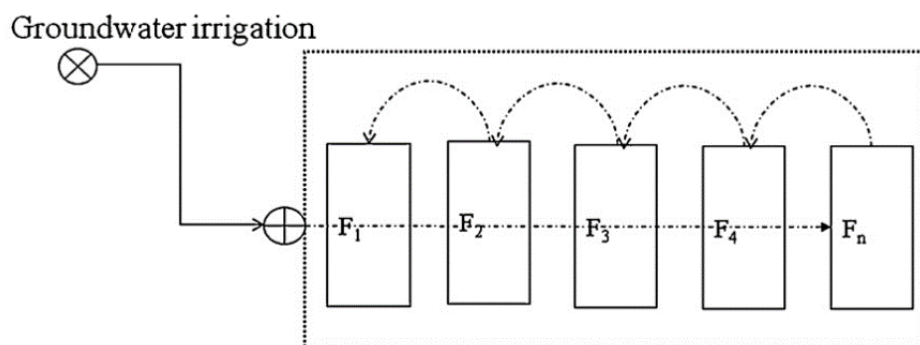
In the first village studied the responsibility for irrigation was devolved to 'farmers' small groups, successors of the production teams in charge of accounting and farm production units (ibid.).

These groups would ensure pump repairs, deepening of collective wells, and the installation of pumps. Costs are covered at the group level according to the amount of agricultural land owned by each household using the well (ibid.). Village 2 opted for contracting out well and irrigation management to contractors. The original pump technicians became the contractors, having to pay an annual fee per tubewell (ibid.). In return they receive a certain amount per kW per hour of electricity supplied by the well. Village 3 opted for a financial strategy, supporting well maintenance with profits generated from taxes raised from rural industries (ibid.). Households have to pay a lump sum that will cover the electricity used for irrigation by the well.

Each one of the three villages also developed different 'irrigation order rules'. The 'spatial order' rule was developed following the sequence of plots from low to high plots. Monitoring occurs amongst neighboring farmers and changes every year. Also, every year the sequence moves one plot subsequently so that the farmer initiating the irrigation turns swops every time. The 'lottery' rule established an arbitrary element of allocation at the beginning of each year as the coordinator will convene a meeting where irrigators will draw lots stipulating the sequence of irrigation. Under the third type of arrangement, 'first-come first-served', farmers approach the coordinator or the farmer already irrigating and join the queue. Access to electricity can be a factor determining the initiation of the irrigation turn, where electricity is limited.

Similar arrangements have been studied by Wang et al. (2013) in Hebei province, Northeast China (east of Beijing). According to Wang et al. (2013) in their study, all users are compliant with irrigation rules and management is transparent. Groundwater in the villages is organized by the group of water users with bottom-up initiatives based on voluntarism and trust and without involving profits (ibid.). Groundwater is charged according to irrigation time. Water users' allocation rules and fees for groundwater are defined amongst users without significant intervention by the village committee. The number of users sharing the groundwater irrigation system varies between 6 and 20. Groundwater is conveyed through channels from the well to the fields (average length of 20 to 600 meters) and irrigates between 2.33 and 7.7 hectares. Groundwater fees are equivalent to the electricity and maintenance costs of a pump well without extra fees for using groundwater. Moreover, irrigation rules follow a sequential order which eliminates inequalities between upstream and downstream users as the monitoring of users' extraction behavior is done starting from the user who is the furthest away from the pump (ibid.).

Figure 5. Groundwater irrigation management in a village in Zhuolu County, Hebei province, China (near Beijing)



Note: F1 refers to a water user, F2 and subsequent are other groundwater users. Arrow from F1 to F_n is the direction of water allocation. Arrows in opposite direction indicate the direction of monitoring of users' extraction behaviors.

Source: Wang et al. 2013.

1.3.2 The Shanxi "water saving society"

In Shanxi province, south-west of Beijing, overdraft has been tackled by defining annual quotas for all well users in the Qingxu county (a total of 1,473 wells are concerned) (The Water Channel 2012; Guisheng et al. 2013; Li He 2011). The wells are operated by farmers through a 'smart system' using swipe cards to activate water pumps (ibid.). The quota is centrally determined for each of the 197 villages and then for each farmer within each village. As reported, the quota depends on existing groundwater resources and household quotas are based on the surface of land owned, number of family members and livestock (ibid.). Likewise quotas are determined for 379 small industries and 59 larger companies. The cards are prepaid and therefore cost recovery is hundred percent.

The price of the service is fixed (paying for electricity) if abstraction remains within the allocated volume per household. If users exceed their quotas, prices rise (ibid.). If farmers exceed their quota by less than 30 percent, the price for this block is 50 percent higher. The price is doubled for an excess between 30 percent and 50 percent, and tripled over 50 percent. The prices charged, however, are not sufficient to allow for full coverage of operation, long-term maintenance and deepening of the well. A complement is paid by the village budget (Li He 2011). Yet, because the cost of water corresponds to 15-25 percent of the net benefice of wheat and corn, it is believed that water prices are high enough to encourage farmers to save water (Guisheng et al. 2013).

These volume quotas can also be traded and a maximum threshold for prices has been fixed at twice the official price. It has been observed that farmers share rather than trade their 'excess of water' not used with other family members and neighbors. All swipe card operations are registered at the Digital Water Resource Information Centre in the county Water Resources Bureau. The fact that swipe cards are individual allows farmers to use different wells (ibid.). Another advantage of the quota system is that farmers may abstract the unused water in the coming years (the preference given to the security option also lessens trade transactions).

With this new system, an increase in groundwater levels has been observed, by up to 4.8 meters and a reduction of abstracted volume (from 59 Mm³ in 2004 to 30 Mm³ in 2010 at the county level) (ibid.). But it is hard to ascribe reductions in abstraction to a particular measure, since the policy implemented also included adoption of micro-irrigation, better field preparation, plastic mulching and greenhouses, adoption of drought-tolerant cultivars and crops (Li He 2011). Similarly, improvements in efficiency have been achieved in the industrial and domestic sectors.

Shanxi province is now considering expanding the experience of Qingxu district to the whole province. This would include a four-tiered process of quota allocation, where available surface and groundwater would be first allocated to the different sectors, then to the regions, the villagers, and finally to individuals. Further improvements in agricultural and irrigation techniques are expected to be combined with supply side-measures, including storage of rain and flood water, and water harvesting.

It is not clear however if improvements in irrigation efficiency will deliver the expected benefits in terms of reduction in net groundwater abstraction. A study on Luancheng County, in

neighboring Hebei province (Kendy et al. 2003), has emphasized that evapotranspiration is what needs to be reduced (what is indeed partly done through plastic mulching and all other on-farm techniques) and not abstraction per se, since return flows go back to the aquifer, even if this has other benefits such as savings in energy costs.

1.3.3 Local management of groundwater in Minqin County, North-Central China

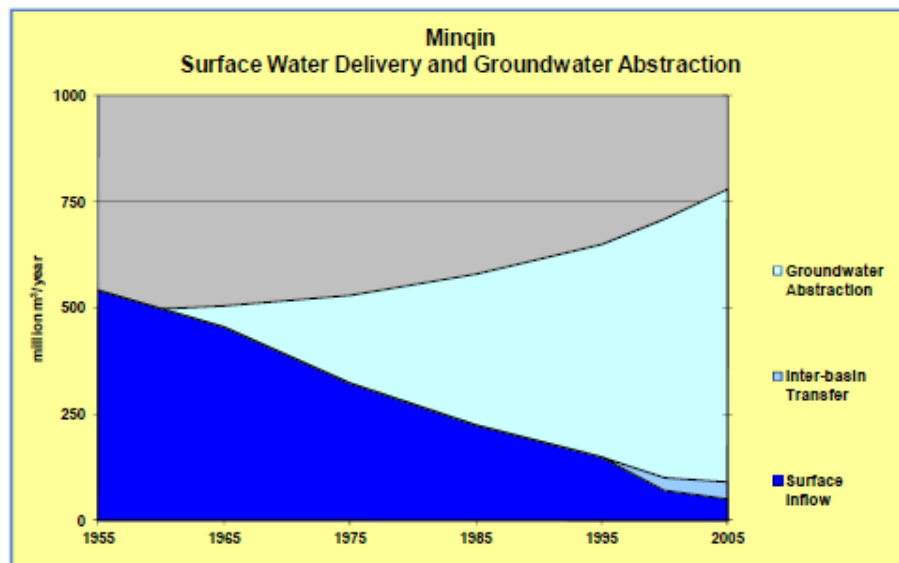
While groundwater over-abstraction has been recognized and tackled since the late 1980s in North Central China, a policy and management reform process was launched in 2007 in the province, in light of severe water scarcity issues and advancing desertification.⁶ This reform included the plan to reduce groundwater abstraction from 500 Mm³ to 90 Mm³ by 2010 by establishing water distribution based on quotas per capita, closure of wells, control of groundwater pumping, and groundwater pricing (ibid.). 254 Groundwater User Associations were also created between 2006 and 2007, forming a new (and the smallest) layer of water management in the province (Aarnoudse 2010).

In the Minqin County in North-central China, even though local authorities said that these water user associations would be created to fulfill new national water policies to promote the re-engagement of users in water management, the associations were identified by the county government as the tool to implement well closure and restrict per capita water use, and provided an additional means of control of water users by the government (Aarnoudse 2010; Aarnoudse et al. 2012). The board of the new Water User Association mimicked the pre-existing village committee and established and developed new alliances between the association and the regional Water Resources Bureau via the retribution of its board members. This way, the Bureau aimed at influencing local institutions via overlaying pre-existing community institutions with a new structure (ibid.). Thus, after 2007 a new link between central government and local water management appeared in the form of these water user associations.

The control and closing of wells was established by the Irrigation District Department by setting limits on the number of wells allowed per village depending on the number of inhabitants (Aarnoudse 2010). The state through the prefecture would compensate well owners but it would be the User Association of each village who would decide what wells were to be closed. In case of communal wells closed, the money would be transferred to the community. The use of smart systems to control groundwater was also implemented in some villages. In these cases, water meters and smart machines were installed and users would activate the well by swiping a pre-paid card. Each well has a card and the community leader is its keeper (in some cases the card is left in the pumping house after use). Access to groundwater is also controlled by restricting access to electricity in some villages as farmers were allocated a certain amount of kW per person per year (60 in 2010) (ibid.).

⁶ An additional driver of this policy change was the intervention of the Chinese Premier Wen Jiabao who expressed concern over the rapidly deteriorating situation of the region, the advance of desertification and the potential environmental threat. If Minqin disappears, the two surrounding deserts would merge, with the potential to create large sandstorms in the East of China (Aarnoudse 2010).

Figure 6. Historical changes in water supply in Minqin oasis



Source: COWI 2013a.

1.4 Groundwater markets in China

Zhang et al. (2008) found that groundwater markets are pervasive in rural northern China with the privatization of tubewells as examined by Wang et al. (2006) leading to instances of groundwater marketization and allocation of services. Since 1990, collective ownership by communities has largely been replaced by private ownership, driven by water scarcity, government grants and bank loans, as well as the declining investment capacity of China's local communities to maintain and invest in these community structures. As mentioned above, the organization surrounding groundwater pumping has evolved over the past few decades from a state-run system to either a community or privatized system after the 1980s.

These markets in north-east China are localized and mostly unregulated. Payments for water are mostly done in cash. Transactions between water selling and water buying networks are done without any type of legal structure or government control, due to the fact that they are very localized (within the village) (Zhang et al. 2010). No contracts are written between buyers and sellers, and their oral commitments cannot be adjudicated in a court of law (Wang et al. 2014). Wherever there is regulation (in fewer than 25 percent of sampled villages in their study in the North China Plain) these regulations are seldom enforced). Payments are enforced through social codes (buyers and sellers are usually living in the same village). These transactions are also limited for the most part to farmers living in the same village and water is paid in cash (ibid.).

According to research by Zhang et al. (2010), prices are fixed and without variation according to the type of buyer or according to the wealth of the villages (the development of groundwater markets was found to be more or less the same in both rich and poor villages) (ibid.). In their study cases, Zhang et al. (2010) also found that farmers who buy groundwater from private tubewell owners use less water for wheat than private tubewell owners. One explanation for this is that farmers who buy groundwater through markets have greater incentive to reduce crop water use because they pay more for water. Tubewell owners use more water, because the cost per unit for them is smaller.

These markets according to Zhang et al. (2008) have also provided access to groundwater for poor farmers and reduced potential income gaps. However, differences between buyers and sellers reflect income disparities between tubewell owners and groundwater buyers (e.g. the per capita income from cropping of water-buying households is only 61 percent of that of water selling households). The researchers also hint at the fact that, despite the lack of formal regulation of these markets, the government still retains a role in groundwater markets. The results of Zhang et al. (2008) research show that when the government grants easier access to capital for individuals (e.g. to sink tubewells) and establishes less stringent local regulations, groundwater market activities increase.

In the area in North China studied by Zhang et al. (2010), the spread of groundwater markets reached 23 percent of the villages in the North China Plain in 2004. In the rest, 47 percent of households obtained groundwater for irrigation from collective tubewells and 30 percent from private wells (ibid.). Divisions in socio-economic characteristics of studied communities are also found when studying groundwater exchanges (irrigation service markets have a negative impact on buyers' incomes as in general their cropping income is 61 percent that of tubewell owners) (ibid.). However, researchers found no important impact of irrigation service markets on income. According to this research, this is due to the fact that farmers use less water when purchased and at the same time yields do not diminish dramatically. Nevertheless, differences in yields can be relevant at the individual household level as yields decrease 1 percent compared to farmers with private wells and 8 percent compared to farmers accessing collective wells (ibid.).

2 Pakistan

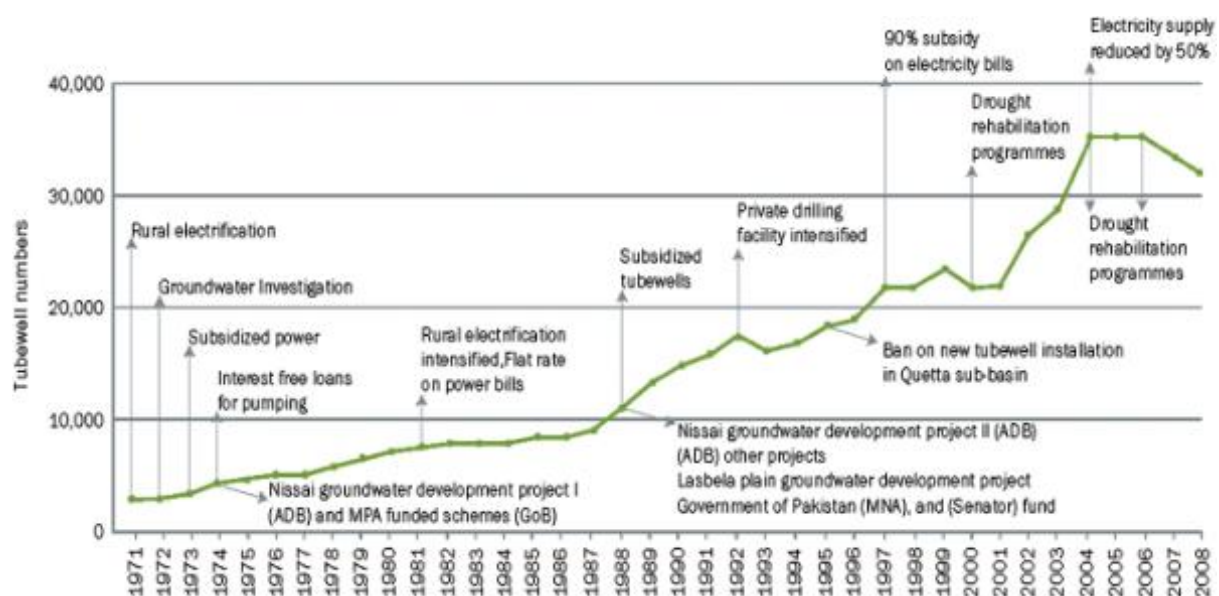
2.1 Groundwater development in Pakistan

In Pakistan groundwater is first and foremost a very important supplement to (less expensive) surface water and makes for the shortfalls of canal irrigation. As Qureshi et al. (2010) found out, the average cost of surface water per hectare per year is USD5.5 against USD167 for groundwater. Groundwater allows farmers to cultivate the bulk of their land plots (90 percent against 63 percent only using surface water) and allows them to grow high water-demanding crops such as sugarcane and rice. Higher crop yields also result in increasing household incomes due to the high market price of these crops (ibid.). The modernization of groundwater abstraction technology in the 1960s with the launching of the Salinity Control and Reclamation Projects saw the installation of 16,700 wells (for an area of 2.6 million hectares) discharging groundwater into the surface water canals (Qureshi et al. 2010). The demonstration of these projects saw the explosive development of tubewells fueled by electricity subsidies and locally made diesel engines (ibid.). The security and flexibility of supply provided by groundwater offered a value addition to farmers over dryland farming or unreliable canal water (Qureshi 2015). This led to the development of 1.2 million private tubewells in Pakistan, of which 0.8 million are found in Punjab province alone (ibid.). Irrigation in Punjab increased from 8.65 million hectares in 1960 to 14.7 million in 2014, with groundwater contributing over 60 percent of all irrigation needs (having increased from only 8 percent in 1960) (ibid.). Over the years, the intensive development of groundwater in Pakistan has had repercussions on the resource itself, with depleting aquifers due to overdraft. Groundwater is now inaccessible in 5 percent of the irrigated areas in Punjab and 15 percent of the areas in Baluchistan (Qureshi 2015).

In Pakistan, groundwater development programs were used by the state as a 'political tool' to obtain the support of the population (Kazmi et al. 2012). The national government, under

pressure to reduce rural poverty and increase food security (due to drought threats), found it easy to allow groundwater abstraction rather than making large investments in surface irrigation projects (Kazmi et al. 2012; Khair et al. 2015; Qureshi 2015). Regulation of groundwater abstractions and controls remained 'soft', given the heavy dependence of farmers on groundwater to meet crop water requirements and to ensure their livelihoods (Kazmi et al. 2012; Khair et al. 2015). The state also facilitated groundwater abstraction via the implementation of public borehole, electrification and tubewell programs (Figure 7). Public tubewell drilling programs started in Pakistan in the 1950s and 1960s as a measure to control high groundwater tables in the Indus Basin, and water logging and soil salinization resulting from shallow groundwater evaporation (Van Steenberg and Oliemans 2002). However, in 30 years this trend was reversed with the spectacular increase in private tubewell numbers in the Indus plains, shifting from a situation where high groundwater tables were a major threat to one where low groundwater levels now pose a major threat to the sustainability of agriculture in the region (ibid.).

Figure 7. Tubewell adoption in Baluchistan, Pakistan



Source: Khair et al. 2015.

The development of large surface water infrastructure (the Mangla and Tarbela reservoirs) in the Indus Basin served to improve water supply for agriculture in the upper areas, contributing towards groundwater recharge used to supplement crop water requirements in Punjab (Van Steenberg et al. 2015). Additionally, as public funds for major investments in surface water and irrigation declined sharply, the development of groundwater-fed irrigation increased allowing the expansion of agriculture to continue (Qureshi et al. 2010). This shift was also driven by government policy aiming to transfer groundwater development from the public sector to private users and save huge spending on the operation and maintenance of public tubewells (Iftikhar et al. 2011). However, given the existing management of the Indus based on historic allocations, waterlogging still persists in 1.5 to 3.5 million hectares in the Lower Indus Basin in Pakistan, where groundwater-fed irrigation is very modest (accounting for 4 to 8 percent of surface water use compared to 50-50 percent in areas of Punjab) (Van Steenberg et al. 2015).

The quick development of tubewells in Punjab for instance also represented a democratization

of groundwater access according to Van Steenberg and Oliemans (2002). Smaller farmers were able to purchase their own tubewells, either individually or by pooling resources with other farmers. In this way they were able to decrease their dependence on water purchased from other farmers owning tubewells. Additionally, for those who were not able to build their own tubewell, the situation also improved as more water providers appeared with the increase in tubewell numbers (Van Steenberg and Oliemans 2002). Groundwater abstraction and development was promoted through subsidies power supply (40 percent less than normal electricity rates in Punjab and 60 percent in Baluchistan) and through the provision of free pump sets and wells along with soft loans (ibid.).

2.2 Groundwater markets in Pakistan

In certain areas of Pakistan groundwater users have engaged in the exchange of services for irrigation using groundwater. These markets can be organized around the exchange of irrigation services (e.g. the renting of pumps by farmers) or the selling-buying of groundwater to supplement irrigation water (Qureshi et al. 2003). In the first extensive and comprehensive study of groundwater markets in Punjab, Meinzen-Dick (1996) found out that large landowners are more likely to own tubewells and pumps and that smaller landowners and tenants are more likely to rely on purchases from other farmers' tubewells for accessing groundwater. The distance over which water can be transported provides a limit to groundwater market sales, but lined watercourses increase the distance over which tubewell water can be sold.

Since the study by Meinzen-Dick (1996), groundwater markets have continued to grow and are found across all four provinces in Pakistan (Khair et al. 2012; Qureshi et al. 2003). In Baluchistan, these markets are not new and research on informal groundwater markets by Khair et al. (2012) showed how tubewell owners with water in excess of their own irrigation needs, dominated the sellers' market portion (with 89.3 percent of total sales). These tubewell owners would usually sell their surplus water for cash and/or crop share. Water rates are determined through negotiation and the price depends on the tubewell discharge flow (measured according to the size of the delivery pipe) (ibid.). On the side of the buyers, Khair et al. (2012) found for different categories: 1) landless tenants undertaking crop cultivation and obtaining a negotiated share of the crop in return for their management and labour inputs. This first category would buy approximately 60 percent of the water; 2) tubewell owners with dry wells; 3) neighboring farmers; and 4) relatives or farmers with some sort of association with tubewell owners. These three latter categories make up the other 40 percent of groundwater buyers (ibid.).

In these informal groundwater markets, payment methods can be established as a flat rate payment (defined as an hourly rate for the use of the pump), increasing as the exchanges occur at higher altitude as a response to the relative scarcity of water and smaller farm size. This method of payment in Baluchistan was the preferred method in high altitude areas, representing 63.5 percent of all transactions according to Khair et al. (ibid.) research. Payments in kind (as a share of the crop output) were more common in lowland areas due to a relative abundance of water and larger farm size (89.2 percent of all transaction in lowland areas) (Khair et al. 2012). These markets have emerged as a feasible option to manage increasing water scarcity on a temporary basis. These markets provide a cushion against declining water tables by reducing the risk of losing high value horticultural crops and enhancing water use efficiency (as the sale of surplus irrigation water allows the reallocation of the resource) (ibid.). Prices have remained relatively stable over time as a result of subsidized electricity ensuring low pumping costs. Relationships of kin and social associations (neighboring farmers) are influential in water sales.

Another study of groundwater markets in Punjab by Jacoby et al. (2001) showed inefficiencies in the market as they appear to deviate considerably from the competitive ideal, due to its high fragmentation (transformation and information costs) and entry barriers, due to the interaction of credit constraints or lack of availability and indivisibilities in investment in equipment. Under these conditions, these authors find the widespread presence of local monopoly groundwater exchange systems with potentially large efficiency and distributional implications (ibid.).

Groundwater markets in Pakistan, according to Jacoby et al. (2001), are also characterized by entry barriers and spatial fragmentation. The need to own land above an aquifer before boring a well, and high installation costs are important barriers for farmers. This limits the ownership of tubewells to (wealthy) landowners. Losses due to heavy seepage arise from groundwater conveyance via unlined field channels also restrict water delivery, and the competitiveness of some water sellers, adding difficulties and externalities to the transportation of water once it has been exchanged. Due to these losses, farmers have limited choices from where to purchase groundwater (usually confined to the command area of a tertiary canal), with each of the pumps participating in the exchanges having a defined area that it can feasibly service (Ui Hassan et al. 2008). The market established around a pump becomes a natural monopoly with usually a single water seller and several competing water buyers. Pump owners usually also form cartels to set the water price which then ensures a reasonable benefit margin above operational costs

Additionally for Jacoby et al. (ibid.), groundwater markets and tenancy contracts are interlinked causing price discrimination and distortions towards buyers who are not the share-tenants of a monopolistic tubewell owner. The exchange of water tends to be between a monopolistic tubewell owner selling groundwater to both his own share tenants and other cultivators. Research shows that tubewell owners charge a lower price to his own tenants for the reason that he shares their output. Due to the fact that irrigation water is a production input for tubewell owners as well as for their tenants, these users utilize considerably more water on their plots in order to compensate for the deadweight loss and transfer the surplus gain from buyers to sellers (Jacoby et al. 2001).

Meinzen-Dick (1996) in her study highlighted the fact that markets were already improving agriculture's productivity (especially for small and medium farmers). However, more general policies expanding tubewell ownership are more likely to provide greater welfare gains and higher returns than those encouraging groundwater trading from wells owned by a limited number of farmers. The match between profitability and gross benefit margins for a few tubewell owners and the total groundwater available for recharge to aquifers, raised concerns about the limited number of tubewells that can be operated sustainably. Thus other strategies to improve access equity to groundwater are also needed (e.g. more efficient conveyance structures, lower capacity tubewells, shared tubewell ownership).

In terms of improving groundwater allocation efficiency in these markets in the areas studied in Pakistan, Meinzen-Dick (1996) has suggested that joint tubewell ownership might be a solution to compensate for the lack of access to technology and ownership of wells for small landowning farmers. These small farmers who cannot afford to cover the full investment costs for a tubewell, can however invest in one jointly with neighbors. These joint tubewell schemes give a stronger right to groundwater to smaller farmers whilst ownership of groundwater resources is shared more equitably. Social transaction costs for this type of solution are high as farmers must negotiate with each other when purchasing the tubewell and deciding where to locate it, establishing maintenance responsibilities, expenses, etc. Although these transaction costs might be higher, Meinzen-Dick considered that the organization of shared tubewell ownership may be

considered as a social capital investment. As argued by Coward (1986 in Meinzen-Dick 1996), the creation of shared ownership in irrigation forms the basis for relationships amongst irrigators and can become the social basis for collective action.

3 Nepal: Groundwater management and the role of the state⁷

In Kathmandu Valley, Nepal, over-abstraction has caused the depletion of aquifer levels and the change in perception about the fact that groundwater is no longer an 'infinite resource'. This has altered the concept of groundwater management, changing from an 'open-access' resource to a 'state-controlled' resource (Pandey and Kazama 2014). The state is increasingly becoming 'resource custodian' by reforming groundwater management agencies, developing tougher regulation on abstractions, and providing scientific knowledge and information towards a more sustainable groundwater management (Pandey and Kazama 2014).

During the dry season, 70 percent of the drinking water supply for the city of Kathmandu relies on groundwater. Traditionally, inhabitants of the valley relied on shallow groundwater abstraction but since the 1970s mechanized abstraction of deep groundwater reserves sustained the urban development of the area leading to an escalation in abstraction. This caused the lowering of the water table (between 0.37 meters and 7.5 meters), a decrease in well yields, and the drying out of traditional shallow wells (Pandey and Kazama 2014).

In Nepal, groundwater was considered an open-resource until 2006 although its ownership was vested in the state through the Water Resources Act (1992). The supply of groundwater by the city's public utility could not cope with the steady increase in demand, creating a supply gap filled by wells developed privately, sourcing water from hill springs and tubewells, and now supplying more water than the public operator (Kansakar 2011). Informal markets appeared, with users buying and selling groundwater without defining water rights nor legal sanctions (Pandey and Kazama 2014). Overexploitation of groundwater has caused a typical situation whereby the water table has dropped below the well depth and pumping capacity of small-size households. The race to the bottom that ensued is clearly affecting the poorer segments of society, who cannot afford to sink deeper tubewells and are eventually excluded. Urban groundwater development in the recharge area of the Valley in the North, has also affected public wells sourcing water from deep aquifers. As emphasized by Kansakar (2011), "since there is no legal requirement of obtaining permission before sinking a new well, and since no law exists to control location, depth or volume of groundwater extraction, groundwater is in practice an unregulated resource. Groundwater in Kathmandu valley is an ideal case of unregulated open access common pool resource which is already at risk."

The water resources act of 1992 vests "the ownership of the water resources available in the Kingdom of Nepal (...)", with water rights confined to the "right to utilized water resources". Customary prior use rights are recognized. Licenses for utilizing any water resource are mandatory, but exemptions extend to individual or collective use for drinking and domestic supply as well as irrigation, which means that a fair share of water use escapes registration. A large proportion of wells are not licensed, and even when they are, there is no mechanism to monitor and control the volumes extracted (Kansakar 2011). Although it is mandatory for industrial users to register their well, the Industrial Enterprises Act, 2049 BS (1992 AD) includes

⁷ Source: Pandey and Kazama (2014) except when referenced otherwise.

a contradictory provision, according to which it is the obligation of the Government to make "available infrastructural services such as [...] water [...] required for the industries". Failing that, industries which have developed water supply infrastructure at their own cost cannot be forced into licensing. This situation of over-abstraction has however prompted several activities by the state and non-governmental organizations aiming at improving the sustainable utilization of groundwater and its protection. Informal initiatives consisted of advocacy campaigns (with expert meetings, media campaigns, and legal action) as well as sustained research by advocacy groups on the groundwater abstraction situation in the valley. A law suit was also filed by Pro Public, an advocacy coalition, demanding the implementation of the law requiring permits for industrial and commercial groundwater abstraction. The Supreme Court ruled in 2010 in favor and ordered government agencies to follow the provisions of the Water Resources Act of 1992 and enforce the licensing system and control illegal abstractions (Kansakar 2011).

Wells have also developed in the Terai plain, with estimates of 87,117 shallow tubewells and 863 deep tubewell irrigation systems installed during the 3 decades prior to 2011 by the government, to which at least 21,000 private shallow tube wells must be added (Kansakar 2011; Kansakar et al. 2009). Total extraction is estimated at around 1 Bm³, i.e. around 12 percent of the estimated recharge. This situation explains why the government is still expanding shallow and deep tubewells for irrigation in this region.

In 2004 the renamed Groundwater Resources Development Board put forward a new groundwater bill and sent it to Parliament. This bill contemplated the integration of all groundwater capacities and management found in different agencies and departments, under a unique authority in charge of data collection, planning, regulation, monitoring, research and management. In 2006, the Kathmandu Valley Water Supply Management Board was created as a result, putting forward a groundwater management and regulation policy which came into effect in 2012. From 2009 onwards, this new organization focused on locating groundwater users, issuing licenses, and identifying wells for monitoring. Regulatory measures included banning abstractions without license for wells deeper than 100 m and as of December 2011, 206 licenses had been issued out of 700-plus deep wells in the valley. The Board has also carried out inspections of various companies and hotels and issued fines for illegal use. It also started monitoring groundwater quality in 41 wells across the valley. Currently however, in the Kathmandu Valley, even though there are agencies involved in groundwater monitoring and research and a level of understanding of the increasing depletion of the resource, groundwater continues to be abstracted through new infrastructure. Lack of data and information on groundwater abstraction levels for each main sector is also lacking, and there is no information on the number of existing tubewells operated by the public and private sector.

4 Bangladesh and the Barind Multipurpose Development Authority⁸

In North-West Bangladesh, the Barind Multipurpose Development Authority (BMDA) was created in the 1992 by the government (Figure 9). The BMDA originates from a project set up by the Bangladesh Agricultural Development Corporation (BADC) which had the authority for the development of irrigation in the country. Due to a lack of favorable geological conditions leading to poor investment, Barind had fallen behind the national average of irrigation coverage (17

⁸ Source (unless stated otherwise): www.bmda.gov.bd; Zaman 2015; Zaman 2015a, pers. com.; Zaman 2015b, pers. com.; Zaman and Rushton 2006.

percent versus 45 percent as the national average). In view of the demands of local representatives to extend irrigation in Barind, a project was devised to develop and improve irrigation services and infrastructure in the area. In 1985, the Barind Integrated Area Development Project was approved, executed by the BADC but with the possibility to create a separate entity in a specific area for 'smooth implementation of the project'.

Between the initialization of the project in 1985 and the creation of the BMDA in 1992, the project was fraught with difficulties, having only used 26 percent of its budget due to lack of delivery of infrastructure, loss of technically trained staff, financial difficulties for payments and staff. With the creation of the BMDA, the objective was to reinstate trust in the Authority. The new organization targeted the Authority's finances, searching financial independence and sustainability. The Authority was organized with a board, with the main goal to have project and financial independence, running with its own revenue alone. The board is set up as a harmonized public and private partnership between elected officials (members of parliament), a government-appointed chairman, and 3 farmer representatives. The board also includes the Deputy Inspector General of Police and the Deputy Commissioners of all original five districts covered by the Authority. Earnings from the Authority must cover O&M costs, salary and wages, and additional benefits for employees. The largest cost in the budget is electricity for the wells and low-lift pumps also operated by the BMDA. The BMDA was created as an autonomous authority under the Ministry of Agriculture, receiving funds directly from the Ministry of Finance and the Ministry of Planning. The BMDA is however self-financed, covering 90 percent of its costs from the irrigation charges, and the rest from the sale proceeds of trees and fruits, bank interests and other miscellanea.

The BMDA is in charge of tubewells providing groundwater for irrigation and drinking water (15,054 deep tubewells in 2014) for 292,000 hectares of irrigated land (in 2014-2015) (Figure 10). Its development priorities include the expansion of irrigation with the use of tubewells, implementing command area development projects, extending the electricity network, re-excavating fishing ponds, afforestation, and crops diversification. It is also engaged with quality seed production, hydrogeological management of groundwater, rainwater collection, and water conservation. Water is provided when users need it and through self-collection before irrigation water supply. BMDA engineers discuss with potential users or farmer representatives the number of wells needed in an area and their location. They revise the application and submit it to the Executive Engineers of the BMDA for approval. In order to obtain a well, farmers will prepare an irrigation scheme map and will submit an application and pay up-front between BDT20,000 (around USD250) and BDT100,000 (USD1,250) for the well. The price depends on the characteristics of the site. Farmers concerned in the command area will have to form a beneficiaries group. Wells have to respect a distance of 2,500 feet between them established by the government. BMDA wells normally discharge between 0.75 and 3 m³ per second. The expected command area for 1 m³ per second of groundwater is 40 acres. Groundwater is conveyed to the plot via underground PVC pipes. The durability of surface water canals and the loss of land by small farmers to convey water were arguments for the installation of these underground pipes (which have to be paid up-front too).

The Authority has worked on evolving the system of irrigation fees. The system evolved from a conventional system with irrigation charges between 1985 to 1992 to a coupon-based irrigation charging system between 1992 and 2004 and, finally, to pre-paid meters, mobile vending units, and irrigation smart cards. The BMDA has a target to reach 82,000 smart cards (in November 2014 it had issued 29,611) (Table 1). The smart card is preloaded by paying cash at one of the BMDA offices or authorized dealers (so far there are 76 mobile vending units and 16 card

readers in the BMDA jurisdiction area). Official sellers are connected remotely to the BMDA. The conventional irrigation fee system worked with incentives, giving farmers who paid before January 31st a 20 percent rebate and those who paid before February 15th a 10 percent rebate. Late payments had penalties of 15 percent from February 16th onwards. The coupon-based system worked with coupon dealers getting 5 percent commission for each sale of coupon. Pre-paid meters are preferred by users as they reduce cash transactions. The pre-paid meter system also offers transparency with checks and balances to counter fraud, water cannot be delivered free of charge by pump operators under coercion from users and there is no opportunity to bypass the meter. This financial arrangement has represented improvement in repairs of pumps and wells and the provision of technical support to farmers. The expansion of the electricity supply network reduces pumping costs due to the government subsidy.

Each well has a pump operator hired by the BMDA. Operators are from the community where the well is located. Farmers can complain to the BMDA if there are any problems but cannot fire the operator. At the well level the BMDA can resolve conflicts among water users, and coordinate among other agencies (e.g. Agricultural Extension Department, Power Development Board). The BMDA will also encourage farmers in areas suffering from water stress during the dry months, to switch to less water-intensive crops (e.g. potatoes, wheat). The BMDA will also check if there is any corruption existing at the pump-house level (by conducting regular inspections). Repair and maintenance of the wells is done by the BMDA. Since wells are electric repair costs are reasonable (the BMDA employs one electrician/mechanic for 100 wells).

This financial ease has also allowed the Authority to improve its technology, and upscale its interventions. Given the specific geology of the Rajshahi Barind area, conventional wells cannot deliver the discharge needed for irrigation. The Rajshahi Barind area is considered with a low groundwater potential, consisting of old alluvial deposits, thick clay deposits, indicating that the main aquifer is not found within the first 300 meters. Traditional wells fail to produce high enough yields as the lowest permeable zone is less than 30 meters below the pumping water level. Innovative forms of well construction (inverted wells) with deeper pumps aimed to increase borehole yields (Figure 8). The solid casing was extended deeper than conventional wells for this type of areas, allowing the pump to reach deeper into the permeable zone. A system of screens was devised, projecting upwards and alongside the casing in order to increase the abstraction capacity of the well. These wells are however more expensive (due to their larger diameter and additional use of material such as screen length).

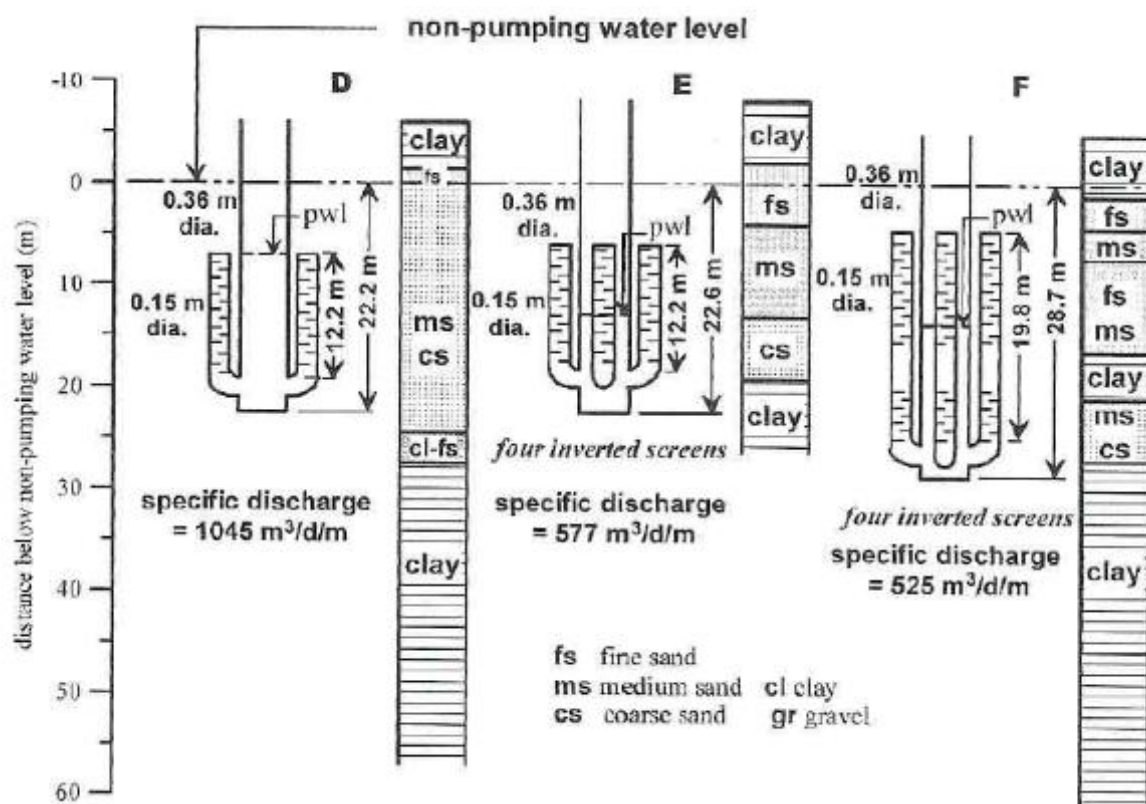
The latest technology innovation with smart cards and pre-paid meters has enabled farmers to 'pay as they use', supplying water on demand on an hourly basis. This has reduced corruption and facilitated well-operations for illiterate farmers. Irrigated area increased 30 percent after installation of pre-paid meters from 30 to 39 hectares in a case study site investigated by Zaman (2015), as well as the number of beneficiaries (from 70 to 89). Irrigation charges increased (12 percent) but the annual electricity bill decreased on average 9 percent. This represented decreases in irrigation costs per hectare (51 percent improvement) and a decrease of average water use (28 percent less), increasing yields (34 percent higher), and 43 percent higher average earnings per hectare (ibid.). Water savings represent 40 percent since the introduction of the pre-paid meter and smart card system.

The improvement in access to irrigation and technology has led to higher yields as seen above. Irrigation costs are for all three types of land ownership (owner, leased, and in shared cropping with shared input cost) kept at under 10 percent of total production costs for all crops (Table 2). Highest water costs are found for cereal and oil-seed crops. Despite increased efficiency the

increase in agriculture production has caused the decrease in groundwater levels, with farmers suffering from rising costs to lift groundwater (Figure 11 and Figure 12) (Adhikary et al. 2013; Aziz et al. 2015; GBK and VSO 2012; Rahman and Mahbub 2012). The introduction of boro rice in the dry season and high-yielding crops with the advent of groundwater-fed irrigation allows for 3 harvests in one year. This reduction in groundwater levels meant that medium-depth wells (200 to 250 feet) fitted with pumps known as Tara pumps, cannot lift the water during the dry season and farmers have to resort to deep tubewells (Mbugua 2011).

Long-term groundwater abstraction also reduced or even suppressed seasonal groundwater fluctuation and potential recharge (Shamsudduha et al. 2011). Recharge is already naturally reduced in the Barind Tract as it does not receive flooding from the Ganges due to its higher elevation and also over the period 2000-2010s due to reduced rainfall (Aziz et al. 2015). Monitoring wells in the Barind tract studied by Shamsudduha et al. (2011) showed abrupt changes in the level of thickness of the shallow upper silt and clay units in the mean water-table depth after the 1990s (where it was for most of that decade above the clay layer). Groundwater reserves have been reduced and in particular areas such as in Tanore Upazila district (Unit 1), aquifer levels studied in selected monitoring wells have decreased by 1.15 to 1.54 feet per year on average between 1983 and 2010 (during the wet season) (Rahman and Mahbub 2012). Within the command area of the BMDA, there are around 1,689 km² (around 5 percent of the total surface) under water stress both from existing groundwater well abstraction depending on the intensity of the monsoon and during the dry months on the preference of farmers to plant paddy.

Figure 8. Schematics of inverted wells drilled in the Barind area



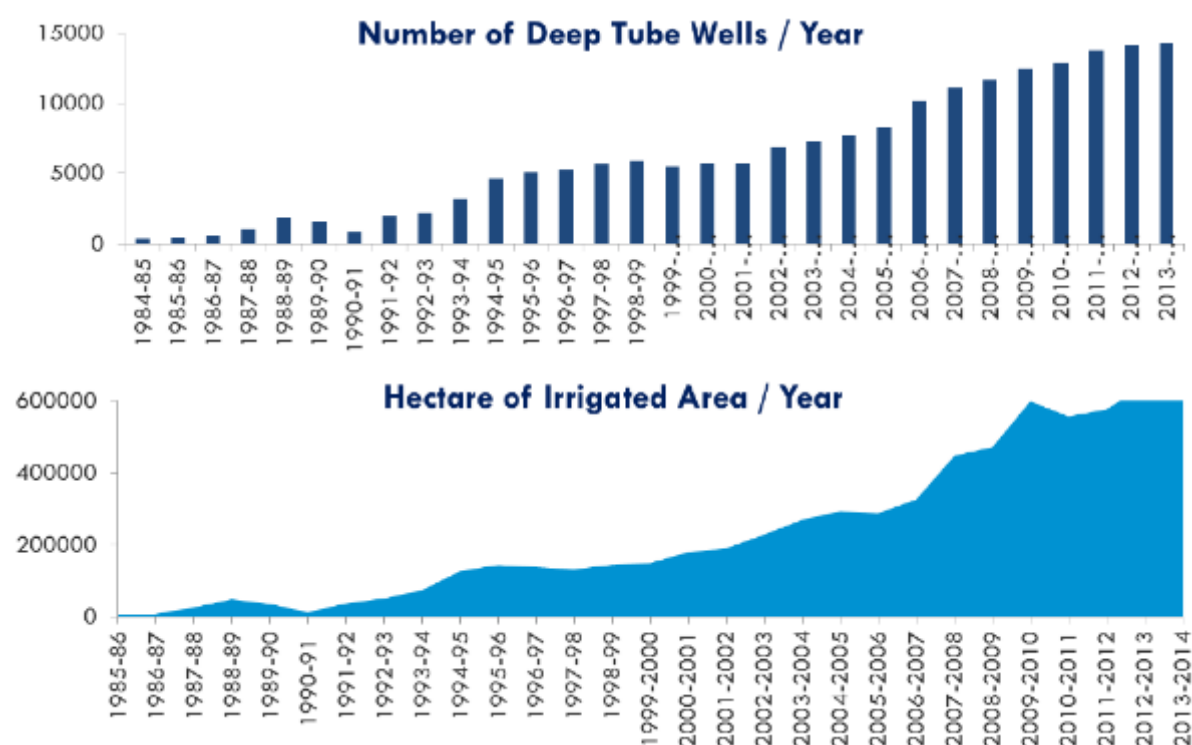
Source: Zaman and Rushton 2006.

Figure 9. Jurisdiction area of the BMDA



Source: www.bmda.gov.bd

Figure 10. Number of tubewells and accumulated irrigated hectares, BMDA



Source: Zaman 2015.

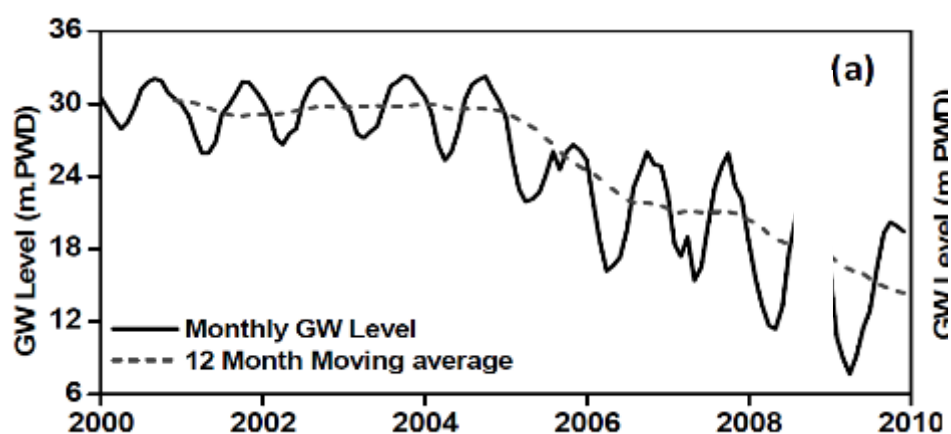
Table 1. BMDA smart card system and components

Components	DPP Target	Achievement up to November 2014	For the year 2014-2015			Cumulative Expenditure* (% of PP Allocation)
			ADP Allocation*	Fund Released*	Expenditure*	
1) Smart Card(Nos.)	82000	29611	1000.00	500.00	313.91 (31.39%)	713.04 (37.36%)
2) Repeating Tools (Set)	9	3				
3) Large Capability Card (Nos.)	110	45				
4) Card Reader (Nos.)	34	16				
5) Mobile Vending Unit (Nos.)	160	76				
6) Card printer with ribbon (Nos.)	34	16				
7) Computer (Nos.)	50	22				
8) Pre-paid pump usages & energy measuring unit with installation (Nos.)	3900	1615				
9) Pre-paid pump usages & energy measuring unit with Telemetry with installation (Nos.)	200	-				
10) Mechanical circuit breaker (Nos.)	4100	1554				

*(Tk. in lakh)

Source: www.bmda.gov.bd

Figure 11. Annual fluctuations for a monitoring well in Naogaon District, Barind Tract



Source: Adhikary et al. 2013.

Figure 12. Water level hydrograph and deep tubewell development in Tanore Upazila, Rajshahi District



Source: Rahman and Mahbub 2012.

Table 2. Production costs of crops in the Barind Project Area (average values, in USD)

Production costs for crops					
Owned land					
	Water cost	% water cost/total costs	Total cost (per ha)	Gross Return	Net return per ha.
Cereals (a)	62	8	753	1,520	767
Pulses (b)	0	0	337	994	657
Root crops (c)	39	1	2,703	5,017	2,315
Oil seeds (d)	29	8	379	1,158	779
Vegetables (e)	51	4	1,151	3,303	2,152
Spices (f)	77	4	2,065	5,661	3,596
Fruits (g)	101	4	2,672	5,403	2,731
Cash Crop (h)	241	2	10,550	16,081	5,531
Leased land					
Cereals (a)	62	6	1,018	1,520	502
Pulses (b)	0	0	530	994	464
Root crops (c)	39	1	3,474	5,017	1,543
Oil seeds (d)	29	5	572	1,158	586
Vegetables (e)	51	4	1,418	3,303	1,885
Spices (f)	77	3	2,354	5,660	3,306
Fruits (g)	101	3	3,347	5,403	2,055
Cash Crop (h)	241	2	11,321	16,081	4,759
Shared cropping					
Cereals (a)	62	10	601	760	159
Pulses (b)	0	0	279	497	218
Root crops (c)	39	2	1,670	2,509	838
Oil seeds (d)	29	10	302	579	277
Vegetables (e)	51	6	876	1,651	775
Spices (f)	77	6	1,391	2,830	1,439
Fruits (g)	101	5	2,163	3,859	1,696
Cash Crop (h)	241	4	6,449	8,041	1,591

Note: values for each crop type are averages. Each crop type includes:(a) Aus paddy (HYV), Aus paddy (Local), Planted Amon (HYV), Maize (Kharif), Boro (hybrid), Boro (HYV), Wheat (irrigated), Maize (Rabi); (b) Lentil, Chickpea; (c) Potato; (d) Mustard (HYV), Mustard (local); (e) Bean, Red Amaranth, Bottle-guard, Radish, Cauliflower, Cabbage, Yard Long Bean, Brinjal, Tomato (Rabi), Cucumber, Pointed Gourd, Ladies Finger, Pumpkin; (f) Chile, Onion, Garlic; (g) Banana, Papaya; (h) Betel-Leaf.

Source: Zaman 2015b, pers. com.

5 Japan

Japan's use of groundwater (around 11 billion m³/year) is largely devoted to industry (48 percent), with lower shares for domestic use (29 percent) and irrigation (23 percent) (Margat and van der Gun 2013), and only amounts to around 14 percent of water withdrawals (Sakura et al. 2003). The use of groundwater is valued in many activities because of its qualities in terms of (constant) temperature, cleanness, and appropriate content of minerals. In addition of conventional uses, it is used as a thermal energy source for melting snow or removing it from roofs, for cooling/heating and hot water supply with heat exchange equipment, for fish farming or to make *sake*, for example (Sakura et al. 2003).

5.1 Regulation and laws

During the Showa era (1926-1945), the involvement of Japan in armed conflicts and its concomitant delay in investing in surface water resources development, gave room for individuals to drill wells, aided by advances in drilling technologies. The Korean War time was associated with an industrial boom that readily further tapped groundwater resources and caused land subsidence in many large cities. This prompted the Industrial water Use Law that tried to tackle groundwater over-abstraction as early as 1956 (Sato et al. 2011). Land subsidence not only damaged infrastructure but carried with it heightened risks of flooding and vulnerability to typhoons in the specific case of Japan. Land subsidence in urban areas was observed as early as the beginning of the 20th century (Sakura et al. 2003). In the 1980s and until the end of the 20th century, a total average of 600,000 ha was sinking by more than 2 cm each year (Figure 13).

Traditionally, and notably during the Meiji era, groundwater has been considered as an extension of the land and therefore imbued with the inviolability of property rights enshrined in the constitution. Conflicts related to groundwater have usually been dealt with through state laws and local government regulations but addressing impacts of groundwater overexploitation proved to be difficult because of the uneasy determination of casualties, the legal protection of private property, and conflicts between the administrations concerned. One of the measures introduced by the 1956 Industrial Law was the possibility to define 'designated areas', where groundwater could be regulated or even prohibited, in places where land subsidence was established and where industrial waterworks which would bring surface water as a substitute would be under construction or already implemented (Endo 2015b). Regulation only applied to industrial wells (and not to domestic or commercial buildings) and to new wells. Enforcement remained weak and land subsidence continued unabated (Sato et al. 2011; Sato and van Hoang, 1995) but these shortcomings were addressed in a revised law in 1962. Since 1985 preventive measures could only be enforced in three areas (Chikugo-Saga, Nobi and northern-Kanto), but on the other hand, local governments (prefectures, cities and towns) have passed regulations and ordinances in many places (Tanaka, n.d.).

The regulation in 'designated areas' was based on the requirement to ask for a permit from the Prefecture concerned, which would constrain drilling in terms of well diameter and depth. For example in Koto Ward (Tokyo), well outlet size was to be between 21 and 46 cm² and depth longer than 250 m (Endo 2015a). In 1962, only wells with outlet under 21 cm² and deeper than 650 m would be allowed, which virtually made any pumping uneconomical and impossible (Endo 2015a). These technical constraints, however, were largely made effective because of the development of surface water networks by the government, which delivered subsidized water as a substitute, and of a reduction in groundwater abstraction in factories and buildings,

resulting from recycling of water and use of this water for cooling (Tanaka, n.d.). Savings in groundwater resources were also due to a substantial wastewater charge, whereby industrials had to pay for any water released in the drainage system, prompting efficiency gains and recycling (Endo 2005b).

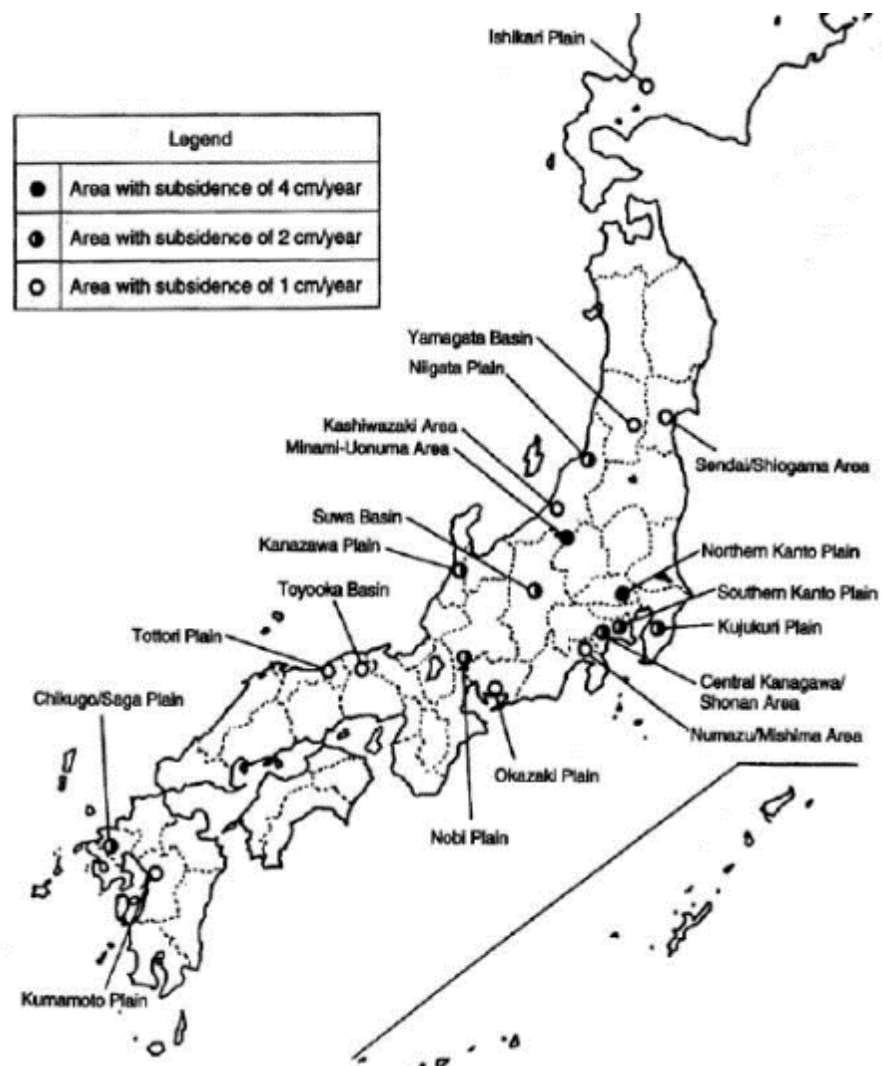
Groundwater levels were stabilized (Figure 14) after these measures were put in place, and sometimes even recovered, largely because of the quite substantial rainfall and recharge (Tanaka, n.d.). Efforts at reducing or stabilizing over-abstraction through the measures described above have been successful, but this has resulted in a recovery of groundwater head which has negatively affected under-ground level structures (Sato et al. 2011). Outside designated areas, and up to this date, farmers and other users are free to drill wells without permits. Local ordinances do not require permits, with the exception of Hadano city, in Kanagawa prefecture (Endo 2015b). The use of groundwater in agriculture is modest.

5.2 Community management

Although most groundwater problems in the world are relatively recent, Japan offers an interesting example of customary groundwater management practice developed in the middle of the 19th century: the Kabu-ido system, in the Noubi Plain, Tokai area. Poldered areas, surrounded by dikes and rivers dominating the landscape started to resort to artesian wells in order to cope with occasional water shortages (Endo 2014). Farmers within the polder thus had to face the twin problems of excess water in the rainy season (with flood risks and the need to drain excess water out of the polder), and water shortages in the dry season, especially for those farmers located on the higher land (yet at no more than 2 meters above those at the lower end of the polder). The return flow of those farmers located on higher lands accumulated in the lower lands and compounded drainage problems and flood risk for fellow farmers in lower locations. A system of well permits was established by all villagers within the polder, whereby drilling of wells was restricted and those owning a well had to pay a fee which was then used to build and maintain drainage gates. The negative externality generated by upstream farmers was internalized and dealt with thanks to the fee they paid. Upper and lower villagers would periodically re-negotiate, based on the observation of the water status within the polder, as well as in the case of extreme events. Some degree of transparency was established by numbering all wells and labeling them with a number accessible and visible to all. If a resident was seen to use a well under seasonal restriction without permission, his well would be destroyed and he would have to pay a fine. In the event he could not afford to pay, the village would have to pay on his behalf. Of the total fine, 40 percent would go to rewarding the person who had identified the well. The system was discontinued at the turn of the century, when modern drainage pump stations dealt away with the drainage problem (see more details in Endo 2014).

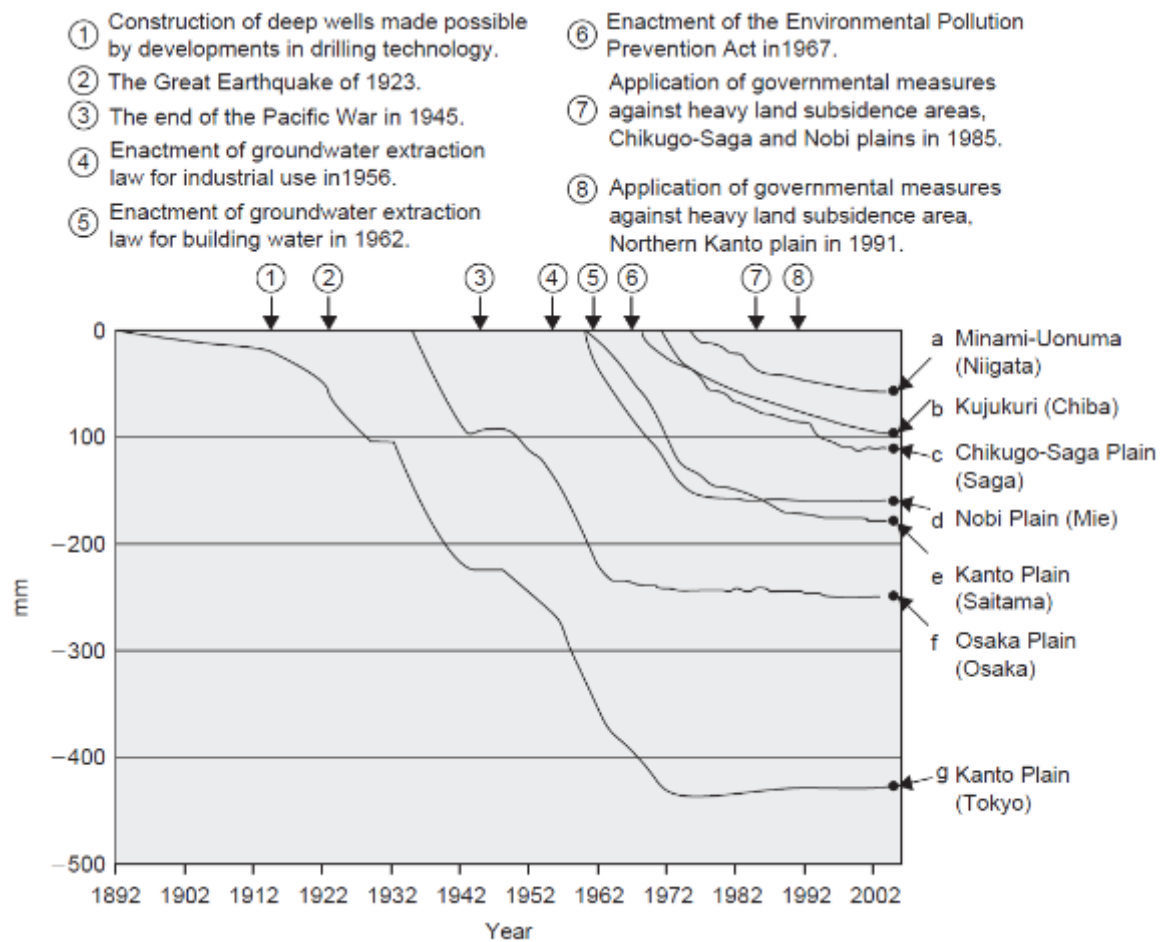
Nowadays, a mix of telemetry, modeling and co-management with users is being used in some places, such as in Toguchi since 1999 (Jinno and Sato 2010). Groundwater head and land subsidence are constantly monitored and when levels reach 'warning' or 'alarm' levels the exploiters/users of a prefectural government-supported union for the prevention of land subsidence and groundwater resources protection are obliged to control groundwater use accordingly.

Figure 13. Status of land subsidence in 1995



Source: Sakura et al. 2003.

Figure 14. Trends of land subsidence and application of state laws in Japan



Source: Jinno and Sato 2010.

Groundwater management and governance in India

1 Groundwater resources and abstraction in India

1.1 Characterization of groundwater in India⁹

India possesses around one-fifth of the total equipped irrigation land in the world, some 62 million hectares of which almost 40 million depend on groundwater as their unique water source or conjunctively with surface water (Das and Burke 2013; Siebert et al. 2010). This resource occurs in highly diverse geological formations (CGWB 2013a) as water bearing and conveying formations can vary greatly even over small distances across the country (Muddu et al. 2011). In spite of such geological diversity, as the 2012-2013 Groundwater yearbook states (CGWB 2013a), two main rock formations can be distinguished affecting the hydraulics and characteristics of groundwater: porous formations and fissured formations (Table 3).

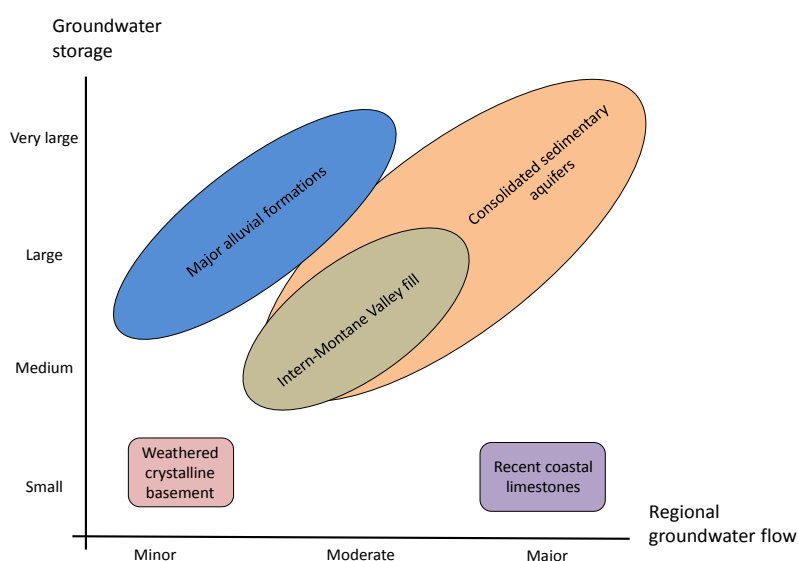
Aquifers are geological formations with the capacity to store and yield groundwater (Foster et al. 2006). Their main characteristics are storage and flow, both depending on the type of geological formation (Figure 15). There are major variations of aquifer storage between unconsolidated aquifers (alluvial formations) and for instance weathered crystalline basement formations (with deeply weathered rocks with very low permeability) (ibid.). Consolidated sedimentary aquifers have a wide range of storage and flow, consisting of sandstones or limestones with consolidation and fracturing which increases with depth and age (ibid.).

Porous formations are found in India in unconsolidated and semi-consolidated formations. Unconsolidated formations consist mainly of alluvial and porous sediments in river basins, coastal and delta areas (Table 3). These are, according to the 2013 Groundwater Yearbook of India (CGWB 2013a), the most significant groundwater reservoirs in the country. Large river basins where these formations can be found include the Indo-Gangetic and Brahmaputra plains (covering the states of Punjab, Haryana, Uttar Pradesh, Bihar, West Bengal, and valley areas of North Eastern states) where high rainfall contributes to the replenishment of these aquifers, and where large reserves can be found (about 57 percent of the annual recharge of groundwater is monsoon rainfall) (Figure 16).¹⁰ Coastal areas where these types of formations can be found can also have extensive aquifers as well as in parts of the desert areas in India – i.e. Rajasthan and Gujarat. Groundwater recharge in these parts of western India, particularly Rajasthan and parts of northern Gujarat which have arid climate is low. Semi-consolidated formations occur normally in narrow valleys and faulted basins with sedimentary rock formations (sandstones, basalts, and crystalline rocks). Groundwater availability depends on secondary porosity developed through the effects of rock weathering and fracturing. Groundwater can be present at shallow depths (between 20 and 40 meters) and deeper in some areas (down to 200 meters).

⁹ Unless stated otherwise, the source for this section is Central Ground Water Board (CGWB 2013a).

¹⁰ Rainfall's overall contribution to groundwater recharge is around 68 percent. Canal seepage, return flow from irrigation, recharge from tanks, ponds, and water conservation structures is 32 percent.

Figure 15. General aquifer types



Source: Adapted from Foster et al. 2006.

Table 3. Aquifer systems in India

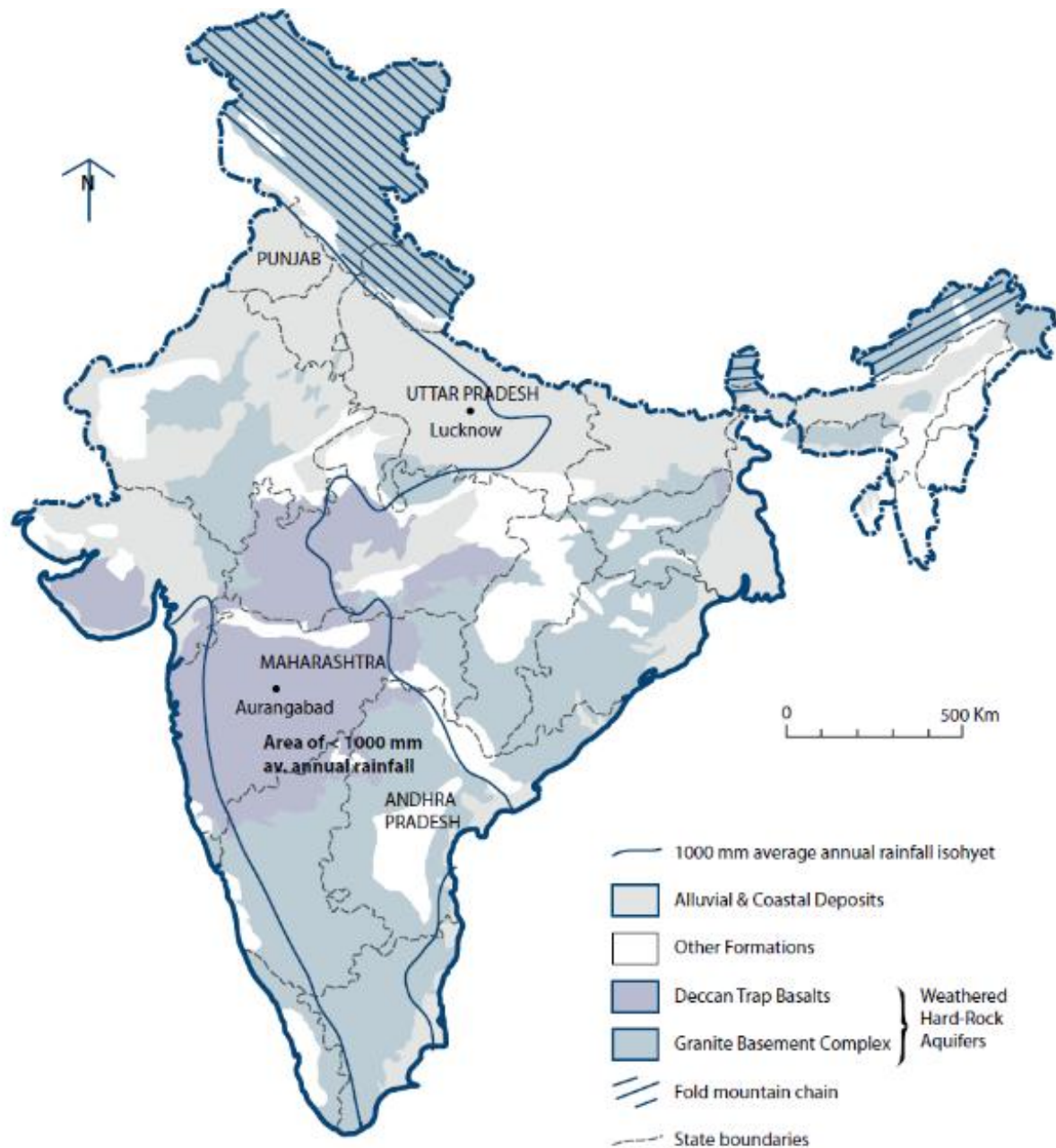
<i>Aquifer system</i>	<i>Areas</i>	<i>Number of states and territories present and % of total area</i>	<i>Groundwater potential</i>
Unconsolidated formations - alluvial	Indo-Gangetic and Brahmaputra plains	25, 28%	Large reserves down to 600 meters in depth High rainfall with large recharge
	Coastal areas		Reasonably extensive aquifers with risk of saline intrusion
	Part of desert areas – Rajasthan and Gujarat		Negligible recharge and salinity hazards. Groundwater availability at great depths
Consolidated/semi-consolidated formations – sedimentary, basalts, and crystalline rocks	Peninsular areas	Sedimentary (soft systems) 11, 3%	Availability depends on secondary porosity developed due to fracturing and weathering. Scope for groundwater availability at shallow depths (20 to 40 meters) in some areas down to 100 to 200 meters in other areas and with varying yields
		Sedimentary (hard systems) 11, 6%	
		Volcanic systems 13, 16%	
		Crystalline (basement) systems 19, 31%	
Mountainous	Hilly and mountainous states	15, 16%	Low storage capacity

Source: Based on CGWB 2013a and Kulkarni et al. 2015.

Consolidated fissured of basalt and crystalline hard rock formations can be found in almost two-thirds of the country (CGWB 2013a; Muddu et al. 2011). They have negligible primary porosity but can attain in some cases, levels of porosity and permeability due to secondary fracturing and weathering. Other fissured formations such as volcanic rocks (basaltic lava) can have poor to

moderate permeability depending on the presence of primary and secondary fractures. In the group of carbonate rocks, limestones dominate, with cavities created due to the circulation of water, thereby increasing aquifer permeability. In major parts of southern India covered with hard rock terrains, recharge occurs during the monsoon but remains also low due to low infiltration and low storage capacity of the rock formations.

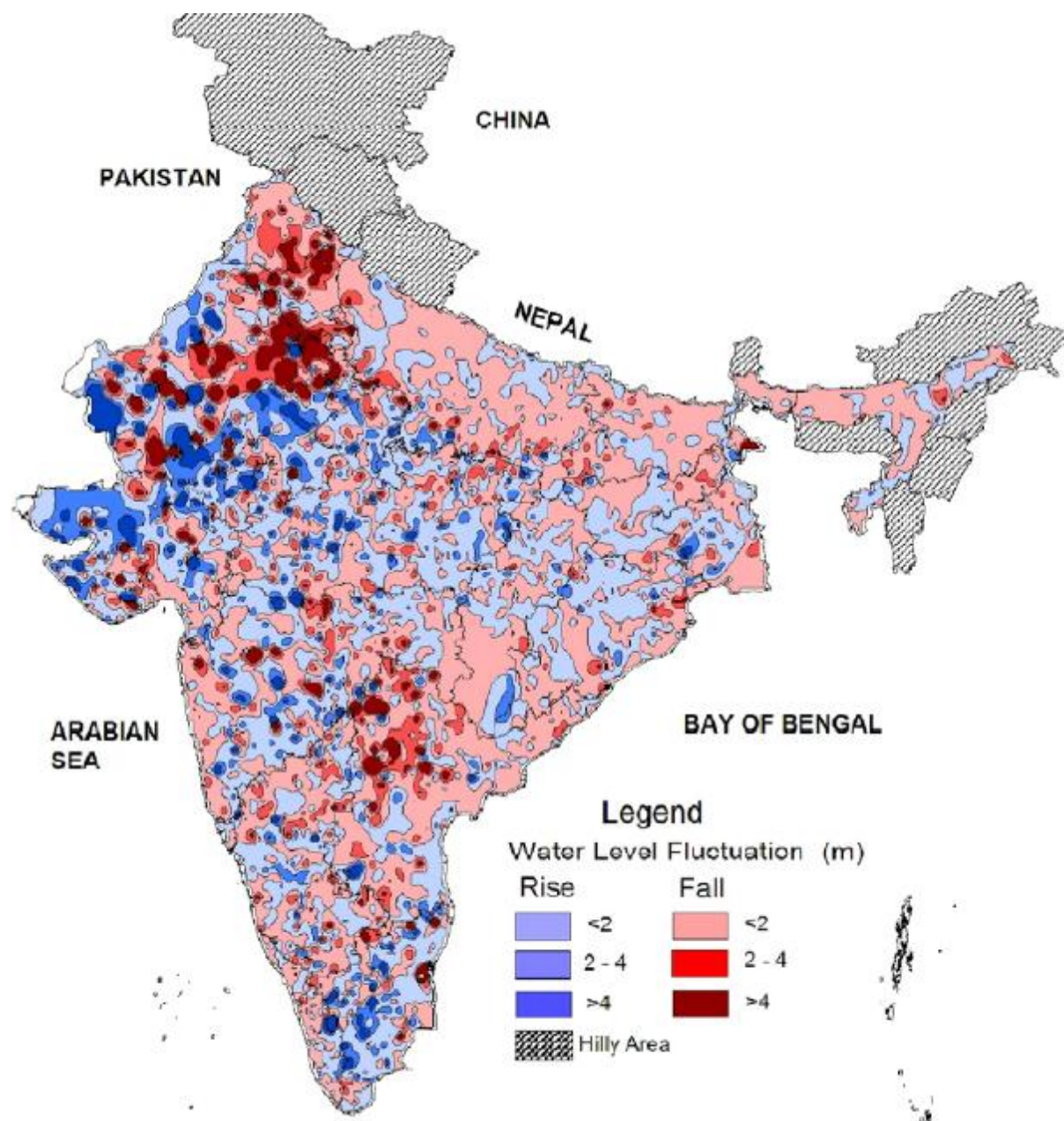
Figure 16. Hydrogeological map of India



Source: World Bank 2010.

As recorded by the Indian Central Ground Water Board (CGWB), groundwater level fluctuation registered during the decade 2002-2012 shows a decline in aquifer levels in the north-west, east, and north-eastern parts of the country, where porous unconsolidated formations are predominant (CGWB 2013a) (Figure 17). There is also a rise in groundwater levels in Gujarat in central India and in Tamil Nadu in 50 percent of the Central Board's monitoring wells (with around 37 percent of wells registering a rise of less than 2 meters). This is due, for a major part, to rainfall patterns in these areas, changing groundwater regimes, the adoption of revised values for parameters (e.g. specific yield), or the implementation of rainwater harvesting measures (ibid.). Groundwater level decline is most prominent in Rajasthan, Punjab, Delhi, and Andhra Pradesh, with declines of sometimes more than 4 meters in one year (ibid.).

Figure 17. Groundwater level fluctuation, decadal mean pre-monsoon (2002-2011) versus pre-monsoon 2012



Source: CGWB 2013a.

1.2 Groundwater abstraction technology in India

The depletion of groundwater and lowering of water table levels make further abstraction with traditional techniques more and more difficult.¹¹ India's Ministry of Water Resources differentiates in its Minor Irrigation Scheme Census (Ministry of Water Resources) three types of groundwater lifting technologies: dug wells, shallow tubewells, and deep tubewells. Dug wells are open wells dug or sunk into water bearing formations.¹² Shallow tubewells are defined as boreholes not exceeding 60 to 70 meters. These can be either cavity tubewells or strainer tubewells usually drilled by percussion methods. Deep tubewells go deeper than 100 meters, drilled by rotary percussion or compression rigs.¹³

Open wells can be built with or without masonry and dug by hand, and their diameter could vary from very shallow open dug wells (2 to 3 meters) to 10-15 meters in Pondicherry, as reported by Aubriot (2013). These would be fitted with traditional groundwater lifting devices such as a Persian wheel. Later technology advances would allow farmers to install a small pump to lift water, provided that the water table remained shallow enough. With the advent of more modern drilling techniques and the arrival of pumps (first centrifugal and then electric and submersible), farmers were able to rely on a constant supply of groundwater. This is however also dependent on hydrogeological and geological characteristics, aquifer yields and storage, etc.

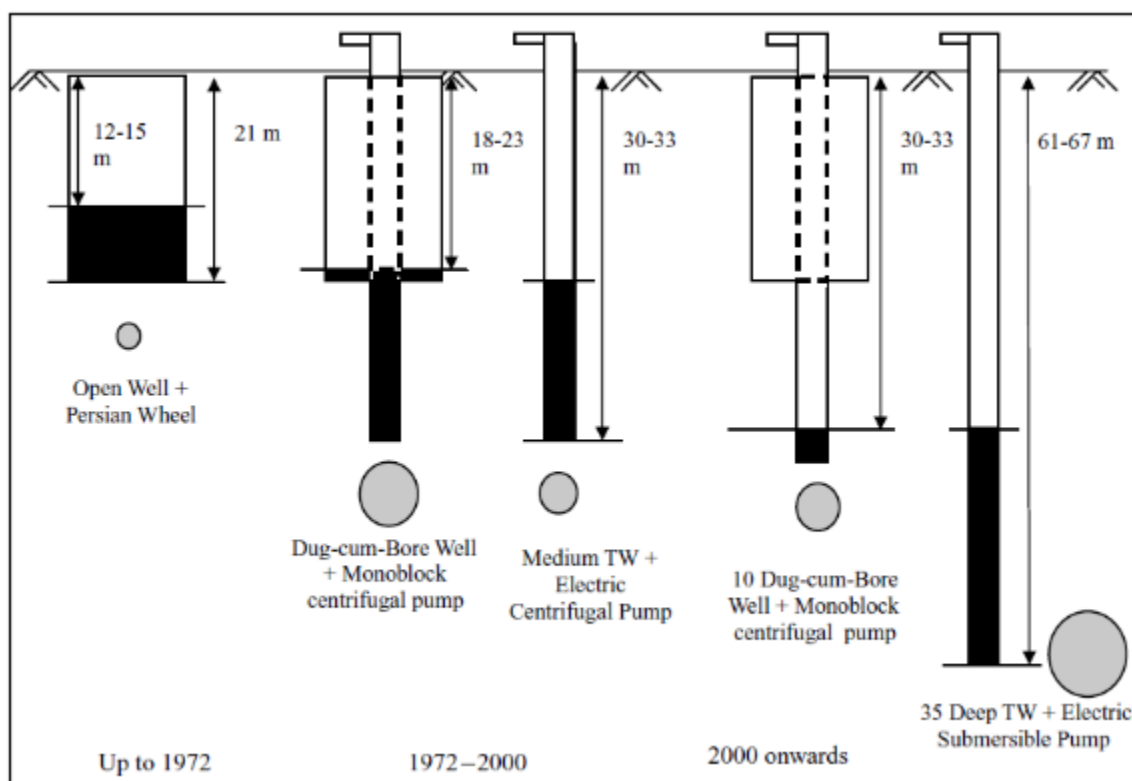
Pumping devices have evolved over time. In the example presented by Selvi et al. (2009) in Punjab, open wells were converted to dug cum bore-wells with either diesel or electricity operated mono-block pumps (Figure 18). As the water table got deeper, mono-block pumps were replaced by electrical submersible pumps for those farmers able to afford the well-deepening operation.

¹¹ Techniques employed to lift groundwater can be divided between direct lifting by the user or via the use of a pump (Fraenkel 1986). Direct methods for groundwater lifting are variations around the use of a bucket or recipient used cyclically (e.g. shadoof) or used continuously with rotating movement (e.g. Persian wheel). The use of pumps (either displacement pumps with cyclic mechanism, for example, the standard hand pump, or velocity pumps with rotary mechanism such as the centrifugal pumps) increased the possibilities of abstraction as well as the capacity to reach further deeper in aquifers and pump increasingly larger quantities of water (ibid.).

¹² The Minor irrigation schemes census of 2010 further differentiates between Pucca, Kutcha, and Dug-cum borewells, (<http://micensus.gov.in/CensusMISch.html>, Accessed 9th November 2014).

¹³ Minor Irrigation Schemes Census 2010, Ministry of Water Resources, <http://micensus.gov.in/CensusMISch.html> (Accessed 9th November 2014).

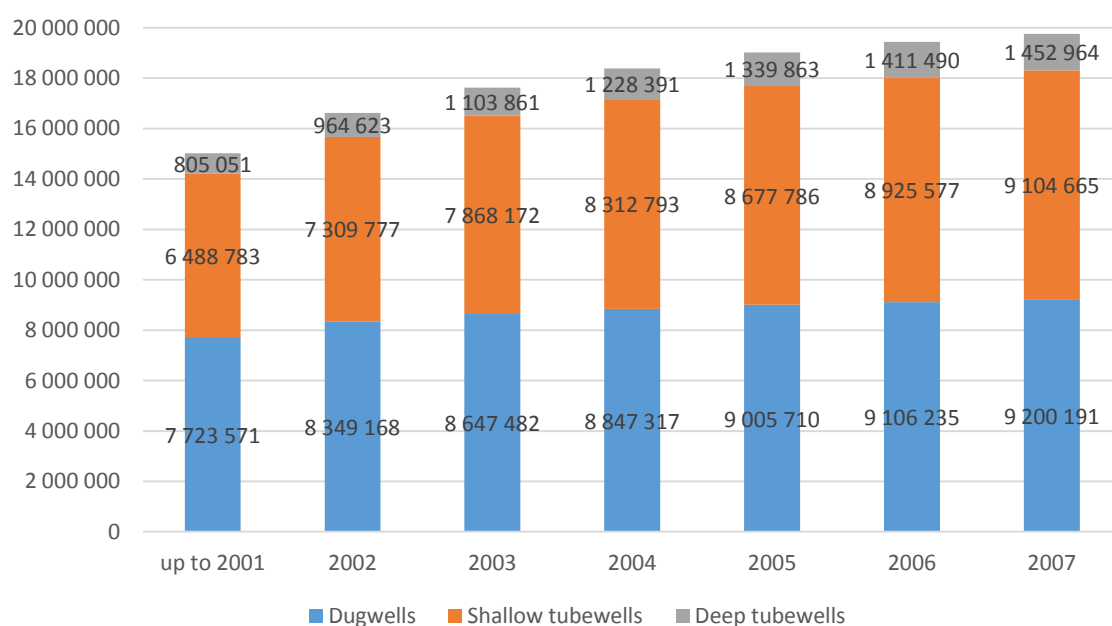
Figure 18. Evolution of tubewell technology in Bajjal village, Punjab, North India



Note: a monoblock centrifugal pump is a pump in which motor and pump are mounted on a single shaft. TW: Tubewell.

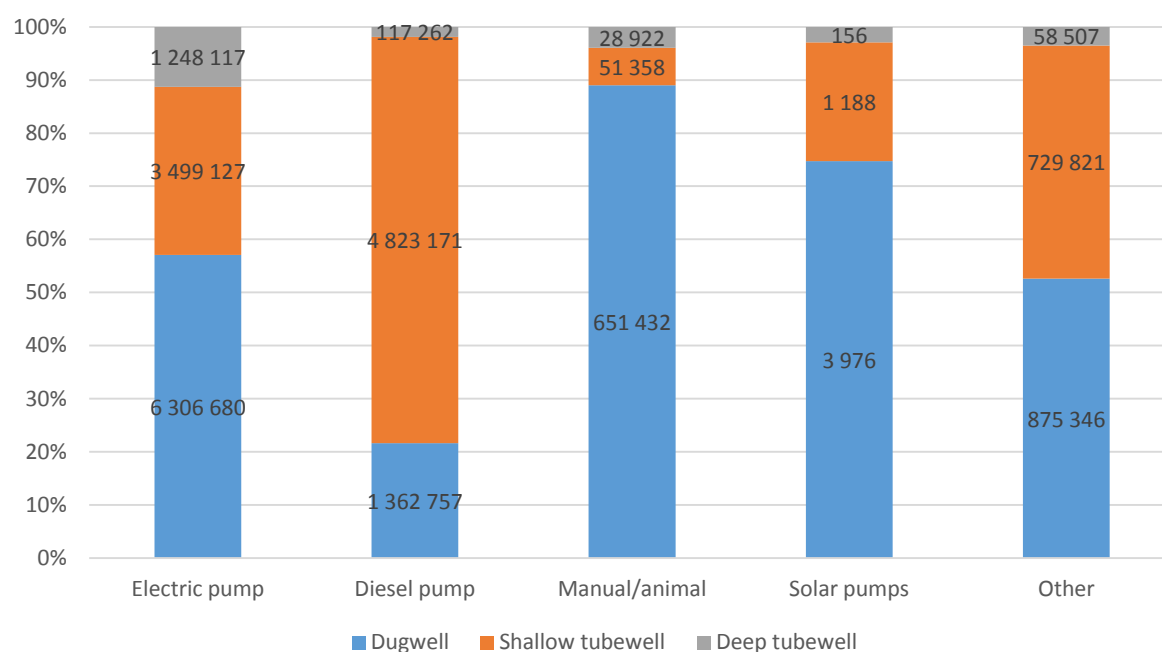
Source: Selvi et al. 2009.

Figure 19. Evolution of groundwater lifting technologies in India (up to 2007)



Source: Based on data from Minor Irrigation Schemes Census 2010, Ministry of Water Resources, Government of India.

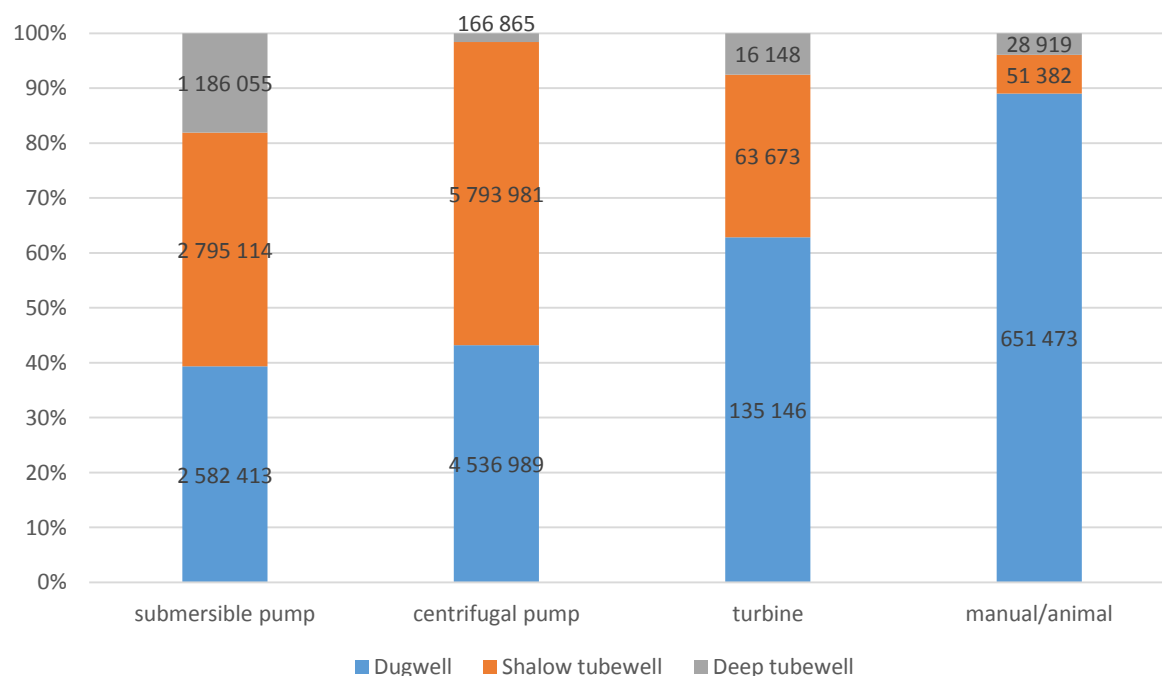
Figure 20. Groundwater wells and source of energy in India



Note: Others includes wind mills.

Source: Based on data from Minor Irrigation Schemes Census 2010, Ministry of Water Resources, Government of India.

Figure 21. Groundwater lifting mechanisms installed in wells in India



Source: Based on data from Minor Irrigation Schemes Census 2010, Ministry of Water Resources, Government of India.

According to India's 4th Minor Irrigation Schemes Census (2007-2010),¹⁴ there are 19.75 million wells in India. Dug wells are the most common (with 9.2 million devices) followed by shallow tubewells (9.1 million) and deep tubewells (1.4 million) (Figure 19). Electric pumps are the most common type of pump powering dug wells (6.3 million). Most shallow tubewell owners have however installed diesel pumps (4.8 million) (Figure 20). The majority of dug well owners (4.5 million) have installed centrifugal pumps so have shallow tubewell owners (5.7 million) (Figure 21). The majority of wells in India are privately owned. There are total of 362,000 publicly owned dug wells (including government owned, cooperative owned, and panchayat owned) against 8.8 million privately owned. For shallow tubewells, there are around 150,000 publicly owned against 8.9 million privately owned. Of the privately owned wells, individual farmers own the majority of the wells.

The occurrence of these technologies is related to the type of aquifers and water depths. Shallow dug wells tend to be found in areas with high aquifer levels (e.g. alluvial formations easily replenished by the monsoon) and used to be also found in fractured aquifer systems. Deep wells can be found in consolidated areas or in fractured systems with water table abatement. Groundwater depth levels in India¹⁵ measured by the CGWB fluctuate between 0 to 123 meters¹⁶ (CGWB 2013a). The most common groundwater depth found in India is between 2 and 5 meters (found in 41 percent of CGWB's monitoring wells and especially in the unconsolidated areas of the sub-Himalayan alluvial plains – Gangetic and Brahmaputra valleys, eastern coast of Orissa, Andhra Pradesh, and Tamil Nadu states).¹⁷ In the north Western states, water levels generally range between 10 and 40 meters (ibid.). Western states show deeper water levels (between 20 and 40 meters and more in parts of Gujarat, Rajasthan, and parts of Haryana). In coastal areas, groundwater is generally less than 10 meters deep.

1.3 Impacts caused by groundwater over-abstraction in India

India's green revolution was partly driven by the availability of shallow groundwater and the access to cheap abstraction technology. Additionally, access to groundwater also sustained the introduction of high yielding crop varieties, driving increases in income over the long term after 1966 (Sekhri 2014). This led to the increase of irrigated land with groundwater wells to the detriment of surface water irrigation (Figure 22).

Presently, groundwater accounts for over 65 percent of the country's irrigation water needs and up to 85 percent of drinking water supplies (World Bank 2010). Even though the general state of groundwater units in India according to official data shows that almost 75 percent are designated as safe by the Central Ground Water Board (CGWB) (Figure 23), there are large disparities at the regional and state level. In north-western India, large areas are over-exploited with significant declines in water table levels (averaging across Rajasthan, Punjab, Haryana, and Delhi to one-third of a meter per year between 2002 and 2008) (UNEP and GEAS 2012). In Delhi

¹⁴ Data of the Minor Irrigation Schemes Census was reviewed by Rawat and Mukherji (2012). These authors compared the data from the Census with other censuses in India (the Agricultural Census, Input Survey, and the State Electricity boards as well as States Statistical Bureaus) finding a large divergence in data, not solely attributable to time lags and definitional differences and a further example of the poor and deteriorating conditions of irrigation databases in India. Larger disparities in numbers are added by calculations by Mukherji and Shah (2005a, 2005b) having estimated that there were around 26 million wells and tubewells in India.

¹⁵ These are measured by the CGWB through a network of 15,653 monitoring wells drilled all over the country (CGWB 2013a).

¹⁶ The deepest level has been observed in Rajasthan (CGWB 2013a).

¹⁷ These are pre-monsoon water levels.

for instance, 74 percent of water units are in an over-exploited state, in Haryana it is 59 percent, in Punjab its 80 percent and in Rajasthan 69 percent of groundwater units have been declared over-exploited (CGWB 2013a).¹⁸ Regions in Gujarat in Rajasthan have also very low rainfall and almost no surface canal water, increasing the reliance and pressure on groundwater resource.

These official figures however paint a 'too rosy picture' of the state of groundwater resources in India and are inadequate and too general, given its methodology and the country's complex local and regional geology (Kumar and Singh 2008). The widespread over-exploitation in areas of India where hard rocks are predominant (covering almost 75 percent of the country, found in Tamil Nadu, Karnataka, Maharashtra, Madhya Pradesh, Andhra Pradesh) has serious consequences, especially as aquifer recharge is comparatively slower, leading to increasing pumping costs, decreasing well yields and well failure due to seasonal or sometimes permanent water table decrease (Bassi et al. 2008).

According to Shah (2012: 17), there are four main broad types of aquifer-human relations in India where "systematic patterns of 'coping and adaptation'" mechanisms by farmers can be identified (Table 4). These broad aquifer categories have specific social systems linked to them whereby farmers and communities have adopted strategies and behaviors according to the access and availability of groundwater and social, political, and economic systems have arisen from these different contexts (so called socio-ecologies) (Shah 2009). The abstraction and use of groundwater has created, according to Shah, different social situations characterized by varying degrees of social interaction, from the atomistic individualism of farmers in the large alluvial basins of India, to cooperation instances in small hard rock and fractured aquifers in Eastern Rajasthan and parts of Gujarat.

With nearly 88 percent of total groundwater abstraction dedicated to irrigation (Kulkarni et al. 2015), groundwater over-abstraction has also caused negative environmental, social, and economic impacts whilst frequent droughts in areas of India (north-west) are also critical constraints to improving livelihoods and agriculture productivity (Sharif and Ashok 2011). Increasing economic costs of depleting groundwater reserves are also disproportionately borne by small and marginal income farmers (Reddy 2003). This can cause a spiraling race for short-term gains sought after by wealthier and bigger farmers, leaving smaller ones out of the race and with reducing irrigated land year by year (such as in the Charamarajanagar district in Karnataka state) (Sharif and Ashok 2011). In extreme cases, the over-abstraction of groundwater has led to the abandonment of irrigation altogether. In Satlasana, Gujarat, farmers traditionally practiced rain-fed agriculture but switched to groundwater-fed irrigation with the advent of rural electrification, market integration, and access to cheap credit. This development brought the decline of groundwater levels with an increase in well deepening, unable ultimately to sustain irrigation (Gale et al. 2006) (Figure 24). In some areas of Telangana's thin and shallow bedrock aquifers, irrigation area is reduced due to water table fluctuations as farmers assess pre-season water tables to sow paddy fields (Fishman et al. 2011).

¹⁸ The CGWB categorizes groundwater blocks or units in India according to the decline in water level and degree of groundwater use (annual groundwater draft expressed as a percentage of net annual groundwater availability). The 'safe stage' is characterized with 90 percent or less of no pre or post-monsoonal decline in water levels; the 'semi-critical stage' between more than 70 percent and less than 100 percent significant long-term decline in pre- or post-monsoonal water levels; the 'critical stage' is defined as a long term decline of more than 90 percent and less than 100 percent in both pre and post-monsoonal water levels; and the 'over-exploited stage' is defined as a long term significant decline of more than 100 percent in pre or post-monsoonal water levels (World Bank 2010).

Table 4. Broad aquifer types and groundwater socio-ecologies in India

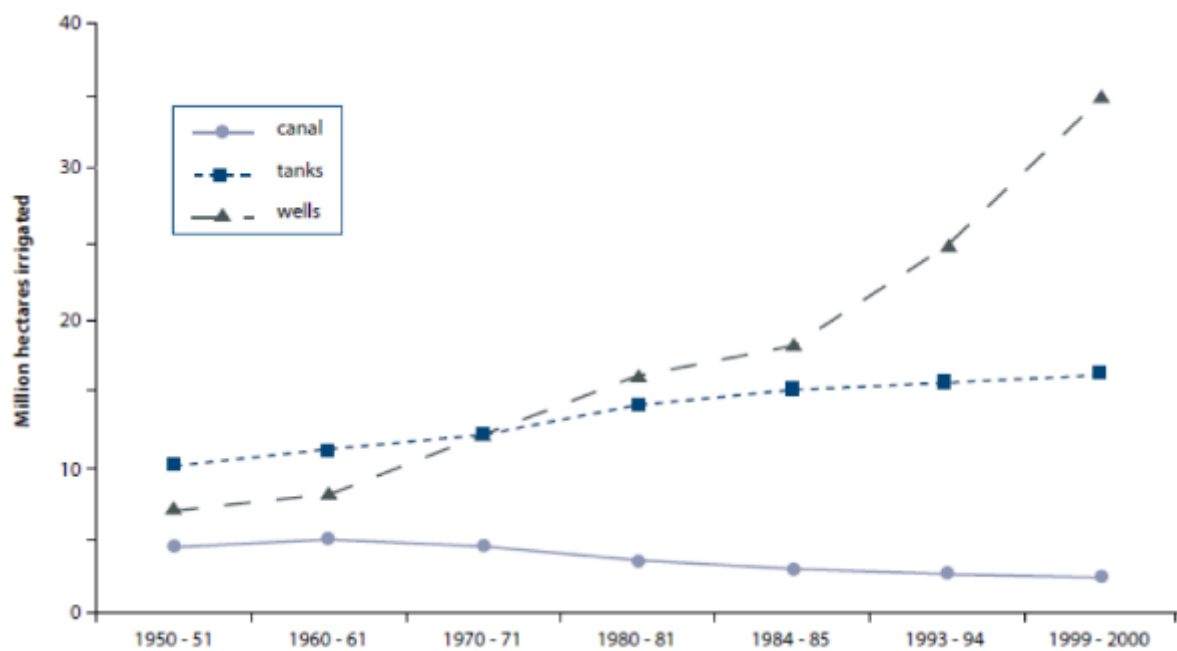
Type		Basic natural characteristics	Basic social characteristics	Examples
1) Ganga-Meghana-Bhramaputra Basin		High storage and high recharge, alluvial aquifer, monsoonal and snowmelt recharge	Little impact between farmers due to large reserves (Atomistic individualism of farmers) with failure to coalesce into aquifer communities (a)	Eastern Uttar Pradesh, North Bihar, North Bengal
2) Arid alluvial aquifers		High storage and limited recharge, Indus basin, underlain with deep sandy alluvial formations, extensive shallow groundwater use	Initial irrigation with shallow dug-wells has been chasing falling water tables, increasing pumping costs. Opportunistic and resource accumulation behavior by wealthier farmers is observed and in many instances resource poor farmers are eased out	Western and north-western India, Punjab, Haryana, parts of Rajasthan, northern Gujarat
3) Salinity-prone aquifers		Coastal aquifers, high-storage alluvial aquifers with limited amounts of fresh water	Rapid groundwater development proved profitable but caused quality deterioration. Phenomenon forced exit from irrigated agriculture for many farmers	Coastal areas in Gujarat
4) Hard rock and confined aquifers	4.1) Hard rock aquifers with rivalry	Fractured formations, limited availability and recharge	Increasing costs with intensive development of groundwater and reduced availability causing competition and rivalry for groundwater	Maharashtra, Telangana, Andhra Pradesh
	4.2) Hard rock and confined aquifers with cooperation	Fractured formations, limited availability and recharge	Instances of cooperation reducing costs and risk of groundwater over-abstraction, decentralized and coordination of aquifer recharge projects	Gujarat, Eastern Rajasthan, Andhra Pradesh

Note: (a) instances of community action and cooperation have been documented in some geographical areas but these are catalyzed by NGOs and sustained by external support and funding.

Source: Based on Shah 2009, 2012.

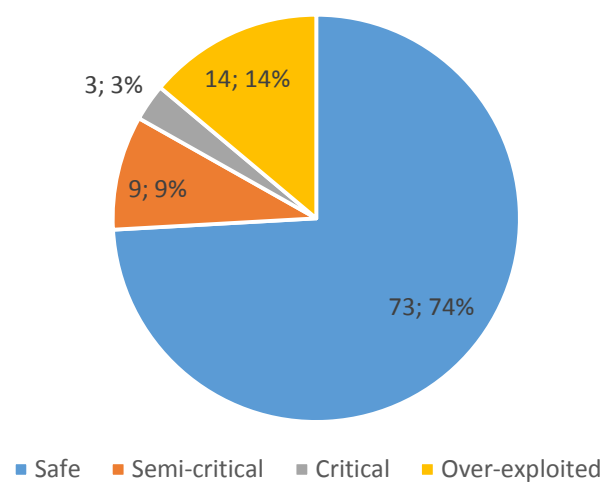
Groundwater over-abstraction in India has also had quality effects with increases in salinity (from sea water intrusion and also inherent saline groundwater) and fluoride concentrations (over 1 mg per liter in Gujarat and Rajasthan) (Sundarajan et al. 2009). In the Himalayan inter-mountain areas, spring discharges have been severely affected by groundwater exploitation and the lack of protection of recharge areas has further increased these negative impacts (ibid.). In hard-rock areas, groundwater abstraction is affected by high groundwater variability and fluctuations within aquifer systems across seasons causing that shallow wells have been severely affected by deepening water tables (the success rate of wells in these areas is around 50 percent) (ibid.).

Figure 22. Evolution of irrigated hectares according to technology in India, 1950-2000



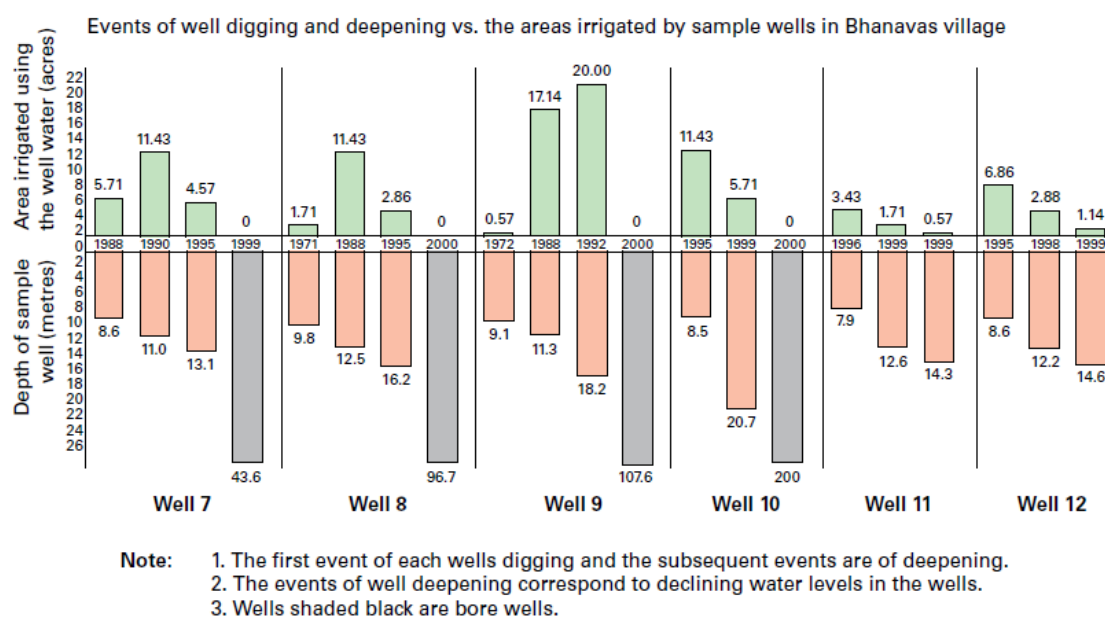
Source: Bhatia 2005 in Garduño et al. 2011.

Figure 23. Status of groundwater bodies in India (2009)



Source: Based on data from CGWB 2013a.

Figure 24. Well deepening and irrigated surface in Bhanavas village, Satlasana, Gujarat



Source: Gale et al. 2006.

2 Groundwater resources and management in selected states in India

This next section briefly introduces the situation of groundwater resources and management in six of India's states: Andhra Pradesh, Gujarat, Karnataka, Maharashtra, Punjab, and West Bengal (Table 5 and Figure 26. States and union territories of India). Each of these cases reflects on several of the issues such as the use of groundwater recharge programs, the effects on local communities, or the groundwater/energy nexus. The different cases also present different policy directions and management tools used by the different state governments to regulate groundwater use and abstraction.

Table 5. Main aquifer and well characteristics of the selected states

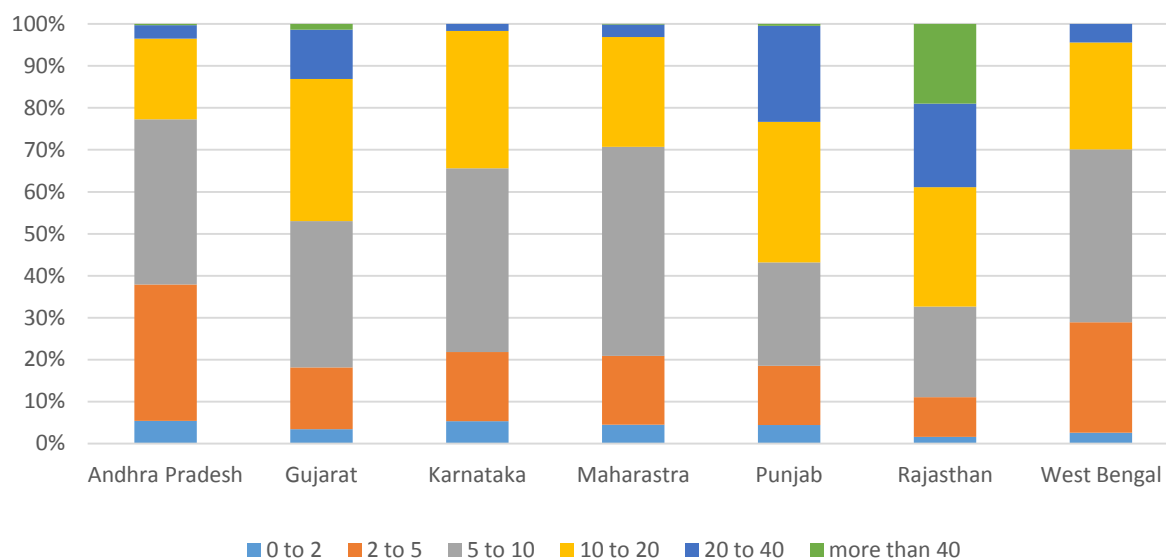
<i>State</i>	<i>Main geology</i>	<i>Main groundwater depth</i>	<i>Type of wells</i>	<i>Ownership (*)</i>	<i>Owner's holding size</i>
Andhra Pradesh	Fractured hard rocks	2-10 meters (72 % of monitoring wells)	46 % DW 42 % STW 13 % DTW	99 % of total wells are privately owned	44 % of DW serving 0-1 ha 41% of STW serving 0-1 ha
Gujarat	Consolidated formations and alluvium	5-20 meters (67 % of monitoring wells)	80 % DW 7 % STW 13 % DTW	99 % of total wells are privately owned	35 % of DW serving 1-2 ha
Karnataka	Hard rock	5-10 meters (43 % of monitoring wells)	25 % DW 75 % STW	99.9 % of total wells are privately owned	66 % of STW serving less than 2 ha
Maharashtra	Deccan Basalt Traps (hard rock)	5-10 meters (50 % of monitoring wells)	91 % DW 4 % STW 5 % DTW	99 % of total wells are privately owned	37 % of DW serving 1-2 ha
Punjab	Alluvial sediments	5-20 meters (58 % of monitoring wells)	73% STW 27 % DTW	99.9 % of total wells are privately owned	37 % of STW serving 2-4 ha
West Bengal	Alluvial sediments	5-10 meters (41 % of monitoring wells)	2 % DW 97 % STW 1 % DTW	94 % of total wells are privately owned	54 % of STW serving 0-1 ha

Note: (*) Following the categorization of the Ministry of Water Resources in its 4th Minor Irrigation Schemes Census, the ownership of wells when not private, is in 'public' hands, which includes government owned wells, cooperative societies, panchayats, and others.

DW= Dug well; STW= Shallow tubewell; DTW= Deep tubewell.

Source: Based on data from CGWB 2013a and Ministry of Water Resources 2010.

Figure 25. Ranges of depths to water levels in meters in selected states in India (in percentage)



Note: Data indicates depth ranges found in CGWB monitoring wells in each state (expressed in percentage of total wells).

Source: Based on data from CGWB 2013a.

Figure 26. States and union territories of India



Source: <http://www.stephen-knapp.com/koresh4.gif> (Accessed 19th August 2014).

2.1 Andhra Pradesh

2.1.1 Groundwater resources and management in Andhra Pradesh

The state of Andhra Pradesh in India falls under the semi-arid region of Peninsular India, characterized by hot summers and cold winters. Geologically, the state can be divided into pediplains, coastal alluvial plains and hill ranges (Reddy and Reddy 2010). The State is mainly underlain with fractured granitic rocks (nearly 85 percent), creating shallow 'low-storage' aquifer systems annually recharged to varying degrees by the monsoon (Garduño et al. 2011; Reddy and Reddy 2010). In its most favorable lithology and geology, aquifers can have between 15 to 25 meters of thickness below the surface. Elsewhere, more heterogeneous formations have led to patchy and thinner groundwater bodies (Garduño et al. 2011). Groundwater is mostly found at 2 to 10 meters below the surface.¹⁹

Andhra Pradesh has around 1 million dug wells, with an increasing proportion falling dry or only becoming seasonal due to the proliferation of deeper tubewells (estimated at over 1.7 million) leading to the intensive exploitation of groundwater and the 'dewatering' of main groundwater-bearing formations (ibid.). This phenomenon, which has happened over the last 30 years, has also been incentivized by inefficient tubewell pumping practices fostered by a flat-rate rural electricity tariff (ibid.). In the State of Andhra Pradesh, 49 percent of water demand for irrigation is met with groundwater (Kumar et al. 2011). Almost half of the dug wells and shallow tubewells found in Andhra Pradesh serve land plots smaller than 1 hectare (Ministry of Water Resources 2010). Agriculture also accounts for around 25 percent of the state's GDP and nearly 70 percent of its population is dependent on agriculture (ibid.).

According to Kumar et al. (2011) and Taylor (2013), problems in the estimation of some of the components of the groundwater balance in some regions have led to the under-estimation of groundwater over-exploitation in Andhra Pradesh. Some of these problems relate to the failure to estimate the actual abstraction at the watershed level, as the only assessments of groundwater development in the state are done by the central groundwater board and state minor irrigation departments. Following Kumar et al. (2011), their estimates are based on "simplistic consideration of only the 'recharge' and 'abstraction'". In many watersheds in hard rock regions in Central and peninsular India, outflows from groundwater to surface water bodies and streams are very significant. These relationships, according to Kumar et al. (2011) are not duly acknowledged in groundwater estimates for Andhra Pradesh.

The State of Andhra Pradesh was the first in India to promulgate state-wide water reforms, beginning with the Andhra Pradesh Ground Water (Regulation for Drinking Water Purposes) Act and the Andhra Pradesh Water Resources Development Corporation in 1996 (Aguilar 2011). Following these reforms and utilizing the Model Bill approach (i.e. adapting a model bill proposed at the federal level), the State enacted the Andhra Pradesh Water, Land and Trees Act (WLATA) in 2002, instituting a permit and registration system for wells under the supervision of the Andhra Pradesh State Water, Land and Trees Authority, mandating that well owners (including those not fitted with power driven pumps) should register their well with the Authority, and setting up well spacing rules (Taylor 2013).²⁰ Drilling equipment and rig owners must also register with the Authority. The Act granted the Authority to forbid pumping to

¹⁹ In 72 percent of groundwater monitoring wells controlled by the CGWB (CGWB 2013a).

²⁰ See Part 2 for a further analysis of Model Legislation in India.

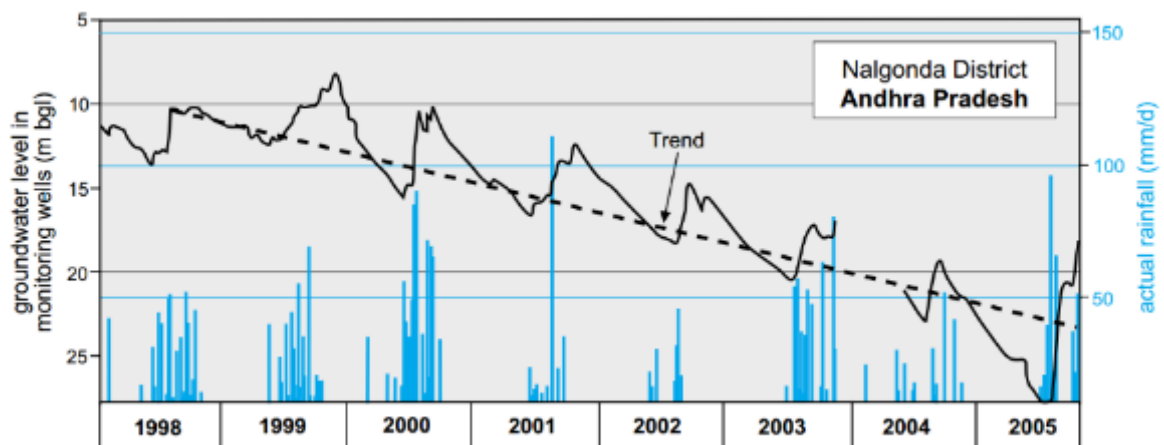
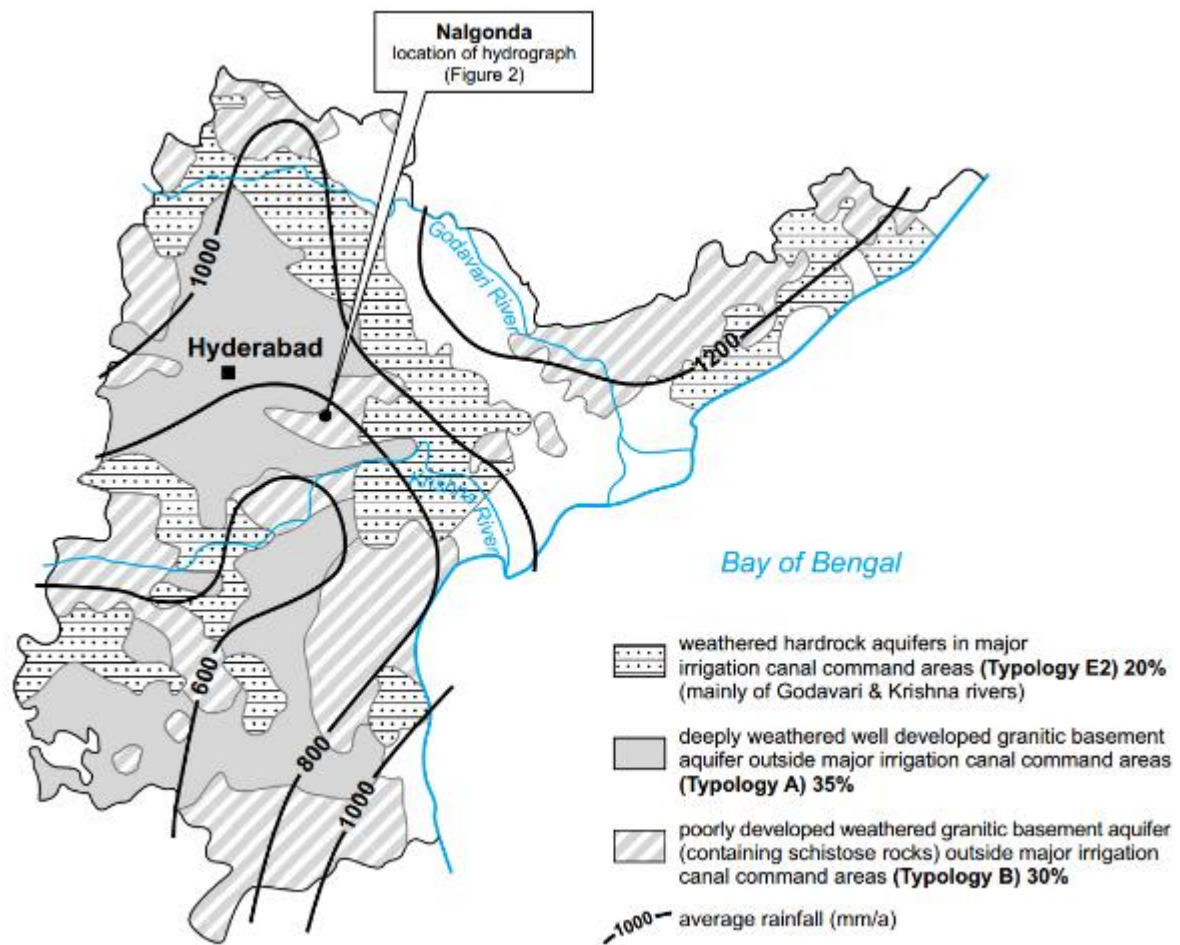
individuals in areas where it is likely to cause damage to groundwater levels or cause deterioration to the environment or natural resources (the prohibition can extend to six months or more if the Authority considers that harmful conditions are still present. The prohibition is to be renewed every six months at a time) (ibid.). According to the act, the Authority is allowed to enter the land and remove the installed equipment, disconnect the power supply, and close the well.

Despite these measures, according to Aguilar (2011: 643), "there are no enumerated guidelines in the statute for what constitutes 'damage to the level of groundwater' or 'deterioration or damage to the natural resources or environment'." Enforcement of these rules and the suspension of pumping rights is at the discretion of the officer from the Authority granted by the board (Aguilar 2011). To preserve drinking water supplies, the WLATA has also regulated well spacing, with a minimum of 250 meters from drinking water sources for private wells. Following Aguilar (2011: 647), despite the good intentions of the law, the Authority is unequipped with databases, machinery, and staff, depriving it of any "meaningful implementation". Corruption is also an important element to mention when referring to hindering aspects for the implementation of water laws in India in general. Aguilar (2011) refers to a 2004 study²¹ in India that reported that more than 40 percent of individuals polled had bribed state water officials in order to alter water-meter figures and decrease their water bill.²² In the same study, 12 percent of individuals surveyed, had bribed state officials to speed up the installation of water connections (ibid.).

²¹ The 2004 study by Davis (2004) quotes a study from 1995 (Paul 1995 in Davis 2004) documenting the prevalence of informal payments in the delivery of public services (water and sanitation) in Indian cities. The 1995 study reflected payments to junior staff of public water and sanitation agencies by household members. Payments are made in order to expedite applications and administrative procedures for new connections, repairs, the falsification of water bills, or ignoring illegal service connections. The falsification of meter readings was according to Paul the most common contravention of the law.

²² The installation of water meters was considered a priority by the Indian National Water Policy adopted in 2002. The different states adopted under the umbrella of the National policy their own state-wide water policies. Full-cost recovery, universal coverage and the provision of improved water and sanitation services are elements present in these policies, such is the case for the state of Karnataka. Full meter coverage for drinking water supply remains a problem as it has led to customers unable to pay for water supply, being disconnected from the network (Grönwall 2008).

Figure 27. Hydrological map of Andhra Pradesh and groundwater hydrograph for a weathered granitic aquifer



Source: Garduño et al. 2009.

2.1.2 The groundwater/energy nexus in Andhra Pradesh

The government of Andhra Pradesh announced in 2004 free power to farmers, as part of an electoral promise by the Congress Party candidate, in order to win rural votes (Birner et al. 2007). Prior to that announcement, energy was already subsidized via a flat rate regime between 1977 and 1991 (ibid.). According to these authors, the emergence of electricity subsidies has to be seen within the context of India's Green Revolution. Subsidies as part of the Green Revolution were strategic in order to achieve the country's national goal of food self-sufficiency (ibid.). The initial introduction of electricity for agriculture was however metered and it was only the electoral promise of flat-rate tariffs by the Congress Party that changed that, leading to similar policy decisions in other states (ibid.).

The 2004 elections brought some changes in the free electricity subsidy scheme, as 5 percent of the farmers were excluded from it (based on criteria such as large landholdings or having more than one pump set). The government also aimed to promote power saving by making compulsory the use of energy saving devices (capacitors) for pump owners (with the incentive for farmers who failed to install them by March 2006 would not be eligible to the free-power scheme) (Birner et al. 2007). The government also tried to establish that farmers would also not be eligible if they grew paddy during the winter season. In view of stiff opposition, this measure was revoked (ibid.).

In spite of the 2004 free power policy, Reddy and Reddy (2010) have not noticed an increase in groundwater consumption and growth in well numbers. According to their research, the number of agricultural service connections reached its peak before the introduction of such policy. Average energy consumption also stagnated, probably due to a lack of supply on the state side and not farmers (as farmers complain that they get 7 out of 9 hours of electricity promised by the state)(ibid.). Impacts of this change of policy have however, affected the state's finances, as "the free power burden mainly in terms of loss, due to the loss of revenue from the flat rate collections from the existing number of energized wells" (Reddy and Reddy 2010: 35).

It must be noted that before 2004, the state government of Andhra Pradesh also faced the refusal of farmers to pay for the energy their pumps consumed as they are not willing to take on another financial burden after investing on sinking a borewell and installing the pump set (Narendranath et al. 2005). Compared to surface canal irrigation where government covers all capital and infrastructure costs and charges a nominal price for water supplied per season, farmers using groundwater bear the entire capital expenditure costs, well deepening, etc. Regarding this issue, research has found that farmers have to pay 10 to 20 times the water cess charges being collected from the canal irrigated farmers (ibid.). Farmers thus demand that the government only collect water cess charges, instead of power supply charges on top of their 'sunk investment costs'.²³

2.1.3 Community based well management in Andhra Pradesh

Andhra Pradesh is, according to several authors (AFPPRO 2006; Das and Burke 2013; Garduño et al. 2009; Ratnakar and Das 2006), a pioneer state in India when it comes to community based groundwater management. In 2000, Aggarwal examined the determinants of cooperation in the

²³ The authors also allude to a problem of mistrust towards public institutions and they find little transparency in the government's functioning or its labyrinth institutions. There is also little attempt to involve farmers and beneficiaries and the top-down approach and bureaucratic controls at every level encourage corruption (Narendranath et al. 2005).

use and management of wells collectively owned (open wells and borewells) in two villages in the Mahabubnagar District in Telangana region.²⁴ Research findings highlighted that there are certain activities more prone to informal cooperation even when the size of the group is small and members are family-related. When activities are of a repeated nature and require low contributions by users such as everyday water allocation and routine maintenance these activities function best if left to the local people. For activities requiring much larger commitments and entailing higher risks such as investing in a joint well, the probability of collective action was observed to be very low. In such cases, Aggarwal (2000) observed that farmers preferred to invest individually in spite of the benefits from pooling capital and risk sharing. Additionally, the sharing of duties was very much facilitated by close neighbor relations and kinship ties. The use of formal contracts in these communities was found to be rare, and instead informal rules such as trust, reputation and social norms fill the gaps (*ibid.*). Water is allocated in these groups before every crop season, agreeing on the crops each member of the group will grow and the amount of water that will be pumped (the number of hours for which the pump is operated) (*ibid.*).²⁵

Although water transportation costs due to user location and distance between each other limit the extent and reach of commonly group-owned well ventures to only neighboring land plots, the joint and local management of wells allows for a higher flexibility of management and relative lack of allocation conflicts. Most of these group-owned wells originated from a single land ownership structure, "where ownership got divided over time due to inheritance (wherein sons inherit a share in the well together with a share in the land of the father) and/or sales of shares of the well" (Aggarwal 2000: 1486). Users of a shared well can allocate pump rights according to the ownership share in the well and pumps can be turned on and off at the same time to ensure less conflicts during rotations (*ibid.*).

Despite these social arrangements allocating water use, irrigation access in one of the villages studied by Aggarwal (2000), Dokur, has been decreasing since then due mainly to a persistent decade-long drought (Deb et al. 2014). Research by ICRISAT suggests that the open wells found in the village of Dokur (of which there were 80 in 1975) had practically disappeared in 2010 (only 3 remaining), replaced by 170 borewells, nonexistent in 1975 (*ibid.*) (with 50 found by Aggarwal (2000) in 1994). The increase of borewell drilling powered by electricity is also a result of specific energy policies in Andhra Pradesh, as, since 2004, electricity was delivered free to eligible farmers (Fosli 2014; Nageswara Rao et al. 2009).

Farming had also decreased due to the split of households and the formation of nuclear families (Deb et al. 2014). Household debt from credit loans in Dokur had also increased, suggesting new individual ventures for agriculture (almost three times higher in 2011 than in 2000 for formal credit sources and 1.5 times for informal credit sources) (*ibid.*). The value of agricultural and farm asset holdings by households also increased, suggesting an individualization of farming activities linked to access to credit, new technology, leading to opportunities for well irrigation.

Additional community experiences in Andhra Pradesh include the Indo-Dutch bilateral initiative Andhra Pradesh Groundwater Borewell Irrigation Schemes (APWELL) Project that started in 1995. The project was designed at a time when the groundwater table had been declining

²⁴ In what is now Telangana State.

²⁵ Aggarwal (2000) added however that problems in negotiating the allocation of water for crops are rare as the main crop produced is paddy.

gradually (pre-monsoon levels felt by 10 to 15 meters between 1995 and 2005) with almost all dug wells drying-up early and the aquifer levels reaching the critical depth of 15-25 meters and discharges of 2 and 3 liters per second (found in 55-80 percent of dug wells) (Garduño et al. 2009). This project aimed to assist small farmers organizing them into Water User Groups (WUGs) and Borewell User Associations (BUAs) and construct and operate sustainable small-scale borewell schemes. These activities were implemented in partnership with NGOs and various departments at the district level. The participatory component of APWELL aimed at strengthening village institutions; improve extension networks; enhancing water users' skills in social cohesiveness; village institutional management; and local hydrological monitoring (ibid.). This initial project covered an area of around 14,000 hectares of irrigated agriculture in 370 villages involving 14,500 farmers. By 2003, the Participatory Hydrological Monitoring component had trained some 3,450 Water User Groups, 600 female self-help groups and 250 Borewell User Associations (ibid.). The project also set up District Training Units as multi-disciplinary teams comprising engineers, hydro-geologists, social scientists, agriculture graduates, gender specialists, and grass-root community organizers in charge of implementing the training programs of Water User Groups (Ratnakar and Das 2006).

District Training Units also facilitated the discussion of Water User Groups on water sharing and potential conflicts arising from water distribution after the commissioning of a borewell. These meetings were convened and embraced by the members of the group and agreements reached written down on the logbook and signed by all the WUG members. This type of participatory management and joint ownership of borewell was considered as a unique activity in the APWELL project aimed at development sustainable water utilization (Ratnakar and Das 2006).²⁶

The Andhra Pradesh Farmer Managed Groundwater Systems (APFAMGS) scheduled to be implemented between 2006 and 2009 took the APWELL experience a step further and was adopted with a sub-basin approach selecting habitations and half of the APWELL villages. Implementation was done via a nodal executing agency supported by a number of local NGOs working closely with socially-sensitive hydro-geologists in order to propose technically-sound and economically feasible groundwater management measures (Garduño et al. 2009). The project covered 650 habitations (i.e. village units) in 66 hydrological units (Reddy et al. 2014).

The concept behind the APFAMGS project was, according to the projects reports studied by Das and Burke (2013), that farmers' understanding groundwater dynamics made the difference, seeking to 'demystify' hydrology by training farmers in measurement and analysis of water data leading them to sustainable resource management.²⁷ This was achieved by enabling primary stakeholders to learn and participate in a 'Participatory Hydrological Monitoring' test implemented through a network of community based organizations. The project introduced community approaches towards observing rainfall trends with daily measurements and records, community well monitoring (yield and water levels),²⁸ crop water budgeting promoted through water balance studies in the specific micro-sheds, daily rainfall monitoring, women

²⁶ For a critical appraisal of these projects see Part 2.

²⁷ Much of the conceptual framework for the APFAMGS project was inspired by Ostrom's design principles to govern the commons (Ostrom 1990 in Verma et al. 2012) by developing clearly defined user boundaries (as hydrological units), matching governing rules to local needs by allowing users to set their own rules.

²⁸ Extensive training in Farmer Water Schools and a hydrological monitoring system were also put in place in order to facilitate a participatory exercise of community decision making (Verma et al. 2012). A network of 2,026 observation wells was put in place to control water levels and monitored by farmer volunteers, and 190 rain gauge stations were installed for every 5 square kilometres in the project area (Reddy et al. 2014).

empowerment and gender sensitization, display boards recording rainfall and water levels for communication and awareness (AFPRO 2006). Farmers in each 'habitation' (i.e. village unit) in the hydrological units were trained in measuring water tables. These trained farmers became the nucleus of the Groundwater Monitoring Committee which in turn became the basis for the Hydrological Unit Network set up on the basis of sub-basins, legally registered and allowed to operate accounts and handle funds (ibid.). The project also ensured that these rules could be flexible according to temporal and geographical contexts. The project also enabled the development of self-monitoring systems with training and monitoring in place.

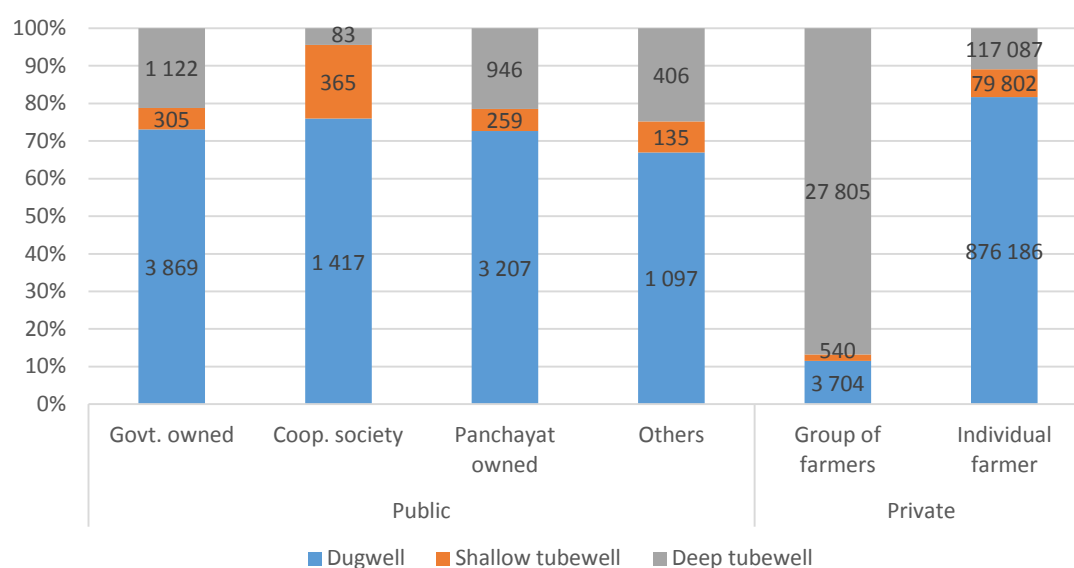
However, as will be described later in Part 2, the design and setting up of the APFAMGS encountered some difficulties. The project continuation suffered after donors stopped funding it and during its set up it did not include formal recognition of the sanctioning authority of the Groundwater Monitoring Communities regarding sanctions for violators nor the formal definition of dispute resolution methods (each community would take up this role if wanted) (Verma et al. 2012).

2.2 Gujarat

2.2.1 Groundwater resources and management in Gujarat

The geological diversity in Gujarat, with different types of rock formations has produced different groundwater occurring situations. Broadly speaking the State can be divided into two main hydrogeological units: porous formations comprising alluvium with consolidated and semi-consolidated sedimentary rocks, and fissured formations comprising consolidated sedimentary rocks (Gupte 2009). Most of Gujarat's groundwater development occurs in the former, in the mainland areas through 600 metre thick multi-layered aquifer systems comprised of Quaternary alluvium and Tertiary sediments (ibid.). Saurashtra and the south and south-eastern parts of Gujarat are formed by the hard and fractured rock formation of the Deccan Basalt Trap with little groundwater yielding potential. Its coast line shows different lithological characteristics as well, with scattered aquifer systems consisting of unconsolidated alluvium formations, marshes, and fissured metamorphic formations (ibid.). Precipitation falls unevenly in the State, varying from 2,000 millimetres in the south to as low as 300 millimetres in the northwest (ibid.). Most wells in Gujarat are individually owned tubewells (over 870,000 wells out of a total of 1.1 million) although there are around 27,800 deep tubewells owned by groups of farmers (Figure 28). Groups of farmers coalesce around the investment in a well and pull resources together in order to overcome the costs required to drill a deep well.

Figure 28. Well ownership in Gujarat



Source: Based on data from Minor Irrigation Schemes Census 2010, Ministry of Water Resources, Government of India.

Groundwater management started being regulated in Gujarat in 1967 when safe well distance was introduced in order to prevent over-abstraction (ibid.). The amendment of the old 1879 Bombay Irrigation Act of 1976 tried to limit the drilling of deep tubewells in the alluvial parts of Gujarat State but failed to be enacted due to serious legislative delays, only to enter into force in 1988 (Dubash 2002; Gupte 2009).²⁹ Other resolutions enacted by the government in the 1960s regulated farmers' access to government loans and credit to dig a well of a depth less than 150 feet by only observing area-specific spacing criteria (without the need for a formal authorization) (Bhatia 1992). For wells deeper than 150 feet a 'no objection certificate' was introduced in 1967 in order to obtain a loan from the government (ibid.). The government would consider the state of groundwater resources in the area, the annual recharge and extraction rates, well spacing, and well density in the area (ibid.).

Several later changes however reduced the effectiveness of these regulations, as in 1982 a 'special case' category was introduced for new tubewell applications, allowing high-level Gujarat Water Resources Development Corporation officials to deal with these cases directly for tubewells not fulfilling the stipulated drilling criteria (ibid.). Well spacing rules were also eased, with the abolition of two of the three well spacing categories (zone with a minimum distance between wells of 5,000 feet and 7,000 feet) and the relaxation of these rules for cooperatives 'belonging to economically and socially backward cases' (Bhatia 1992: 51). The Amendment to the Bombay Irrigation Act was revived in the Gujarat Ordinance No.2 of 1989, making compulsory the acquisition of a license for the digging of wells exceeding 5 meters in depth in coastal areas, exceeding 45 meters in specific areas, or exceeding 25 meters in all others (Bhatia

²⁹ The proposed amendment coincided with a period of drought in the State and a declared nation-wide emergency was declared between 1970 and 1977, limiting the powers of the Gujarat Assembly to pass new laws (Bhatia 1992). In 1988, despite the fact that the State Gazette had announced that the government of Gujarat would enact the Amendment, the State Legislature was not able to implement it as the ruling government "decided that the drought conditions then prevailing in the state made it impossible or unwise to enforce the Amendment" (Bhatia 1992: 57).

1992). The Ordinance was however delayed through study committees as it was felt that some aspects of the document needed 'improvement' (ibid.).

In 1992 the Ministry of Water Resources circulated a Model Bill draft to be enacted by the government. A revised draft was being considered in 2005 but it was not until 2013 that the state assembly sought to replace the 134-year-old Bombay Irrigation Act (Bhatia 1992; Gupte 2009). This revision tried, amongst other objectives, to make the requirement of licensing groundwater abstractions beyond a certain depth, compulsory and with prescribed penal actions in case of non-compliance.^{30, 31} The bill aims provoked strong reactions at the Assembly, as opposition parties deemed it 'anti-farmers' and requested its review by a select committee.³² The bill also proposed the appointment of canal officers with given powers to detain erring farmers. The bill was passed in February 2013 amidst strong opposition and received the approval by the Governor in March 2013.³³ With India's general elections looming, the governing party in Gujarat (with India's president-to-be as its leader), decided to shelve the irrigation bill in February 2014 'for fear of irking farmers', and as a message of 'good governance to the people'.³⁴

2.2.2 Aquifer recharge programs in Gujarat

In Gujarat, a 60-million people state in west India, aquifer recharge policies have been promoted by the state government through the Central Groundwater Board as part of one of the most proactive takes on groundwater depletion in India (Shah 2014). In 2008 the state set up a task force to explore the potential gains arising from an integrated managed aquifer recharge program. The task force found that 95,019 km² were appropriate for aquifer recharge (out of 196,000 km²), and that alluvium deposits were the most common formation where to develop recharge projects (with 43,728 km²). The task force further recommended the construction of 7,700 percolation tanks and over 31,000 injection wells and the modification of more than 32,000 dug wells for aquifer recharge (ibid.).

Despite the innovative approach to integrating managed aquifer recharge at the state level, Shah (2014) observed that some points had been overlooked and that the program had a very strong supply-driven approach. The task force prioritized existing large surface water storage structures for the allocation of runoff even though only 0.63 million out of a total of 3.39 million irrigated hectares in Gujarat are served by surface water canals (the other 2.76 million are

³⁰ Outlook India, "Gujarat: new bill makes license to draw water compulsory", 26th February 2013, <http://www.outlookindia.com/news/article/Gujarat-New-Bill-Makes-Licence-to-Draw-Water-Compulsory/790972> (Accessed 17th August 2014).

³¹ In the early 2000s the government of Gujarat tried to control groundwater abstraction, by declaring aquifers below 200 metres as 'protected aquifers' and designated exclusively for drinking and domestic water use (Gupte 2009). In 2001 the government also created the Gujarat Ground Water Authority. In 2002 the use of permits for new and renewed wells for industries was made mandatory.

³² According to an interview carried out by Bhatia (1992: 58-59) to a High Court advocate, "[w]hen the government does not want to take action, or wants to postpone action, the issue is referred to a Select Committee. This way the promise is fulfilled and the results is not achieved."

³³ The Times of India, "Gujarat governor gives ascent to irrigation and drainage bill", 29th March 2013, <http://timesofindia.indiatimes.com/city/ahmedabad/Gujarat-governor-gives-ascent-to-irrigation-and-drainage-bill/articleshow/19281062.cms> (Accessed 17th August 2014).

³⁴ The India Express, "Non-populist' irrigation bill shelved for fear of irking farmers", 5th of February 2014, <http://indianexpress.com/article/cities/ahmedabad/non-populist-irrigation-bill-shelved-for-fear-of-irking-farmers/> (Accessed August 17th 2014).

served with groundwater) (ibid.). This approach, criticized by Shah, does not take into consideration that these investments are currently sunk costs and that its relevance has declined vis-à-vis groundwater use and storage over the last few decades. Shah (ibid.) therefore makes the case for a more intensive approach allocating more runoff (especially from the monsoon) for aquifer recharge as it has become more critical to manage groundwater than surface storage.

The task force in charge of assessing the potential for aquifer recharge in Gujarat also did not factor in, in its work, the size of the energy footprint of groundwater-fed irrigation in Gujarat (Shah 2014). Presently, farmers are pumping groundwater from around 115 meters (representatively), using 12 billion kWh at the power stations across Gujarat. With aquifer recharge, lifting groundwater down at 30 meters instead of 115 would only require 3.30 billion kWh at the generating stations, thus representing important savings in energy consumption and investment for farmers and the state (ibid.).

In the Saurashtra peninsula in Gujarat, 15 years of aquifer recharge with dug wells have created common pool recharge structures benefiting the whole community (Shah 2009).³⁵ The stimulus for such community programs was led by spiritual leaders at the end of the 1980s and communities responded by modifying private dug wells to receive flood waters and building small check structures. In 2007, some half a million dug wells had been modified for recharge and more than 100,000 check structures had been built (ibid.). This has allowed farmers to count on one kharif crop during years early monsoon years and in good rainfall years, to have water for rabi (winter) crops.

2.2.3 The groundwater/energy nexus in Gujarat: energy policy reforms to tackle groundwater over-abstraction

As a result of a nearly three-year-long process of agitation and lobbying by big farmers, in 1987 Gujarat switched from a regime of pro-rata electricity pricing to one of flat-rate pricing (Bhatia 1992), whereby farmers would have to pay flat-rate charges each year related to their pump's power, with a uniform fee applied to all pumps above 10 horsepower (ibid.).

Until the electricity reforms in 1987, Gujarat had one of the highest electricity subsidies in India. With heavy losses in the electricity supply infrastructure, the poor power supply in the state affected the quality of life in rural areas (World Bank 2013). The government, facing the opposition of farmers, decided not to meter tubewells and to separate agricultural electricity feeders³⁶ from non-agricultural ones (Figure 29). Under this scheme, the Jyotigram Yojana scheme (Shah 2009), electricity for agriculture was rationed to 8 hours per day delivered as 3 phase power with which only tubewells could run, whilst electricity for households was supplied 24 hours per day (using a different metered connection per household).

Before the scheme, feeders served electricity for domestic, agricultural and commercial use in groups of 2 to 5 villages provided in three-phase electricity, 400 to 440 Volts for eight hours for agriculture where as domestic and other users received single-phase (230-240 Volts) round the

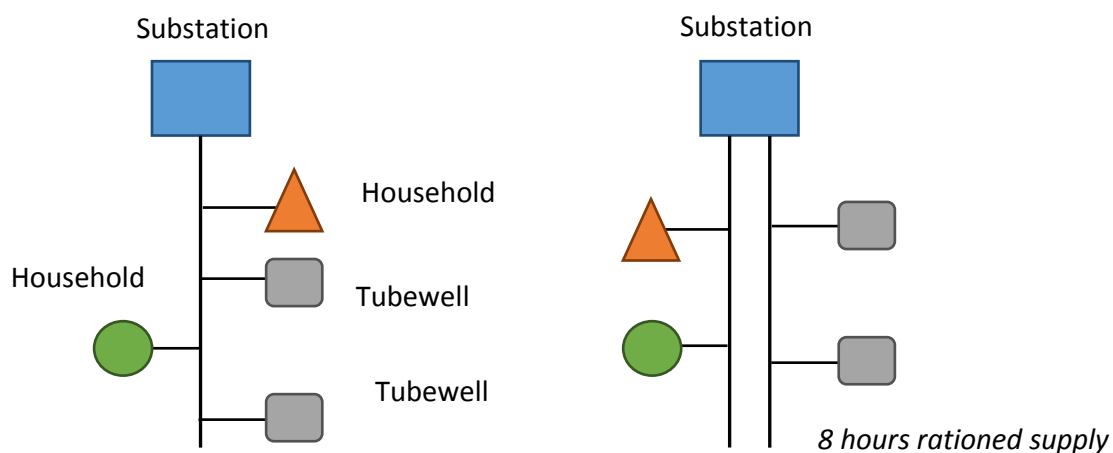
³⁵ In Saurashtra, the use of monsoon rain and floodwaters are used as a resource and not as a nuisance as many farmers still view it where the floodwaters are desilted and diverted into the dug well. In hard-rock Saurashtra, the stimulus was given by spiritual leaders who played a crucial role in encouraging the population to modify dug wells to receive floodwaters and building small check structures after a bad drought in 1987 (Shah 2009).

³⁶ Medium voltage power line used to transfer electricity from a distribution substation to distribution transformers.

clock (Grönwall 2014; Shah 2009). There was a lot of electricity theft and farmers would refuse to comply with rationing regulations as they would illegally convert the domestic and single-phase electric current into three-phase in order to have continuous power for their pumps (Grönwall 2014). This caused a higher consumption of electricity, and also a higher abstraction of groundwater. By the year 2000, the Gujarat State Electricity Board was on the verge of bankruptcy and unable to meet the demand for electricity for other customers given the high demand for agriculture (ibid.).

The Jyotigram Yojana Scheme in Gujarat was preceded by sectoral reforms aiming to unbundle and re-structure the electricity provision sector (ibid.). These were facilitated by the Gujarat Electricity Industry (Re-organization and Regulation) Act, passed in 2003 and transferring the assets and liabilities of the Electric Board to seven successor companies. The Scheme itself involved an investment of USD 260 million to build a new transmission network, re-wiring rural parts of the state and bifurcate supply feeders into agricultural and non-agricultural (Grönwall 2014; Shah 2009). A system of meters was installed on each feeder (especially the agricultural feeders so that the electricity company could identify the source of any out-of-normal peak in demand) (Mukherji et al. 2010). Electricity for agriculture was delivered through a high voltage distribution system aimed at enhancing system performance (because of its higher efficient transportation resulting in a higher quality of service delivery with less voltage fluctuations and power outages that could affect motors). A survey carried out by the World Bank (2013) in Gujarat and Rajasthan about agricultural feeder segregation, found that only 6% of consumers were complaining of low voltage problems (compared to more than 80% of consumers before the scheme), and with more than 50 percent of the agriculture consumers complaining of frequent power outages reduced by less than half after the scheme was implemented.

Figure 29. Electricity supply before and after the Jyotigram Yojana Scheme in Gujarat



Source: Based on Shah 2009 and Shah 2014 (pers. com.).

The new system implemented however was, according to Grönwall (2014), neither flawless nor popular. The Jyotigram Yojana scheme also affected small, marginal, and landless farmers as the market for groundwater shrunk and prices soared (World Bank 2013). This is due to the fact that previous to the scheme, it was a buyers' market as power was available. With the rationing of electricity, the water market shrank as the water supply was dependent on electric tubewells. As poor buyers were affected the most, the government gave in exchange more licenses for tubewells (Shah 2014, pers. com.).

This scheme was however neither tamper-proof nor popular as the dependence on electricity for pumping had led to the creation of powerful farmer lobbies aimed at maintaining the beneficial power tariff structure and not willing to see access to electricity reduced or subsidies limited (Grönwall 2014; Shah et al. 2012). The implementation of these reforms was also challenged by a culture of non-compliance, bribing, theft, vandalism from users directed to the electricity board and threats to staff (reluctant to venture into villages for fear of violence). Local politicians backed the violent opposition from farmers to the Scheme and a practical solution was found in order to protect the new infrastructure and keep local population appeased: dedicated police stations were set up and 500 former military men were deployed to try to enforce the rules and keep violence levels under control in villages (the 'electricity police' filed cases against 100,000 farmers) (Grönwall 2014; Water Governance Facility 2013).

Additionally, the system was only implemented for new tubewells or for old tubewells with meters (a small minority) (Shah 2014, pers. com.). New technologies had also to be developed to outsmart farmers (such as the Special Design Transformer, supplying continuous single-phase electricity through feeders that would trip whenever the load exceeds a limit – to prevent bypass and theft) (Grönwall 2014). In general, results show that less groundwater is withdrawn for irrigation as a consequence of the scheme but final estimations of its effectiveness are inconclusive (given the fact that there are no comparative analysis of the situation before and after the scheme) (Grönwall 2014; Water Governance Facility 2013). Farmers still pay a subsidized flat fee, but according to the official narrative, electricity consumption has been reduced (Gujarat is one of the few states in India with surplus power and its energy-related finances in order) (ibid.). Farmers have been able to choose to convert to alternative incomes (e.g. small industries, workshops, shops) when access to electricity improved in their village and access to groundwater with electric pumps decreases when electricity is rationed (Water Governance Facility 2013).

A general study by the World Bank (2013) on electricity reform in Gujarat and in other seven states concluded that the situation of the electric supply in rural India might not improve if the implementation of these schemes remained isolated and subject to a 'one size fits all' approach. Schemes and reforms also need robust data collection and analysis allowing for greater transparency around agricultural electricity consumption. Moreover, better identification of subsidy targets based, at the moment, on under-utilized data from the segregated feeders is needed. At the moment, the lack of estimates of commercial losses through the system is due to the fact that energy audit systems and operational practices are not carried out by most utilities (ibid.).

2.2.4 Groundwater abstraction and inequality in Gujarat

In Gujarat, groundwater abstraction regulation by the government has been met with resistance from organized farming communities. In spite of this mobilization, the struggle between farmers and government is drawn along the lines of political interest, resource control and privilege of certain classes and large landowners (Mukherji 2006). As this author writes, the benefits of unrestricted access to pump groundwater have disproportionately been appropriated by large-scale landowners with capital to drill deep wells and with political access and strong farmers' lobbies. Poorer farmers, on the contrary, have come to depend on these big tubewells for their livelihoods. The wealth generated by groundwater-fed irrigation has helped the social transition of a large number of farming families, however this trend is limited to large and medium-scale landowners (ibid.).

As Dubash (2002) found in Gujarat, the development of groundwater abstraction requires a constant supply of capital (to invest in a well, drilling, paying for the energy, maintenance and repairs). Due to this fact, the benefits and access to this technology are unevenly distributed across rural populations. Smaller farmers, often belonging to lower castes, have in general, less access to credit and the informal social networks needed to access informal credit (i.e. borrowing money from unofficial lenders) on acceptable terms. This results, according to Dubash's research, in a growing concentration of tubewell ownership and control over groundwater driving social polarization. These effects are however mediated by local institutional arrangements, established amongst users in order to reorganize well ownership and commoditization of groundwater via market exchanges. However, these arrangements are village specific and do not uniformly follow price-clearing predictions (ibid.).

Diwakara's (2006) findings in Gujarat, whilst examining cooperation and trust between farming communities sharing groundwater for irrigation, point towards the fact that difference in economic and demographic attributes of individuals is likely to impact trust and cooperation. While ethnic (caste) heterogeneity has no significant impact on trust and cooperation behavior at a micro level, the age of an individual has significant influence on trusting behavior. Household data shows that at the individual level, trusting and cooperating behavior varies with economic and demographic attributes of individuals. This author purports that policies aiming at economic development of farming communities need to consider these variables with other conditions under which trust and cooperation become imperative (ibid.).

2.3 Karnataka

2.3.1 Groundwater resources and management in Karnataka

Karnataka is a drought-prone state, with weathered aquifers, generally low yielding and deep. Geological formations include a predominance of hard rocks (around 79 percent of the area of the state) and groundwater occurs in these milieu under unconfined and semi-confined conditions (Government of Karnataka and Central Ground Water Board 2010). Its occurrence and movement are mostly controlled by secondary porosity after weathering, fracturing and tectonic deformation and well yields in these formations can be as high as 30 liters per second (ibid.).

Sedimentary rocks such as sandstone and limestone represent around 5 percent of the geology of the state and the Deccan basalt traps constitute around 16 percent of the area of the state (ibid.). These jointed and fractured formations can carry groundwater to deep depths (ranging from 40 to 150 meters) (ibid.). General yields are low and drawdown high with capacity of wells ranging from 0.05 to 34 liters per minute per meter. Yields can range from 4 to 1,440 m³ per day (ibid.). Small alluvial deposits along rivers and coastal areas constitute 1 percent of the state's surface.

Groundwater resources in the state are not exploited uniformly, with higher abstraction in the north and south interior of the country (Chandrakanth 2009). The state receives 73 percent of its rainfall during the monsoon season, and groundwater covers 51 percent of the water demand in the state. There are an estimated 1 million wells in Karnataka (around 700,000 dug wells and 300,000 shallow tube wells) irrigating 1.7 million hectares of land (Chandrakanth 2009; Ministry of Water Resources 2010).

In Bangalore, the rapidly growing state capital, a majority of citizens rely on groundwater either as a primary source or as a complement to the inadequate public water distribution (Water

Governance Facility 2013). Pre-monsoon groundwater depth varies between 2 to 10 meters below ground level (ibid.). Groundwater is mostly accessed via dug wells and borewells. Increasing urbanization has brought groundwater quality problems (sewage pollution) as well as over-exploitation via unlicensed wells for private drinking supply and small irrigation (ibid.).

The state of Karnataka has adopted two pieces of legislation, the Karnataka Groundwater Act for protection of drinking water in 1999 and the 2011 Groundwater Act for regulation and control of development and management, based on the 2005 Model Bill (ibid.). The former provides measures for well spacing to protect public groundwater sources for drinking water and the latter stipulates the registration of wells and drilling companies by a set date. The 2011 Groundwater act also established the Karnataka Groundwater Authority (ibid.).

Through these ambitious pieces of legislation, the state of Karnataka aims to regulate all existing well owners, who are required to apply for a registration permit before the end of March 2013. Drilling companies had also to be registered, as well as their equipment before June 2013. Anyone wanting to drill a new well is also required to obtain a permit (not for those deepening existing wells) (valid for commercial wells and drilling companies, as well as domestic wells). Applicants for new wells had also to provide information about the location of the well, the purpose of the well, and the distance from already existing wells (ibid.). The decision granted by the Authority will be based on additional considerations such as the availability of groundwater, the volume expected to be abstracted, the quality of groundwater in the area, and the potential effects on any drinking water sources in the vicinity (wells need to be placed at least 500 meters from a public drinking water source) (ibid.). Any person drilling or digging a well without a permit will be liable to a fine of up to 5,000 Rs³⁷ and could also face imprisonment for up to six months, and also risk having the well seized. Any user continuing to abstract water from an existing well without registration is liable to a fine of 2,000 Rs³⁸ and/or imprisonment for up to 3 months. The lack of permit means that the user is not eligible to any electricity supply for its well (only applicable to new wells) (Water Governance Facility 2013). The government had notified 35 taluks³⁹ (out of about 220) in 12 districts in the state by May 2015 as the places over-abstracting groundwater and where it is mandatory to register borewells.⁴⁰

The 2012 Groundwater Act also stipulated that the Karnataka Groundwater Authority can delegate powers and duties to officers at the District level. Thus, each District collector has also been given the mandate of Local Groundwater Authority. In the city of Bangalore, this role was given to the public Bangalore Water Supply and Sewerage Board (BWSSB) without being granted further funding or other incentives to deal with the matter (ibid.). The enforcement challenge for the Board is amplified by the large number of wells (between 125,000 and 500,000 estimated wells within the city limits depending on the sources) and the limited competencies and capacities of the Board in groundwater management (ibid.).⁴¹ Registration of existing users

³⁷ Around 83 USD.

³⁸ Around 33 USD. The stipulation of these amounts is however not considered a deterrent even in 2011 when they were established, as, given inflation, they will quickly be outdated (Water Governance Facility 2013).

³⁹ As part of the three-tier administrative structure in India, taluks are the middle level administrative units, between the Gram Panchayats and the districts (or zilla).

⁴⁰ "Borewell registrations mandatory in India", May 15, 2015, <https://borewellinfo.wordpress.com/2015/05/15/borewell-registrations-mandatory-in-india/> (Accessed 9th June 2015).

⁴¹ According to the reference, Subramanyan indicates a number of 125,000 wells in Bangalore although other estimates indicate a much higher number of wells ('BWSSB trying to register all the borewells in Bangalore', 12 March 2013,

in Bangalore has been done via the already existing water meter readers and assistant engineers processing applications and distributing forms to the around 100,000 drinking water customers officially owning wells (ibid.).

Even though the notification making well registration mandatory for existing wells and the application for permits for new wells after December 3rd, 2012, the BWSSB had only recorded 135 borewells three months later, considered a 'drop in the ocean'. The deadline established by the Board to register existing wells was extended three times and by December 2013 only some 66,000 well-owners had registered their well (Water Governance Facility 2013). Regarding this process the Board expressed that it did not have a plan to check on existing wells, nor sufficient staff. Also, via different media, Board officials sent contradictory messages as they had stated that the Board had no specific rules to be applied to limit illegal wells or penalize users, but at the same time had threatened that power supply would be cut to owners without permit (something outside the powers of the Board) (ibid.). Enforcement of these measures is however lax and results in a growing disrespect for legislation, fueling a culture of non-compliance with the law (ibid.).

The regulation of groundwater was also problematic as board officials were not very enthusiastic, as they knew the "various ways in which well owners tend to tamper with irrigation pump meters and refuse to adhere to binding regulations" (Grönwall 2008: 356). Moreover, the Groundwater Act does not appear to be well known, "at least in the urban environment, maybe because it comes under the Department of Rural Development and Panchayat Raj" (ibid.). Despite all these initiatives, borewells "continue to be sunk indiscriminately" according to the Department of Mines and Geology, collecting only 725,000 RS from penalty fines from 145 unregistered rig owners.⁴² There is poor awareness of the rules and there are also frauds (with intermediaries claiming that they can deal with the application procedure but keeping the fees).⁴³

2.3.2 The disruption of traditional irrigation in Karnataka

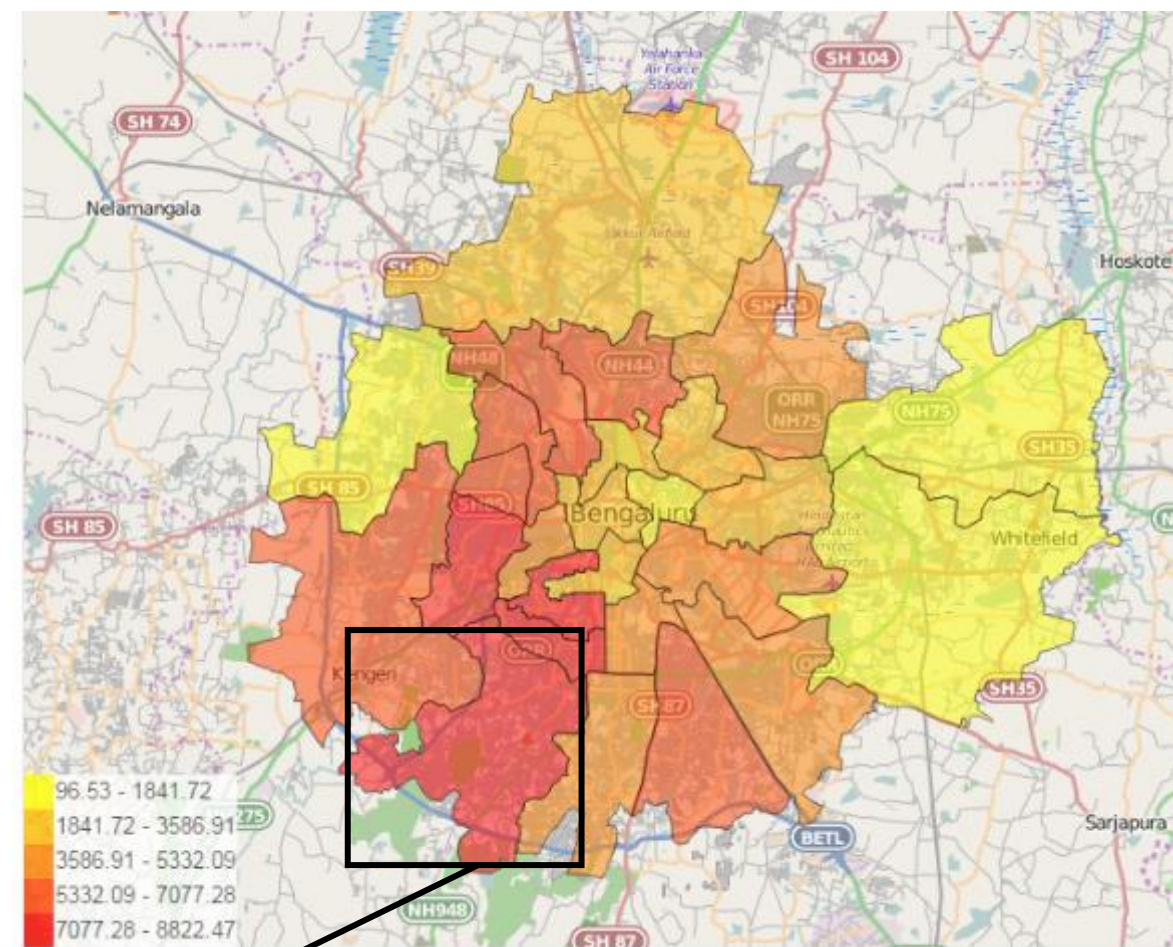
In Karnataka State, the construction and maintenance of traditional irrigation tanks by state rulers since the eleventh century were functionally linked with irrigation wells through groundwater recharge (Chandrakanth and Romm 1990). Although institutions governing such activities were largely religious in nature as they were part of endowments donated to temples, they also represented economic and social relations as irrigation was expanded in the land granted to temples (Shah 2012a). Historically, construction of irrigation tanks was an act of piety conferring religious merit and their construction and maintenance were of fundamental importance for the prosperity of society, and were considered to be one of seven meritorious acts a person could perform in a lifetime (Chandrakanth and Romm 1990). Their construction however, as Shah (2012a) has studied, represented political and ideological control by the elites funding these schemes in the form of compulsive labor for some communities.

<http://bangalore.citizenmatters.in/articles/5004-bwssb-trying-to-register-all-the-borewells-in-bangalore>, Accessed 9th June 2015).

⁴² Deccan Herald 2014 'Groundwater authority yet to gain ground', 12 March 2014, <http://www.deccanherald.com/content/391629/groundwater-authority-yet-gain-ground.html> (Accessed 9th June 2015).

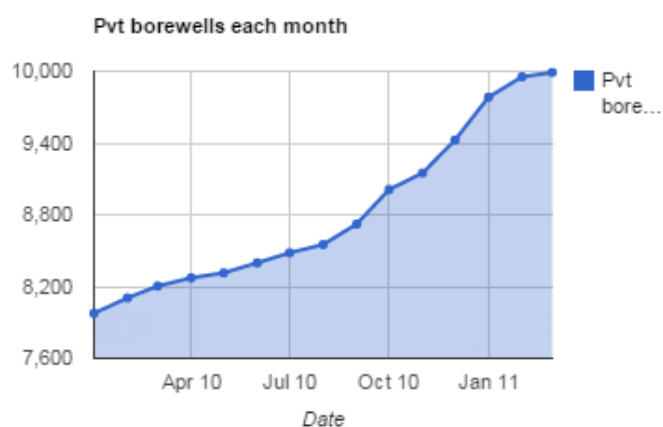
⁴³ 'Register your borewell now, if you haven't already!', <http://bangalore.citizenmatters.in/articles/bangalore-borewell-registration-2014> (Accessed 9th June 2015).

Figure 30. Estimated average borewell density in Bangalore



Feature Info

Average Pvt borewells per month: 8822.47



BWSSB subdivision ID: S2

Source: <http://bangalore.urbanmetabolism.asia/geoportal/#> (Accessed 9th June 2015).

Chandrakanth and Romm (1990) have studied the history of communities using these structures. Their construction and maintenance was also sustained by gifts and temples provided funds for maintenance and land to encourage their construction (ibid.). During the 18th century, a 'tank fund' was created by local bodies. Villagers paid a local tax for tank maintenance and fines were levied for those who did not (ibid.). Tanks also exerted positive externalities (social, environmental) by recharging the groundwater resource and also providing tank silt, which farmers applied to their farm lands when the tanks were empty. Community cohesion was sustained through the common management of these structures (ibid.).

Administrative and political changes promoted however the rapid exploitation of groundwater and discouraged maintenance of the tank systems that had sustained the vital groundwater resource (Chandrakanth and Romm 1990). Community relations organized around tank maintenance and construction slowly faded away as the government in 1911 passed the 'Tank Panchayath Regulation' leaving it to the state to restore, repair and maintain the tanks (ibid.). With British rule, land tenure reforms further weakened the traditional centers of village control and resulted in further deterioration of tanks, and customary obligations of collective efforts to maintain and manage tanks, broke down (ibid.).

Access to groundwater wells further deteriorated traditional tank systems. With the land consolidation reform of 1952, each land tenant family received a fourth share of the title to their well and continued as partners to work in it (Rosin 1993). With the subsequent rural electrification and arrival of pumps, land partners tended to divide their lands into fourths with each partner taking turns at running the pumps to irrigate their own separate fields (ibid.). Individual families developed their own wells on the lands to which they have a clear and separate land title (ibid.).

Further changes affected these systems. Shah (2012a) has explained how, with the 'Green Revolution', tank irrigation systems in the wet zone of western Karnataka intensified and expanded agriculture modernization processes as well as reproduced power relations amongst users. In some instances, tanks underwent a re-design with the disappearance of water distribution infrastructure (e.g. sluices and distribution canals) in order to favor larger farmers located in the favored parts of the tank command areas with more access to water (in upstream areas). In other instances, tanks were simply abandoned and replaced by more modern technologies. These changes were due, following Shah (ibid.), to the introduction of new rice varieties and also to shifts in state irrigation policy. With the intensification associated with the Green Revolution, new varieties of rice (as opposed to the previous dry seeds used before) needed continuous water supply and drainage. The increasing use of fertilizers reduced the necessity to use tank silt (Chandrakanth and Romm 1990). The removal of water distribution infrastructure affected rotation and ensured that head users (historically privileged and wealthier landowning families) would have constant access to water for paddy cultivation (Shah 2012a). This represented also the breakdown of the old tank managerial order as local elites felt they had no social responsibility to maintain the physical structures anymore as long as they had access to water (ibid.).

2.4 Maharashtra

2.4.1 Groundwater resources and management in Maharashtra

About 85 percent⁴⁴ of the land in the state of Maharashtra in western India overlies a complex low-storage weathered hard-rock aquifer systems originating from the Deccan Traps Basalt (Foster et al. 2007). There are however some alluvial patches in the Eastern parts of the state as well as portions in the north (Phansalkar and Kher 2006) (Figure 31). Groundwater is however a major resource for the state and in the drought-prone areas of state of Maharashtra it is a crucial resource for both rural drinking water supply and subsistence and commercial agriculture (Foster et al. 2007). According to Foster et al. (2007), intensive groundwater abstraction since the mid-1980s has led to dug wells drying up before the dry season in the Deccan Traps Basalt areas. In these geological formations, storage reduces rapidly as the water table level drops "through critical horizons in the weathering zone (usually below the uppermost 2-6m of fractured bedrock which is typically situated at 5-25 bgl.)" (Foster et al. 2007: 3). Despite Foster's views, according to the CGWB, 90 percent of aquifer units in Maharashtra are considered safe and only 2 percent are categorized as over-exploited (CGWB 2013a). The CGWB has declared 7 talukas overexploited and 1 as critical.⁴⁵ Of all monitoring wells in Maharashtra, 49 percent of them show groundwater depths of 5 to 10 meters and 26 percent show depths of 10 to 20 meters (ibid.).

According to the Ministry of Water Resources, there were 1.8 million dug wells in use in Maharashtra in 2007 and over 113,000 shallow and deep tubewells.⁴⁶ Most wells in Maharashtra are owned individually (1.6 million) and around 14,000 are owned publicly (by the government, panchayats or others) (Figure 32). Of these 1.6 million dug wells, around 600,000 of them are for irrigating land plots between 1 and 2 hectares (Ministry of Water Resources 2010). The deepening of these wells has resulted in reduced yields, also affected by the intensification of drilled borewells (ibid.). The use of deep wells had been limited for lack of access to drilling technology until 1972 when a non-governmental organization with Swiss development aid funds brought modern drilling technology to Maharashtra for addressing drinking water scarcity (Phansalkar and Kher 2006). Seeing the advantages of such technology, agricultural commercial enterprises (bananas, sugar cane, oranges) started drilling deep boreholes, even in the water scarce regions of the state (ibid.). The State's energy supply policy and pricing have also exerted influence on groundwater abstraction for irrigation. The state charges electrical power through highly-subsidized lump-sums based on pump horse-power and due to the fact that in much of the state there is high electricity coverage and the electricity supply is 'sufficiently predictable overall', farmers can rely exclusively on electric pumps, allegedly leading to inefficient irrigation practices (ibid.).⁴⁷

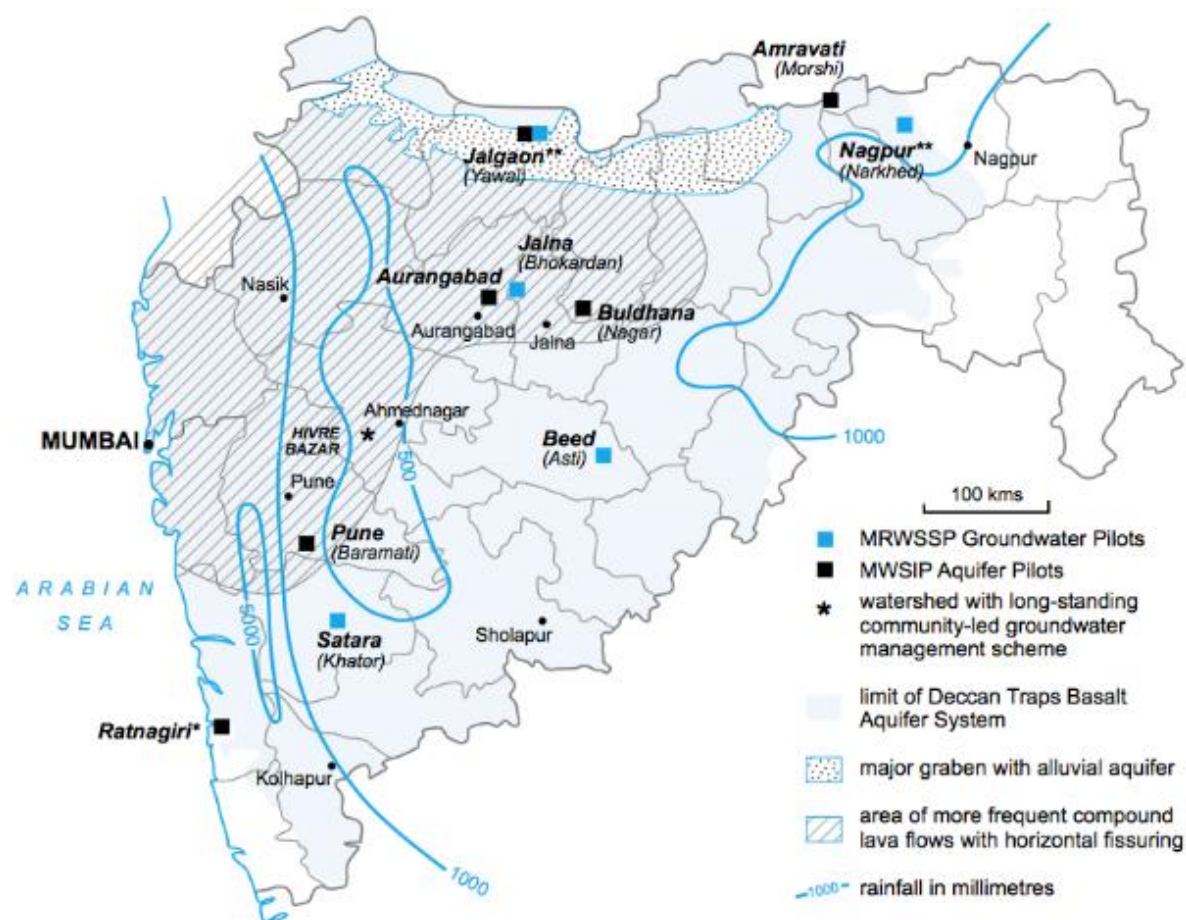
⁴⁴ Maharashtra State Profile, Central Ground Water Board, http://cgwb.gov.in/gw_profiles/st_Maharashtra.htm (Accessed 14th August 2014).

⁴⁵ Ibid.

⁴⁶ Minor Irrigation Schemes Census 2010, Ministry of Water Resources, Government of India.

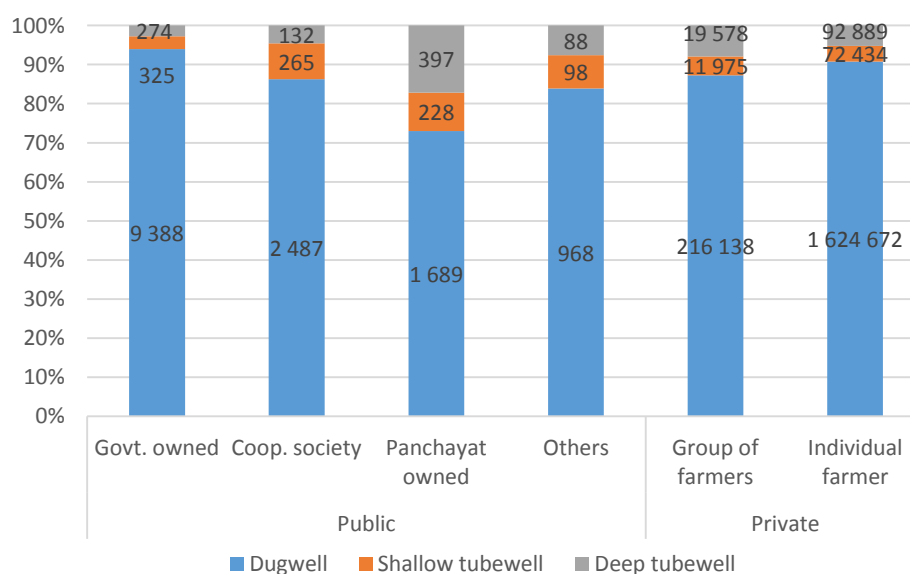
⁴⁷ Some of these inefficient irrigation practices mentioned by Foster et al. (2007) include the practice by farmers to leave pumps switched on to obtain supply when electricity comes back (as it is not a regular service). These inefficiencies according to Foster et al. (2007) have caused a financial burden on the state for little return for the state-run electric company. Additionally, farmers also operated borewells at deep levels where well entry and pump friction losses are high.

Figure 31. Hydrogeological map of Maharashtra



Source: Foster et al. 2007.

Figure 32. Well ownership in Maharashtra



Source: Based on data from Minor Irrigation Schemes Census 2010, Ministry of Water Resources, Government of India.

Drinking water needs for Maharashtra were first sustained via the state and the state-managed Groundwater Survey and Development Agency (GSDA) created in 1971 (Phansalkar and Kher 2006). The agency helped local self-government institutions (e.g. Gram Panchayats and Municipal Boards) surveying groundwater for locating public drinking water wells. Although the private right of farmers to pump water is recognized by law, the state could also confiscate wells for drinking water purposes in times of drought via administrative dictates (ibid.). As Phansalkar and Kher (2006) note, this was the beginning of state intervention in groundwater regulation in Maharashtra. As the situation in some areas of the state continued to deteriorate, the GSDA continued to assess the situation of groundwater levels. The agency categorized groundwater zones into white (zones with no scarcity), grey (zones where caution has to be exercised), and black zones (where groundwater is overexploited) (ibid.). As a result, a state-wide program of groundwater recharge was launched, with the construction of small check dams,⁴⁸ as well as a declaration by the government that the banking sector would not lend farm credits for sinking wells and the installation of pumps in zones designated as 'black' (ibid.). However, due to the fact that national guidelines issued by the National Bank of Agriculture and Rural Development about restriction of bank credits to farmers, had been ineffective, without really posing restrictions on accessing groundwater, the state realized that these measures were insufficient to cope with groundwater exploitation (ibid.). In the midst of a serious drought in the early 1990s, the state enacted in August 1993 the Maharashtra Groundwater Act (Regulation for Drinking Water Purpose).

The Maharashtra Groundwater Act of 1993 was modeled on the 1970 Model Bill, and regulated groundwater management for drinking water purposes as well as groundwater extraction for non-drinking purposes (ibid.). It specified minimum well distances between drinking water wells and other wells (500 meters), also giving power to the GSDA to regulate groundwater in areas notified with scarcity. The GSDA can impose controls on existing wells used for irrigation, whether they fall within the safe distance from public drinking sources or otherwise, authorizing bans on new wells in over-exploited watersheds, also prohibiting farmers to abstract groundwater from wells for certain periods of time for purposes other than drinking water needs (ibid.). The GSDA can also gather technical information about the interference of wells with drinking water sources and submit it to the chief administrative officer in a district, so that the well or wells can be closed down. The Groundwater Act also grants wide agency to the state as to what kind of measures can be used, going from well closure in case it affects public drinking water supply (or it has been drilled within 500 meters of a public supply source), pump removal, or even the disconnection of power supply (ibid.).

The amendment to this Act in 2000 kept the concept that groundwater belongs to the state and that the state reserves itself "the prerogative to decide the priority of appropriation and apportionment of the groundwater to meet public good as it deems fit" (Phansalkar and Kher 2006: 73). Later, in 2005, the State of Maharashtra passed the 'Maharashtra Water Resources Regulatory Authority Act', strengthening water resource control provisions for the state, empowering the Water Resources Regulatory Authority to draw State water use plans, assign water use priority, determine water allocation for users, and require drilling contractors to

⁴⁸ See Part 2.

register and require prior permission before drilling new wells in notified and non-notified areas (Aguilar 2011).⁴⁹

The implementation and application of the Act in the eastern region of Vidarbha has been studied by Phansalkar and Kher (2006).⁵⁰ These authors found out that there was a general lack of awareness about what the Act was about, and specific provisions were not clearly known or understood. There was also, as the authors write, an "exaggerated and erroneous impression about the power of the Collector⁵¹ to ban construction of new wells and to take over existing wells for the purpose of protecting drinking water sources" (Phansalkar and Kher 2006: 75). Furthermore, the lack of adequate yields from wells pushed farmers to improve the well or ask for a tapped water scheme from a nearby dam, using the opportunity which arose from the failure of their well "to press for an 'upgrade'" (ibid.).

Additionally, individual violations of the Act need to be officially registered and processed via the Gram Panchayat. Despite the fact that violations are known to take place, farmers usually consider that this type of practices are revengeful against the offenders (Phansalkar and Kher 2006). The fact that groundwater abstraction is viewed as an individual right of farmers and that there is also sympathy for the view that people would want to use groundwater to improve their lives has led to an absence of social legitimacy of legislation (ibid.). This absence of legitimacy makes the Gram Panchayat reluctant to take the required actions against offenders. Users have relied also on compromises instead of applying the regulation rigorously.⁵²

Additional problems for the State of Maharashtra include, as Aguilar (2011) purports, relate to the lack of resources. According to official estimates, between 1996 and 2000, actions to restrict groundwater abstraction in water-scarcity areas were only taken in 15 cases (taking into account the fact that Maharashtra has more than 1 million wells) (ibid.).

2.4.2 Aquifer recharge projects in Maharashtra

In view of major declines in groundwater levels and following a series of droughts in the 1970s, the then Chief Minister announced a state-wide program with the aim to recharge aquifers (Phansalkar and Kher 2006). The construction of small check dams and weirs in many streams of the country was then undertaken (ibid.). A subsequent drought in the early 1990s proved these measures to be insufficient to cope with over-exploitation by commercial agriculture and as many as 30,000 villages were declared affected by groundwater scarcity (ibid.). As a consequence, the state took legislative steps to try and preserve groundwater resources by

⁴⁹ The Maharashtra Groundwater (Development and Management) Act of 2009 which replaces the 1993 Act was published as the Maharashtra Act no. 26 of 2013 and published in the Government Gazette on the 3rd of December 2013.

⁵⁰ The study comprised surveys in fifteen villages in three of the worst affected districts (dominated by orange orchards) (Phansalkar and Kher 2006). The province of Vidarbha, the most eastern province in Maharashtra sits at the limit of the Deccan Basalt Trap (Phansalkar 2003). Moving towards the easts, sandstone formations are found in Central Vidarbha (ibid.). The east of the province has weathered soils with primary porosity but low permeability which causes poor recharge levels and wells drying out once water is pumped (ibid.). The orange producing area is located in the north-eastern part of the province, where alluvial deposits are found and historically shallower groundwater was tapped into via dug wells. Groundwater development is based on the competitive struggle between users and well owners and is encouraged through well digging rather than the increase in well depth (ibid.).

⁵¹ The Collector is the chief administrative and revenue officer of an India district.

⁵² The authors Phansalkar and Kher (2006) refer to one case as illustrative where a compromise has been reached between local officials and farmers. In one instance, the offender was told that he would continue irrigating his orchards as long as he supplied his village with drinking water to the village during stipulated hours every day. The matter was then closed and resolved without going to court or even formally registering the offence under the Act.

enacting the above mentioned Maharashtra Ground Water (Regulation for Drinking Water Purposes) Act in 1993 (ibid.).

In the Kolwan Valley, Maharashtra, Kulkarni et al. (2005) found that artificial recharge in the area has been able to balance recharge and discharge and translate into the maintenance of water levels and baseflows to streams and rivers, and consequently lagging stream flows (up to two additional months in project watersheds). However, of the 7 recharge structures studied in the Kolwan Valley, only three indicated evidence of artificial recharge whilst the other 4 structures were largely 'water harvesting' structures for irrigation often collecting baseflow or precipitation.

Aquifer recharge levels originating from the project are quite small compared to rainfall or surface runoff although this limitation has more to do with available storage in the aquifer than the availability of water for recharge. According to estimates by Kulkarni et al. (2005), natural infiltration exceeds 100 mm whereas estimated artificial recharge from one of the check dams is about 33 mm. This amount of water recharged is however not a small proportion when compared to the aquifer storage.

Following the construction of recharge structures, their maintenance is handed over to the watershed association and watershed committee but their involvement and activity levels are low. As a consequence, the maintenance of the structures is done on an ad hoc basis by the local NGO as the implementing project partners. The lack of maintenance of these structures in the village of Chikhalgaon, Kolwan Valley, can also be linked to a lack of clear ownership and responsibility as recharge structures such as check dams have formed new natural boundaries and zones of influence between villages and these not always coincide with existing administrative boundaries and village based management groups (Gale et al. 2006).

When Kulkarni et al. (2005) studied aquifer recharge in the Kolwan valley, groundwater abstraction was limited and therefore did not present a serious danger for aquifers. This dependence was however expected to grow, especially as complementary water for crops. Well deepening is already happening in some areas of the Kolwan valley for summer irrigation. Given this expected surge, the full repercussions of aquifer recharge will be evident once groundwater is more intensively abstracted as more storage is available in shallower aquifer to accommodate additional recharge.

2.5 Punjab

2.5.1 Groundwater resources and development in Punjab

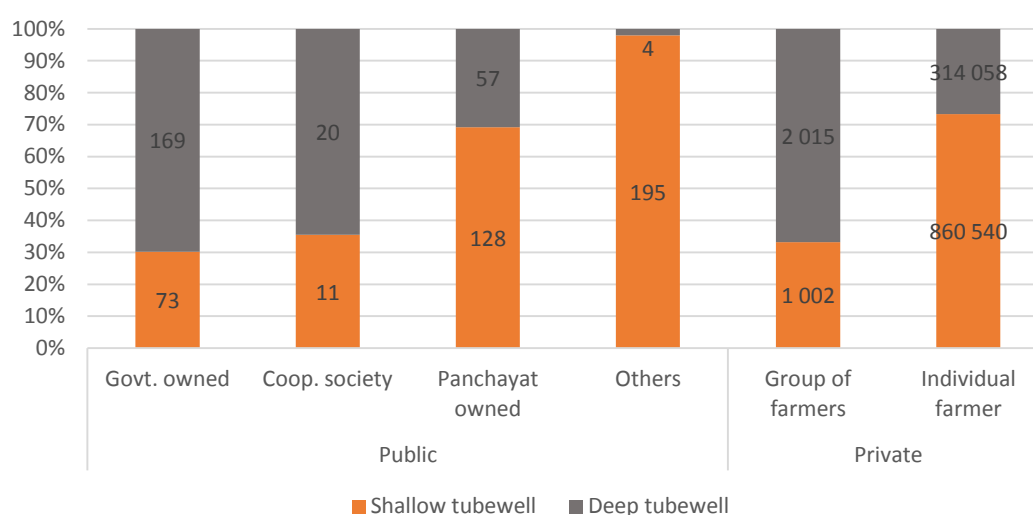
The deep alluvial state of Punjab is one of the most productive states in India agriculturally, and a leading supplier of food (rice and wheat) for the country (Fishman et al. 2011). Quaternary alluvium is the predominant geological formation underlying around 90 percent of the state, and aquifer lithology consists mostly of sandy gravel (Fishman et al. 2011; Gupta 2009). The rest of the state, the north-eastern part, is formed of tertiary hilly formations. In the alluvial plains, groundwater is found in regionally extensive and fairly thick aquifers covering over half of the state (29,000 km² of a total state area of 50,362 km²) and 450 meters deep with average well yields of 150 m³ per hour (Gupta 2009). Groundwater depths on average range between 10 to 20 meters below ground level, up to less than 5 meters in some areas. Groundwater near some of the main cities in the state is at depths deeper than 20 meters (ibid.).

The level of groundwater development in Punjab is around 140 percent above the safe yield, the highest in India, with also the highest proportion of villages having tubewell irrigation (92.2 percent) (Gandhi and Bhamoriya 2011). There are currently 103 blocks declared over-exploited by the CGWB (out of 138).⁵³ The summer monsoon accounts for 80 percent of the state's annual rainfall but even during the monsoon season, parts of Punjab experiences declines in groundwater levels (Nelson et al. 2013).

In Punjab, no shallow dug wells were reported in the 4th Minor Irrigation Schemes census (2006-2007) and the majority of wells found were shallow tubewells (around 860,000 out of 1.17 million wells in total, including 316,000 deep tubewells). These shallow tubewells are generally owned by individual farmers (Figure 33) with around 710,000 of them running with electric pumps (Ministry of Water Resources 2010). Semi-medium size landowners (between 2 and 4 hectares) have the majority of shallow tubewells (37 percent of owners) followed by medium size owners (4 to 10 hectares) with 34 percent of landowners (Ministry of Water Resources 2010).

According to Selvi et al. (2009), during the early 1950s tubewells did not exist but in 1970 their number had escalated to 500,000 (Garduño et al. 2011). One reason was the introduction in Punjab of high-yielding varieties of wheat during India's Green Revolution. Constrained by the limited availability of irrigated land with sufficient surface water, farmers were driven to private investment in groundwater abstraction, a more reliable and flexible source of irrigation (Humphreys et al. 2010; Sarkar 2011; Veeman 1978). This development, which allowed Punjab to become the bread-basket of India, was sustained by subsidized input use and high procurement prices and state-sponsored rural electrification programs (Sarkar 2011). The initial increase in costs of groundwater irrigation (e.g. tubewell construction) was offset by the gains obtained from highly productive crop varieties (ibid.).

Figure 33. Well ownership in Punjab



⁵³Punjab State Profile, Central Ground Water Board, http://cgwb.gov.in/gw_profiles/st_Punjab.htm (Accessed 10th June 2015).

Source: Based on data from Minor Irrigation Schemes Census 2010, Ministry of Water Resources, Government of India.

Punjab also presents inequity patterns regarding groundwater access linked to landholdings, widening income distribution (Sarkar 2011). Decreasing water levels in three villages studied by Sarkar (2011) in the Amritsar District (North Punjab) caused inequality in cost and returns of rice and wheat as marginal farmers (owning 1 to 2 acres) are not able to invest in technology.⁵⁴ In Sarkar's (2011) studied villages, large farmers (more than 10 acres) in the village with depletion problems have on average deeper wells than marginal farmers (109 meters against 46 meters for marginal farmers), which can lead to prior appropriation by richer farmers and potentially lead to greater inequality (ibid.). Crop selection is also dependent on capital income of farmers. Larger farmers devote a larger surface to rice cultivation (cash-crop) and gain additionally from high minimum support prices from the government as well as free electricity (ibid.). Smaller farmers in some instances cannot access irrigation water and have to shift crops (only 15 and 28 percent of cropped area by marginal and small farmers in the water depleted village of Ballab-e-Darya in Amritsar District, North-West Punjab, is devoted to rice cultivation, compared to 47 percent in the case of large farmers) (ibid.).

Due to groundwater over-abstraction, in 2009, the Government of Punjab passed an act stating that summer paddy would not be allowed to be transplanted before June 15 (Sarkar 2011; Singh 2009). The so called 'Punjab Preservation of Sub Soil Water Act' was initiated by the Punjab State Farmers Commission and promulgated as an Ordinance in 2008 (Singh 2009). This measure was aimed at preserving sub-soil water before the monsoon, thus controlling and limiting groundwater irrigation before the monsoon season (ibid.).⁵⁵ This caused preoccupation as transplantation is usually done by hired labourers from Eastern Uttar Pradesh and Bihar. With the new law, if applied dutifully, transplantation would have to be done over a very short period of time, thus limiting the availability of workforce during the peak season of rice transplantation which will increase wage rates (Garduño et al. 2011; Sarkar 2011). As a result, the Government of Punjab also encouraged the mechanization of crop sowing, making 700 paddy transplanters available to growers during the 2009 kharif season (Sarkar 2011).

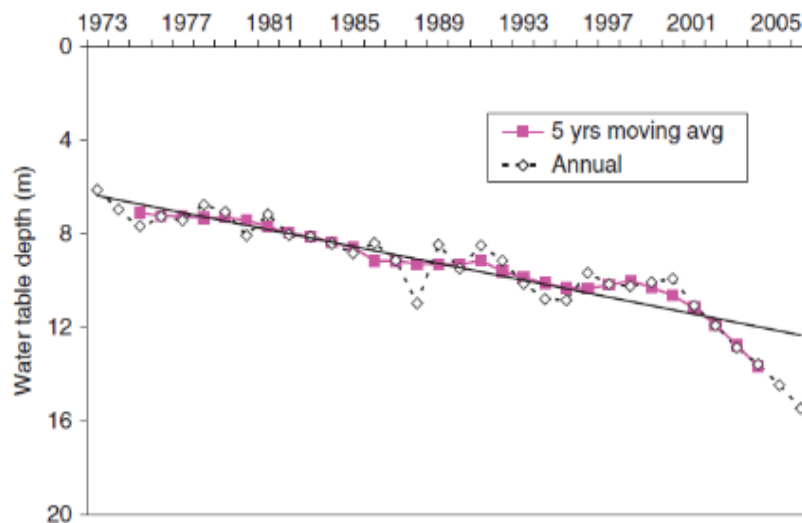
Additionally, the early transplantation of rice in mid-May would require more electricity for the pumps (equivalent to six irrigation turns, or 42 cm of water in the fields), taking about 10-12 hours to irrigated one hectare of paddy fields according to research by Singh (2009) in Central Punjab. The implementation of the Act, according to estimates by Singh (2009), saved around 270 million kWh of electricity. Data from the Punjab State Electricity Board confirms the reduction in electricity, from an expected rate of increase for 2008 of 8 percent to a real increase in demand of only 5 percent. This decline in demand would include the savings due to the Act but also, following Singh (2009), heavy rainfall patterns for 2008.

⁵⁴ Marginal operation costs would increase resulting in loss of farm inputs and lowering net returns (Sarkar 2011). Returns per unit of cost in the village studied by Sarkar (2011) with problems of depletion varied depending on the size of the farm plot. Marginal farmers (1-2 ha) had a return of 1.09 Rs per unit of cost compared to 2.00 Rs for medium size farmers (4-10 ha) and 2.94 for large farmers (more than 10 ha). The cost of groundwater depletion is borne by resource-poor farmers. These farmers have to buy water for irrigation in some instances (as the water table decreases), which in turn increases their costs.

⁵⁵ In order to be able to plant wheat in October (after the rainy season), farmers would start the planting of their nurseries for rice in advance (in late April and May one month before the rain season) this process is groundwater intensive and would require the use of tubewells as it would be done before the beginning of the rainy season (Shah 2014, pers. com.).

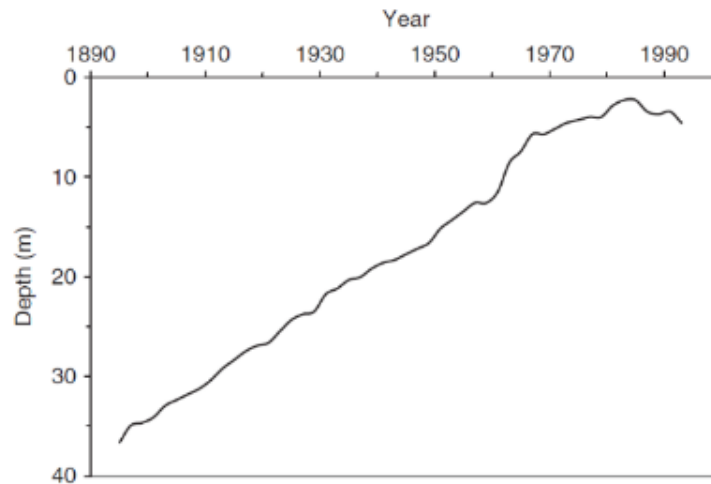
Despite serious problems of groundwater over-abstraction in Punjab (Figure 34) (103 blocks declared as over-exploited by the Central Ground Water Board), South-west Punjab is suffering from water logging and salinization of soils. These problems are broadly attributed to the specific geology of the area, a depression with poor percolation strata made of impervious clay, as well as a lack of proper drainage system and constant seepage from the Rajasthan feeder canal and the Sirhind feeder canal (Fishman et al. 2011; Planning Commission 2013). In addition, during the nineteenth century, the development of canal irrigation by the British, without proper drainage from canals and irrigated fields, raised water tables (Figure 35) (Humphreys et al. 2010). The intensity of irrigation and land-leveling leading to the obliteration of the natural topography of the area, are also added drivers of the water logging (Planning Commission 2013). Major shifts in cropping patterns and practices have also contributed to this phenomenon. The effects have been felt in much of the unsaturated zone, which has become 'thinner' with the rise of groundwater (ibid.).

Figure 34. Depth of groundwater table in June in Gujjarwal, Ludhiana District, Punjab (1973-2005)



Source: Humphreys et al. 2010.

Figure 35. Rising groundwater table in Ran Singh Wala village, Faridkot District, South-west Punjab



Source: Hira et al. 2008 in Humphreys et al. 2010.

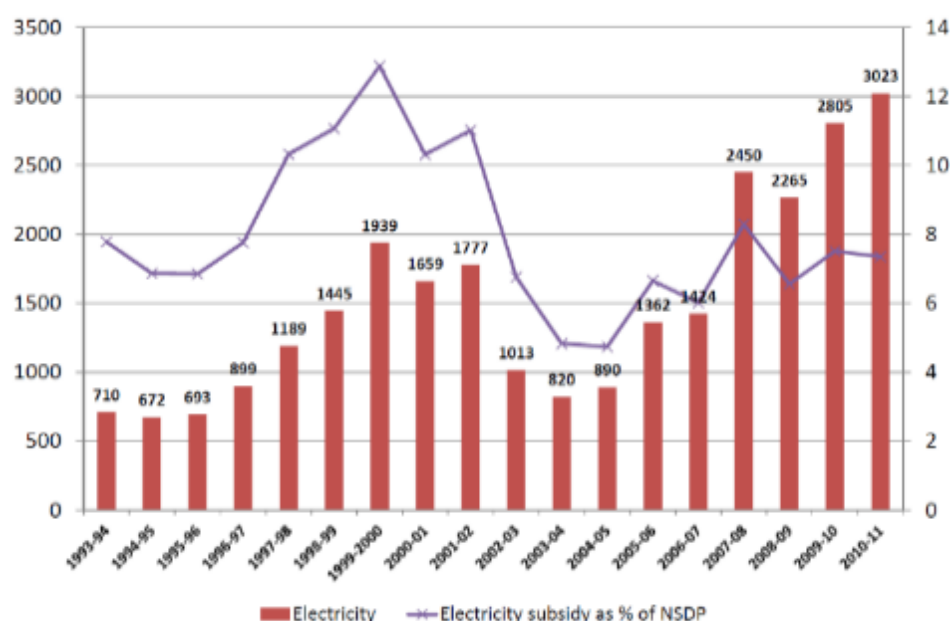
2.5.2 The groundwater/energy nexus in Punjab

The provision of free electricity to farmers in Punjab has made groundwater abstraction for agriculture accessible to farmers as part of a 'populist' political period since 1997 (Birner et al. 2007). Electricity reforms have however been hindered in Punjab by politically powerful groups (with political connections or politicians being themselves large-scale farmers), due to the nature of the electoral competition at the local and state level (with electoral promises), and by past developments that created path dependency especially, as Birner et al. (2007) have pointed out, the abolition of meters for electric agricultural connections in the 1980s.

In Punjab, over 7 percent of the State's total expenditure is dedicated to the electricity subsidy for agriculture (ibid.). Moreover, over 40 percent of the State's budget deficit is due to the subsidy of electricity (Singh et al. 2004) as farmers do not complain as long as the state government compensates utilities for the revenue losses (Figure 36) (Birner et al. 2007). Farmers are however dissatisfied with unreliable electricity supply, with voltage fluctuations which can potentially damage pumps (Perveen et al. 2012). Additionally, electricity is supplied through one grid and is only available a few hours each day (around 6 or 7 hours) leading farmers to use diesel pumps as a supplement (Fishman et al. 2011; Nelson et al. 2013).

These subsidies have encouraged farmers to abstract groundwater at unsustainable rates. Moreover, the excessive use of electricity by agriculture has also made electricity more expensive for other sectors not related to agriculture, "inhibiting thus the non-farm economy's ability to absorb labor from the farm economy, and hence, serves as a drag on the country's economic growth potential" (Nelson et al. 2013: 4). Additionally, the study by Birner et al. (2007) found out that the electricity subsidy in Punjab benefits large (4 to 10 hectares) and very large (over 10 hectares) farmers the most, with 45.4 and 28.4 percent respectively (compared to 1.9 percent for marginal farmers under one hectare).

Figure 36. Trends in power subsidy in Punjab (RS 10 millions)



Note: NSDP: Net State Domestic Product.

Source: Sidhu 2013.

2.5.3 Groundwater exchange arrangements and access in Punjab

Access to cheap electricity by farmers lowered marginal groundwater abstraction costs, providing an incentive for over-pumping as groundwater could be sold to other farmers (Pandey 2014). These markets emerged as a response to a constantly increasing demand for irrigation (ibid.). In fully groundwater-dependent economies, non-tubewell owning families have to buy water for irrigation, thus increasing their running costs (Sarkar 2011). Groundwater exchange arrangements in three villages, studied by Sarkar, (ibid.) led to sellers devoting a larger area to more profitable crops (as well as more water intensive) such as rice, than buyers, who would grow less water-intensive and also much less productive crops (i.e. maize). This would support the theory by Ballabh (2003 in Sarkar (2011) that these types of arrangements (or markets) can create 'water lords' who appropriate agricultural surplus from the poor, based on their reliable access to groundwater, control of production inputs, and larger landholdings.

Accessibility to groundwater by farmers in Punjab is different for large farmers and small and marginal farmers, and large farmers can control access to groundwater as they control larger portions of land (Sarkar 2012). According to this author, water is the most important factor for cultivation and the ownership of groundwater can determine the terms and conditions of land tenancy. Some of these small farmers, without their own source of irrigation, are not "in a position to buy water for irrigation" and "are compelled to lease out their land to the large farmers especially in the kharif season when there is acute water scarcity on account of rice cultivation" (Sarkar 2012: 8). This is still, according to the author, more profitable than rain-fed maize cultivation.

Farmers with access to groundwater will also develop exploitative tenancy relations with land owners (in cases, small farmers with no access to water) (Sarkar 2012). Lowering groundwater levels also led to standardized cash contracts (seasonal or hourly) as opposed to non-standardized and informal transactions (e.g. exchange of water and farm labour as required by

the seller) (Sarkar 2011). In the latter, arrangements would see the land owner paying for all inputs (seeds, fertilizers, insecticides, labour) and the large landlord only providing irrigation water, and profits would be distributed fifty-fifty between the land owner and the tenant (Sarkar 2012)..

These informal exchanges of services can also be subject to kinship ties, thus varying from one buyer to another. Land could be leased by groundwater sellers during water scarce kharif periods (Sarkar 2011). Farmers studied by Sarkar (2011) would consider leasing land a more profitable business than rainfed maize cultivation. Buyers have also mortgaged their land leases to water sellers, "who are more than often large landlords" (Sarkar 2011: 64). In areas of water stress, debt can rise to the extent when farmers have to sell out their land at distress prices, thus becoming landless laborers. Usurious credit arrangements can also be established between 'owners of water' and small 'owners of land', driven by the necessity of groundwater and allowing the creditor to dictate production decisions (related for instance to cropping patterns) (Sarkar 2012).

In the villages studied by Sarkar (2012), incidences of hiring of tubewells were not common as land and water are considered complementary (the leasing in and out of land automatically results in the leasing in and out of the respective tubewell). The hiring of tubewells alone was not a practice as, with groundwater depletion, it would lead to conflicts as to which party would have to deepen the well or repair it (ibid.). It was found that, in those instances where land was rented, farmers would prefer to lease-out the entire plot of land with the tubewell in order to have complete control and responsibility (ibid.).

2.6 West Bengal

2.6.1 Groundwater resources and management in West Bengal

Groundwater can be found in two distinctive types of geological formations in West Bengal: fissured formations where groundwater is found in fractures, fissures and joints in limited quantities (less than 20 m³ per hour for well yields) and in two different thicknesses, an upper weathered mantle (around 5-10 meters thick) and a deeper formation down at 60 to 100 meters. The second type of geological formation where groundwater can be found are porous alluvial formations occurring in confined conditions.⁵⁶ Up to two thirds of the State are underlined by alluvial sediments, deposited by the Ganga and Brahmaputra rivers. Aquifers in these areas can yield up to 150 m³ per hour. Following data from the CGWB (2013a), 41 percent of all monitoring wells show a water table depth between 5 and 10 meters.

According to the Central Ground Water Board, there are no aquifer units declared over-exploited in West Bengal, only one considered critical, and 37 semi-critical. There are however wide-spread incidences of arsenic contamination which threatened drinking water supplies. In 1999, Das et al. (1996) reported that arsenic concentrations above the maximum permissible levels had been found in 37 administrative blocks, all in the Ganga upper delta, covering an area of 34,000 square kilometers and a population of 30 million. In 2007, the government had banned groundwater abstraction in 54 blocks (Mukherji 2007a). Even though the source of arsenic is geological, picked up by groundwater abstraction, it is inconclusive whether increasing

⁵⁶ Groundwater Scenario of West Bengal, State Profile, Central Ground Water Board, http://cgwb.gov.in/gw_profiles/st_westbengal.htm (Accessed 17th August 2014).

groundwater abstraction is the cause of these high levels of arsenic (Das et al. 1996; Kumar and Singh 2008; Mukherji 2007a).

Despite the under-utilization of groundwater due to fragmented land holdings, unreliable energy supplies, poor economic conditions and lack of infrastructure facilities, groundwater abstraction picked up in the 1990s and subsequent decades (Sikka and Bhatnagar 2005). In 2004-2005, the 'Million Shallow Tubewell' scheme launched by the Indian Government, increased groundwater abstraction (by digging 377,111 shallow tubewells in Bihar alone) (ibid.). In West Bengal, the Ministry of Water Resources in its 4th Minor Irrigation Schemes Census established that there were around 520,000 wells in the state of which 12,000 were dug wells (of which 8,700 were owned privately by farmers) (Ministry of Water Resources 2010). The most common water lifting devices are however, shallow tubewells, with around 502,000 found in the state (96 percent of all wells in the state) (ibid.). In terms of ownership, 94 percent of these shallow tubewells are private. According to Mukherji (2007a), the number of people benefiting from groundwater in West Bengal is much larger due to informal groundwater exchanges between well owners and buyers. According to her estimates based on data from 1999, of the 6.1 million households in West Bengal, only 1.1 million had reported owning water abstraction devices whilst over 3 million reported that they hired irrigation services from other farmers. Marginal farmers cultivating between 0 and 1 hectare of land own most of these shallow wells (54 percent of all farmers) (ibid.). Diesel pumps are the most common way to abstract groundwater as they are fitted in around 80 percent of all shallow wells in West Bengal (ibid.).⁵⁷

Increasing groundwater abstraction in the 1970s and 1980s, highlighted by the Minor Irrigation Census⁵⁸ in 1986, led to the first restrictions in 1993 imposed for tubewells fitted with submersible pumps in 8 districts (Banerjee 2010; Sengupta 2011). Permits had to be obtained from the Senior Geologist or Executive Engineer before applying for an electric connection (Sengupta 2011). However, findings of the 3rd minor irrigation census in 2002 found that these restrictions had not worked, as the indiscriminate expansion of groundwater abstraction continued unabated with a predominance of privately and group-owned irrigation structures (94.4 percent recorded in the 3rd Minor Irrigation Census owned by individuals and groups of individuals) (Figure 37) (Banerjee 2010).

In view of the continuous depletion of groundwater resources, the Legislative Assembly of West Bengal introduced in 2005 the West Bengal Groundwater Resources Act (management control and regulation) (Cullet 2010). This legislation gives the competent Authority the mandate to develop policy to conserve groundwater and organize people's participation and involvement in the planning and use of groundwater (ibid.). The Act created three authorities in three different administrative levels: District Level Authority (DLA), the Corporation Level Authority (CLA), and the State Level Authority (SLA) (Banerjee 2010). The Act also created through the SLA

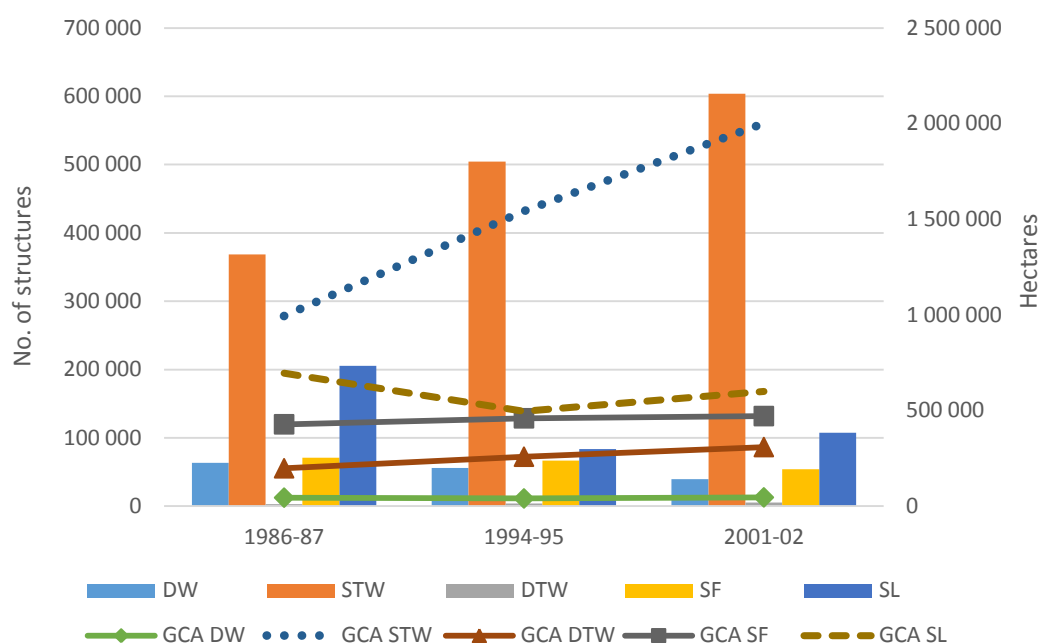
⁵⁷ Due to rising prices of diesel, having increased 450 percent from 1994 to 2006 (Mitra and Buisson 2014), Indian-made diesel pumps are being replaced by Chinese made pumps as they cost less to run (more fuel efficient) and can also run on kerosene which is cheaper than diesel or on a mixture of kerosene and diesel. Their design is also lighter so they can be easily transported from the fields back home, thus reducing the number of thefts (AgWater Solutions 2010).

⁵⁸ The Minor Irrigation Census has been carried out in West Bengal in the years 1986-87, 1994-95, and 2001-02. It was sponsored by the Minor Irrigation Division of the Ministry of Water Resources. In these censuses, only surface water and groundwater irrigation schemes (both flow and lift) and with an agricultural command area of up to 2,000 hectares were considered. These agricultural command areas could be implemented by government departments as well as by individual farmers, groups of farmers, cooperatives, and local bodies (Banerjee 2010).

subsequent decentralised levels of groundwater management, forming the district level authorities and a Metropolitan authority for Kolkata (Eastern Zonal Water Partnership 2013).

After 2005, groundwater users wishing to fit a well with a mechanical or electrical pump will have to obtain a permit from the DLA or the CLA (Banerjee 2010). Before issuing the permit, the local authorities have to consider the water balance quality and quantity available in the area. The authorities have the power to issue registration permits for wells abstracting no more than 50 m³ per hour and 100 m³ in the case of the Kolkata Metropolitan Ground Water Authority. For wells drawing more water, the case is referred to the SLA (ibid.).

Figure 37. Number of structures and irrigated area for surface and groundwater irrigation in West Bengal



Note: DW: Dug well; STW: Shallow tubewell; DTW: Deep tubewell; SF: Surface flow scheme; SL: Surface lift scheme; GCA: Gross irrigation potential created.

Source: Based on data from Banerjee 2010.

2.6.2 The groundwater/energy nexus in West Bengal

The introduction of energy reforms in India has not happened without an impact on groundwater users and differences in electricity tariffs have resulted in a variety of impacts and political economy systems linked to groundwater abstraction and the use of energy for pumping. The existence of a high flat tariff in West Bengal coupled with small-sized land holdings and the abundance of groundwater, encouraged the emergence of competitive informal 'groundwater markets' (Mukherji et al. 2009; Mukherji et al. 2010). In West Bengal, the government embarked upon the task to install meters for agricultural electricity consumers, mainly due to the fact that there are no strong farming lobbies that could oppose such a policy (Mukherji et al. 2010). This decision represented for the state of West Bengal a shift from a flat rate tariff to a pro-rata tariff, altering the cost and incentive structure of pump owners and affecting their pumping behavior (ibid.). Initially, tubewell owners were under pressure to sell water to recover what they had spent in their high electricity bill. This was given the fact that their land plots were not large enough to justify the high costs of electricity flat rates, thus giving enough bargaining power to small and marginal farmers turned water buyers (ibid.). The high

level of competition kept water prices relatively stable despite increases in flat tariffs (ibid.) Between 1991 and 2006 electricity tariffs rose tenfold with the intent to keep it in line with increasing electricity generation and supply costs, whilst water prices only rose by 3 times (Mukherji et al. 2009).

The introduction of meters and the reform of the electricity sector however, changed the incentive structure for water sellers as they now pay only for the amount pumped. According to Mukherji and Das (2014), the implementation of this policy across the state was received positively amongst tubewell owners as it made economic sense to them since they were paying a very high flat tariff. Metered tariffs were fixed at a much lower rate than flat tariffs (34 to 45 percent less), which caused metered farmers to pay smaller electricity bills for similar hours of use (ibid.). At the same time, in order to establish a more accurate system of payment, the government of West Bengal also installed remotely sensed tamper-proof meters operating on the 'Time of the Day' principle (i.e. recording daily electricity consumption at different rates based on the time of the day, calculated by the electricity supplied, to discourage users from utilizing electricity during peak hours)⁵⁹ (Mukherji et al. 2009; Mukherji et al. 2010). Through this system, meters can be read remotely from more than 100 feet, and readings are transferred in real time to the regional and central commercial offices of the electricity supplier (Mukherji et al. 2009). Additionally, power theft and meter tampering were made punishable offences under the Indian Electricity Act of 2001 (ibid.).⁶⁰ This new technology was used as a management tool differentiating the cost of electricity during different times of the day to discourage from switching on their pumps during peak evening hours (ibid.). The lack of incentives to sell caused an increase in the price of sold water by 30 to 50 percent affecting water buyers and the equality of the system, as they are facing adverse conditions for buying water (e.g. advance payments) (Mukherji et al. 2010). Moreover, due to the fact that it is done remotely, villagers and groundwater users cannot intimidate meter readers anymore (ibid.). The system design also avoids the collusion of meter readers with the users as, according to the design of this system, the meter reader neither knows nor can tamper with the meter readings (ibid.).

The findings of an IWMI-led project on groundwater irrigation in West Bengal also showed a drastic reduction in the number of electric pump connections (Figure 38) between the 1980s and 2010. According to the report (AgWater Solutions 2012), constraints on groundwater use appeared during this period due to the difficulties in obtaining new electricity connections for wells and increasing diesel costs. Since 2003, the West Bengal State Electricity Distribution Company asks for the full cost of the investment (the price of wires, poles, and transformers with costs ranging from 1,000 to 4,000 USD), something beyond the financial means of smallholder farmers. This however led to informal markets for renting irrigation services whereby farmers would pay for accessing groundwater e.g. hiring pumps (around 500,000 farmers own them with 100,000 with electric engines and the rest with diesel) or the purchase of water from pump owners. Owners pump from their wells into flexible pipes and earthen

⁵⁹ The meters were devised with three tariffs: the normal tariff from 6am to 5pm at 1.37 rupees per kWh; the peak tariff from 5pm to 11pm at 4.75 rupees per kWh; and the off-peak tariff from 11pm to 6am at 0.75 rupees per kWh (Mukherji et al. 2009). The cost of meters would be recovered in eight equal payments from customers anytime within 24 months from the date of the installation of the meter (ibid.). The 'Time of the Day' principle has however been removed as farmers were disenchanted. Before the installation of meters farmers wanted them as they were paying very high flat tariffs (Shah 2014, pers. com.).

⁶⁰ According to Mukherji et al. (2009), offenders can be imprisoned for up to 5 years or fined up to 50,000 Rupees. From 2002 to 2003, 2,000 raids had been carried out, and 73 arrests made.

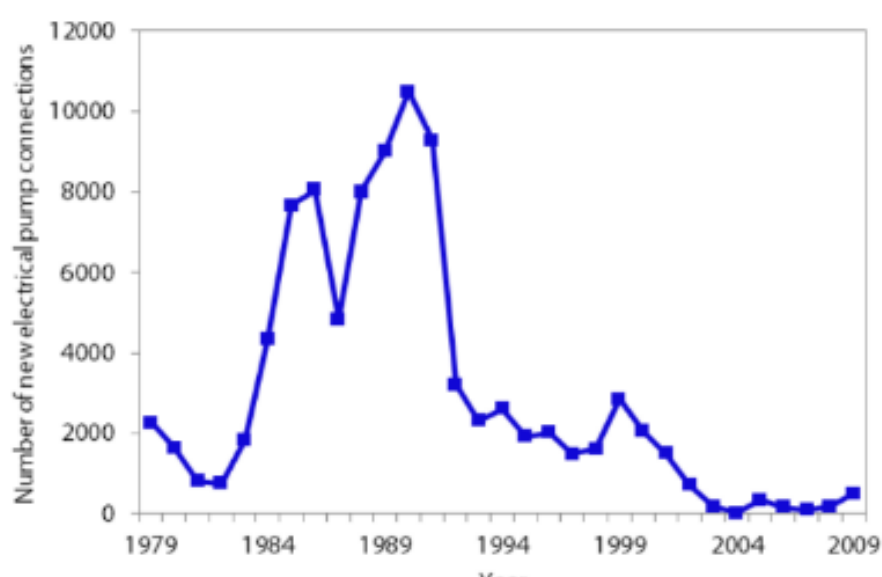
water courses used to convey water to the other fields. According to this report, about 50 percent of all rural households reported hiring some kind of irrigation service (ibid.).

Additionally, the rate of increase in the number of tubewells in West Bengal declined due to a new Groundwater Act in 2005 which required permits for wells. Following the new law, 64% of applications were rejected (even though research found inconsistencies between the level of groundwater development and the refusal of permits – probably indicating rent-seeking issues from the administration side) (Buisson 2015).

As a result of the difficulties to abstract or obtain groundwater due to inadequate supply, reduction of aquifer levels, increasing energy costs, or difficulties in obtaining new electricity connections, the cultivated surface of the lucrative crop *boro* paddy during the dry season decreased from 1.5-1.6 million hectares in the early 2000s to 1.1 million hectares in the 2011-2012 crop season (ibid.). This resulted however in a decrease of the farmers' overall profit margins (as input costs have increased and output prices remained stagnant) and the fall of living standards (ibid.).

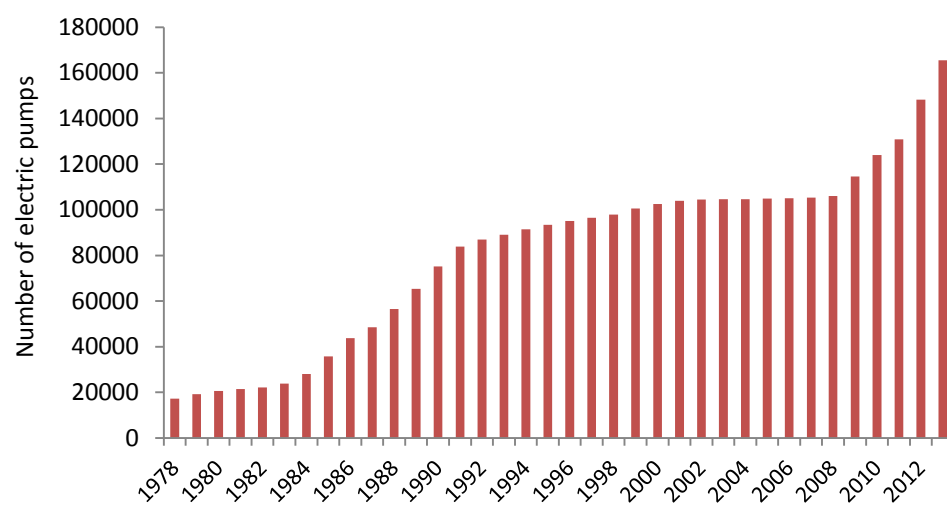
The positive trend observed in the early 2010s has lately been reversed however. The constraints to obtain new connections in West Bengal have been lifted and a program was introduced in November 2012 which included a subsidy for the price of new connections as farmers pay 7,000 Rupees for the connection and the government pays the rest (called One Time Assistance for Electrification of Pump Sets) (Buisson 2015; Shah 2014, pers. com.). Also, an amendment to the 2005 Groundwater Act in November 2011 saw a change in provision and the easement of permit issuing for small tubewells (with the new amendment, farmers located in 'safe' groundwater blocks owning pumps of less than 5 horsepower and discharging less than 30 m³/hour were exempt of permits) (Buisson 2015). This caused, as Figure 39 shows, an increase in the number of electric connections provided after 2009 following a period of stagnation in the early 2000s.

Figure 38. Decline in yearly new electric pump connections in West Bengal



Source: AgWater Solutions 2012.

Figure 39. Number of shallow tubewells permanently electrified



Source: Buisson 2015.

Part 2. Analysis

3 Groundwater abstraction and public policy in India

Groundwater abstraction in India is a phenomenon characterized by its intensity and the 'anarchy' of its development (Shah 2009). The transformation from traditional irrigation to tubewells and pumps has led to the extremely high dependence on this resource for agriculture, with around 60 percent of irrigated areas are served by wells (Das and Burke 2013; Shah 2007a). The advent of modern wells has given farmers security and flexibility, improving their social status and reducing their vulnerability and dependency on rainfall, more reliable food production and income (Molle 2013). At a more general level, the intensity of groundwater abstraction in India has also had an impact on agricultural growth and the size of the economy dependent on groundwater. Estimates show that the contribution of groundwater to aggregate farm output increased by 450 percent between 1973 and 1993 (ibid.). Also as a result, the unchecked spread of pumps and wells has created a very important number of farmers depending on this resource, with an estimated number of 17.5 million groundwater structures (Shah 2009).

In view of the dramatic depletion of the resource in some areas (Figure 17), especially in north-western India (states of Gujarat and Rajasthan with groundwater table drops of more than 16 meters over 30 years) (Sekhri 2012), state public policies have historically made use of three different types of intervention in order to manage and regulate groundwater: direct regulation via laws; indirect regulation via taxes and subsidies; and public investments in infrastructure such as collective wells, managed aquifer recharge structures, etc. (Shah 1993 in Aubriot 2006).

3.1 Public vs. private wells

Public wells in India started in the 1970s as a way to encourage the use of modern mechanical pump technologies as well as to promote equitable access to irrigation (Shah 2009). The system and design of the new public tubewells were developed by a World Bank Project between 1980 and 1983 in Uttar Pradesh. By 1993, 547 public tubewells had been dug and 328 rehabilitated or modernized (Alberts 1998). The project constructed 750 public tubewells and modernized and improved 325. In Uttar Pradesh, the Indo-Dutch Tubewell Project started in 1988 with the objective to increase production in agriculture and improve living rural conditions (ibid.).

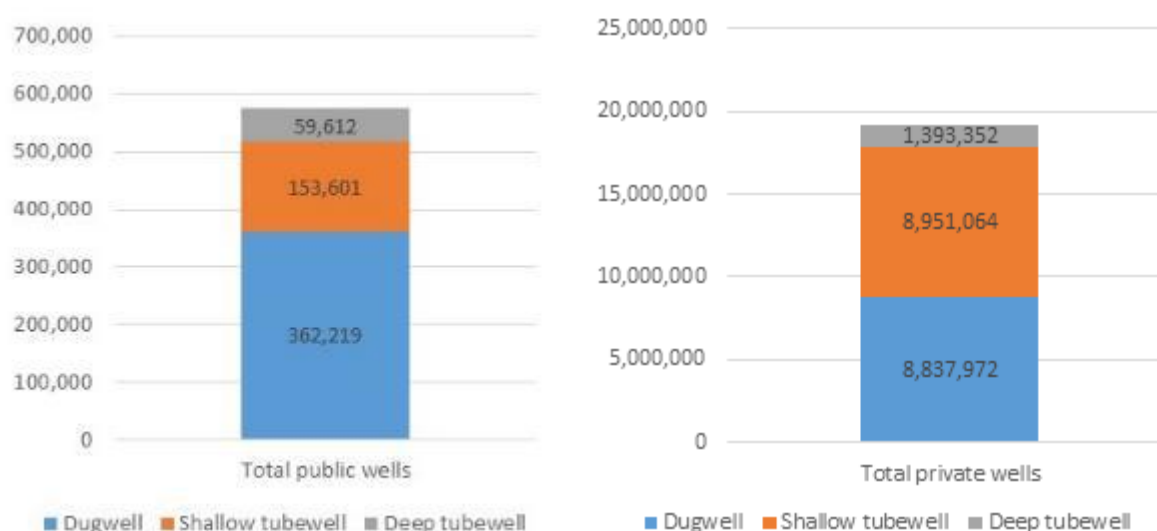
Despite their initial success, unreliability and politicization of these schemes turned them into failure notwithstanding the demonstration of the productive value of modern private tube well irrigation for neighboring farmers (Shah 2001). According to Alberts (1998), public tubewells in Uttar Pradesh were often out of order because of break downs and defects caused by voltage fluctuations. Additionally, the operation and maintenance division of the Department of Irrigation was not able to repair them in time due to small budgets and lack of planning. Moreover, the arising competition with smaller tubewells owned privately and markets selling superior irrigation services to their neighbors contributed to undermine these public programs and led to the era of 'atomistic irrigation' with private wells (Shah 2001).

As Mukherji and Kishore (2003) have examined, although the program of public tubewells in India built to provide irrigation to farmers failed, as did in general the efforts to transfer their management and ownership to water users, in Gujarat the state-owned Gujarat Water Resources Development Corporation (GWRDC) has achieved high success rates in tubewell transfer. According to their research, the state via the GWRDC had invested heavily in tubewell construction, drilling and digging some 4,000 tubewells in Gujarat. The hand over by the GWRDC of around 60 percent of previously state-owned tubewells to users, was done by a simplified

transfer process, setting transfer targets for each section office thus motivating medium and lower level staff to seriously pursue and accomplish the transfer (ibid.). Additionally, the relative success of the transfer program in Gujarat was further sustained by generalized power shortages⁶¹ and the stoppage of canal water in some areas, giving farmers the alternative to turn to tubewells to supplement surface water.

As these authors also found out (ibid.), transferred tubewells performed better than state-managed public tubewells. Despite the success, there is a lack of incentives for long-term maintenance of these tubewells (short leases on the transfer and the condition that tubewells must be returned to the GWRDC intact), and transfer is impeded when tubewells are in poor condition as no user or group of users comes forward to take over. When tubewells are in very good condition, the transfer to users is also difficult as different users or groups of users will lay claim to the tubewell, making it difficult for GWRDC to hand them over.

Figure 40. Public vs. private wells in India



Source: Based on data from Minor Irrigation Schemes Census 2010, Ministry of Water Resources, Government of India.

3.2 Legislation and groundwater management regulation at national and state levels

In India, the legal system in charge of managing and regulating groundwater is established at the state level and under India's constitution, water is managed by the states (including groundwater) (Aguilar 2011). However, the right to groundwater in India is connected to the ownership of the land (a de facto absolute ownership over the resource, which has remained unchanged since the nineteenth century) (Water Governance Facility 2013; Cullet 2012c).⁶²

⁶¹ Due to the poor state of Gujarat's electricity network and the huge losses of the Gujarat Electricity board, power was rationed for tubewells (especially those with low-power pumps installed) to 8-10 hours a day and new electricity connections were limited. Public tubewells with an already set-up connection represented an incentive for farmers to sign up for the transfer (Mukherji and Kishore 2003).

⁶² Enshrined by the Indian Easement Act in 1882 and derived from English common law (Cullet 2014). A landmark court ruling in Kerala in 2004 decided on the issue of excessive abstraction of groundwater by a Coca Cola bottling factory set up in 2000 and stated that states have the right and obligation to restrain use of groundwater if it causes harm to others. The

According to Cullet (2012a: 59), the existing groundwater management and regulatory framework in India is based on principles inherited from the second-half of the nineteenth century, which has been applied "more or less consistently during the twentieth century". For this author, regulation of groundwater is also lacking of "a clear statutory basis" and courts also play a prominent role in shaping the rules that are applied (ibid.). The inherited English common law system in India is not appropriate for the country's climatic conditions, nor is the "overbearing power over groundwater" by landlords, also excluding landless users from the extent of the rules (Cullet 2012a: 62).

Despite this legal system of private rights, India's federal government is entitled to regulate groundwater, as reminded by a Supreme Court ruling in 1997, via an authority empowered to control groundwater in order to ensure its sustainability as dictated by article 253 of India's constitution (Aguilar 2011; Cullet 2014). Following this court ruling, the status of the Central Ground Water Board (CGWB) set up in 1970 was upgraded to that of an Authority, subordinate to the Ministry of Water Resources (Cullet 2014). The original CGWB was established by the Model Bill in 1970 under the direct control of the government with the right to *notify* areas where it is "deemed necessary to regulate and control the development and management of groundwater" (Cullet 2014: 60).

Direct groundwater regulation via legislation has consisted of different legal templates, so called 'Model Bills', put forward by the Central State in 1970, 1992, 1996, 2005, and 2011 in order to be approved by the various state governments. The original Model Bill was approved in 1970 as a response to unregulated tubewell expansion and chosen for its flexibility as "it offers a framework that can be adapted to the needs and situation of individual states" (Cullet 2014: 60). Through these Model bills, the Federal government sought to foster a minimum level of control by recommending the setting up of State groundwater authorities. The template also called for the registration of existing wells and a permit-based system.

According to Cullet (2012a: 63) the different Model Bills up to 2011, which in essence retain the basic scheme adopted in 1970, include the "grandfathering of existing uses by only requiring the registration of such uses" which implies, following this author, "that in situations where there is already existing water scarcity, it does not provide an effective basis for controlling existing overuse of groundwater and will, at most, provide a basis for ensuring that future use is more sustainable". The new 2011 version of the Model Bill represents however, according to Cullet (2014), a step in the right direction as it sets the principles for groundwater management, conceiving it as a common resource, with new rules promoting equity in access, acknowledging its localized impacts (i.e. decentralized management).

The new 2011 Model Bills introduced a number of new approaches (e.g. considering groundwater as a common heritage and that the state is its trustee, the fundamental right to water and the necessity of a provision of 70 liters per capita per day), and also established that groundwater permits are to be granted indefinitely (ibid.). The Model Bill also stipulated that pre-existing rights should continue to be valid for a period of one year from the entry into force

Supreme Court interpreted some constitutional provisions as having indirect implications for groundwater, concerning the right to life and the protection of the environment (Planning Commission 2007). Despite this ruling, during its appeal a two-judge bench reversed the sentence and ruled that "there is a need to 'assume that a person has the right to extract water from his property unless it is prohibited by a statute. Extraction thereof cannot be illegal'" (Cullet 2014: 62). The only concession made was to set up an abstraction limit of 500,000 litres per day for the bottling plant. The appeal at the Supreme Court is pending (Cullet 2014).

of the law in each respective state, and providing no compensation for rights that become extinguished as a result (Cullet 2014). The new model bill of 2011 is however likely to meet resistance from farmers. The development of decentralization is likely to be lost in a plethora of new organizations specifically created at different levels (in the urban environment new 'ward groundwater committees' are proposed) (Cullet 2014; Water Governance Facility 2013).

Out of India's 30 states, 13 so far have passed Acts and regulations with respect to groundwater, loosely based on the Model Bills (Table 6) (Water Governance Facility 2013). The majority of the adopted Acts and regulatory frameworks follow the conventional 'command and control' approach to regulation of the CGWB-notified areas (ibid.). The prohibition of new wells is combined with the obligation to register the existing ones, as well as drilling companies. Regulation is being attempted on a well-by-well basis. In 2009, those states having approved groundwater acts had all adopted a non-confrontational approach by refusing to tackle existing overuse. These bills also lack safeguards to protect nature areas, regulation of pollution. Monitoring and control is mostly done, not at the watershed level, but at the administrative level unit (District or block) (ibid.).

The state, via the CGWB, monitors and assesses the state of groundwater across the country via around 16,000 observation wells. The CGWB in its last assessment on groundwater in India (2013) reviewed all 'assessment units' in the country (each state is divided into administrative assessment units) and declared 802 over-exploited (14 percent)⁶³ and 169 as critical (3 percent)⁶⁴ of which 162 were notified by the CGWB in 13 different states as to impose regulatory measures to reduce groundwater abstraction (CGWB 2013a; Water Governance Facility 2013).

In the 'notified' areas the CGWB has, since November 2012, prohibited new groundwater abstraction structures and clearance for new wells can only be obtained by drinking water agencies. In non-notified areas or areas categorized as 'safe', 'semi-critical', 'critical', or 'over-exploited', water-intensive industries need to apply for prior clearance. Breweries, drinking water companies, and textile and paper/pulp industries are not to be granted clearance in areas classified as over-exploited. In the areas categorized as safe, semi-critical, and critical, volumetric norms apply (varying from up to 200 percent, 100 percent, or 50 percent of the estimated groundwater recharge subject to conditions) (Water Governance Facility 2013). Groundwater users must also apply for a permit from the authority unless the user has installed mechanical means operated manually (hand pump or manual groundwater lifting devices).

To enforce these above-mentioned regulatory measures in the notified areas, the CGWB appointed regional and local bodies in each state to grant permission for groundwater extraction. Despite these efforts however, the process of notification to the various states, which includes a consultative process, is not transparent and not very comprehensive as well observations are sparse. Moreover, the CGWB has only carried out hydrogeological assessments, periodic monitoring, and the limitation of groundwater use in certain areas, refraining from issuing directions aiming to generally protect groundwater bodies or to take

⁶³ Mainly in the states of Andhra Pradesh (84 units); Gujarat (27 units); Haryana (68 units); Karnataka (71 units); Madhya Pradesh (24 units); Punjab (110 units); Rajasthan (166 units); Tamil Nadu (139 units); Uttar Pradesh (76 units) (CGWB 2013a).

⁶⁴ Found mainly in the states of Andhra Pradesh (26 units); Haryana (21 units); Karnataka (11 units); Rajasthan (25 units); Tamil Nadu (33 units); Uttar Pradesh (32 units) (CGWB 2013a).

measures specifically related to pollution prevention. In those notified areas, groundwater users are required to apply for a permit from the authority (unless the user proposed to use a hand-pump or a well from which water is to be abstracted manually). Despite these regulations, the various Model Bills from 1970 to 2005 system failed to tackle groundwater overuse as they provided a mere registration of uses and not a proper regulation of abstractions (Water Governance Facility 2013).

Table 6. Bills and acts regulating groundwater in India

State	Year	Regulation or Act
Andhra Pradesh	1996	Andhra Pradesh Groundwater Regulation for Drinking Water Purposes Act
	2002	Andhra Pradesh Water, Land and Trees Act and Rules
Assam	2012	Assam Groundwater Control and Regulation Act
Bihar	2006	Bihar Groundwater Regulation and Control of Development and Management Act
Chennai	1987	Chennai Metropolitan Area Groundwater Regulation Act
Delhi NCT	2010	Delhi NCT Groundwater Regulation Directions
Goa	2002	Goa Groundwater Regulation Directions
Himachal Pradesh	2005	Himachal Pradesh Groundwater Regulation and Control of Development and Management Act
Jammu and Kashmir	2010	Jammu and Kashmir Water Resources Regulation and Management Act
	2013	Jammu and Kashmir State Water Resources Regulatory Authority Regulations
Karnataka	1999	Karnataka Groundwater Regulation for Protection of Sources of Drinking Water
	2011	Karnataka Groundwater Regulation and Control of Development and Management Act
Kerala	2002	Kerala Groundwater Control and Regulation Act
Lakshadweep	2001	Lakshadweep Groundwater Development and Control Regulation
Maharashtra	1993	Maharashtra Groundwater Regulation for Drinking Water Purposes Act
	2005	Water Resources Regulatory Authority Act
	2009	Maharashtra Groundwater Development and Management Bill (yet to be notified)
Puducherry	2002	Puducherry Groundwater Control and Regulation Act
West Bengal	2005	West Bengal Groundwater Resources Management Control and Regulation Act
Pending regulations		
Chhattisgarh	2012	Chhattisgarh Groundwater Regulation and Control of Development and Management Bill
Haryana	2011	Haryana Groundwater Management and Regulation Bill
Odisha	2011	Odisha Groundwater Regulation Development and Management Bill
Uttar Pradesh	2010	Uttar Pradesh Groundwater Conservation, Protection, and Development Bill

Source: Based on data from Water Governance Facility 2013.

3.3 Main regulatory measures

The basic Model Bill from 1970 and its successive modifications give the right to the authorities to notify areas where it is deemed necessary to regulate and control groundwater abstractions. A panoply of instruments is also put forward to try and regulate groundwater abstraction (Table 7). Indirect regulation by the states in India can involve taxes and prices to control groundwater

abstraction. One of the most important and also controversial issues refers to controlling the use of electricity as it is not only an economic matter but also a political one (as many political parties have in their manifestos or political agendas access to free electricity for farmers) (ibid.).

Table 7. Groundwater bills in states and union territories in India and regulatory measures (as of 2014)

<i>State or Union Territory</i>	<i>Well permits</i>	<i>Well spacing</i>	<i>Drilling equipment registration</i>	<i>Metering*</i>	<i>Volumetric pricing (Tariffs)</i>
Andhra Pradesh (2002)	Yes	Yes (a)	Yes	No	No
Bihar (2006)	Yes	No	Yes	Yes (b)	No
Chhattisgarh (2012)	Yes	No	Yes	Yes	No
Delhi NCT (2010)	Yes	No	No	No	No
Goa (2002)	Yes	Yes (c)	No	No	No
Haryana (2013)	Yes (d)	Yes	Yes	Yes (e)	No
Himachal Pradesh (2005)	Yes	Yes	Yes	Yes	Yes (f)
Jammu and Kashmir (2010)	Yes	No	Yes	Yes (g)	Yes (h)
Karnataka(2011)	Yes	Yes	Yes	Yes	No
Kerala (2002)	Yes	Yes	No	Yes	No
Lakshadweep (2001)	Yes	No	No	Yes (i)	No
Maharashtra (2009)	Yes	Yes	Yes	No	No
Odisha (2011)	Yes	No	Yes	Yes	No
Puducherry (2002)	Yes	No	No	Yes	No
Punjab (2009) (j)	No	No	No	No	No
Tamil Nadu (2003)	Yes	No	No	Yes	No
Uttar Pradesh (2010)	Yes	Yes	Yes	Yes	No (k)
West Bengal (2005)	Yes	No	No	Yes	No

Notes: (*) In all instances where meters are part of the regulatory framework, their installation can be required by the Groundwater Authority but they are not compulsory for all wells with permit, only discretionary;

(a) according to the 2002 Andhra Pradesh Groundwater Regulation, section 10.(1), no person shall sink any well in the vicinity of a public drinking water source within a distance of two hundred and fifty meters in areas susceptible to suffer damage of groundwater levels;

(b) according to the 2006 Groundwater Regulation Act in Bihar, the Groundwater Authority has the power to direct groundwater users to install water measuring devices on any groundwater abstraction structures. According to Clause 11.(f) "provided that where the user of ground water does not comply with the directions issued to him within a period of sixty days, the Authority itself may install such water measuring device and recover the cost from the defaulting user of ground water";

(c) the state of Goa imposes a 100-meter safe distance between private wells and drinking water sources;

(d) well permits are required in all areas (notified and non-notified areas);

(e) users desiring to sink new wells/tubewells will have to install meter devices on the wells/tubewells to maintain the log book of withdrawal of Groundwater (Clause 18.I);

(f) according to Clause 12 (1), "Every user of groundwater in a notified area shall pay to the state government a royalty for extraction of groundwater at such rates and in such manner as may be prescribed" (users irrigating less than 1 hectare of land are exempt);

(g) the Groundwater Authority "can require, by order to writing, the user of ground water to install water measuring device on any ground water extraction structures: provided that the user of ground water does not comply [...] the prescribed authority shall itself install such water measuring device and the cost so incurred shall be recoverable from the defaulting user of ground water as arrears of land revenue" (Clause 119.f);

(h) water usage charges will be fixated by the Groundwater Authority "for exploration and exploitation of ground water by a consumer or a licensee" and will be reviewed every three years (Clause 128.(e)). The Authority can also disconnect the supply in default of payment of charges until the charges are paid (Clause 131.(5));

(i) the Lakshadweep Groundwater Authority will require the user, when necessary, to install water measuring devices on any water supplies to properly administer the water or where there is reason to believe that the user does not comply with the provisions contained in the regulation (Clause 14.vii);

(j) the Punjab Preservation of Subsoil Water Act aims to prohibit the sowing nursery of paddy and transplanting paddy before the state notified dates (the 10th day of May of the agricultural year or such other date notified by the Government). Contravening farmers will be penalized with a fine of 10,000 rupees for every month or part thereof, per hectare of land with paddy (Clause 3.(1) and 7.(1));

(k) Even though the Groundwater Authority does not fix tariffs for abstracting groundwater, according to the Uttar Pradesh Groundwater Conservation, Protection and Development Bill, Clause 20.(1), the Groundwater Authority "shall by notification in the gazette fix the water rates for selling the ground water from private tube wells."

Source: collected by authors.

Other forms of indirect control of groundwater abstraction adopted include overseeing borehole drilling companies but controls are weak and procedures are very simple. In Uttar Pradesh, diesel-pump dealers have been instrumental in transforming small farming communities in the region and sustaining the development of groundwater-fed irrigation (Shah 2001). In this state, farmers only need to submit a photograph and land documents so that the local pump dealer can obtain the necessary approvals and clearances from the different government departments involved, as well as from the bank. When Shah (2001) completed his research, it would take the farmer a week to get the well commissioned, and farmers interviewed by Shah, were happy to pay the pump dealers for these service fees.

Via increasing prices and tariffs, rationing electricity supply, setting up block tariffs or improving pump efficiency, states can indirectly try to curb groundwater abstraction. Other indirect ways to tackle groundwater depletion can involve setting subsidies and financial incentives to improve water efficiency (e.g. reducing losses in irrigation systems, pipes, etc.) although this could have a negative effect on the levels of groundwater recharge via infiltration of leaking pipes and networks (Kemper 2003, in Aubriot 2006). Credit-related policies have also been tried, imposing restrictions on loans to buy groundwater abstraction technology in areas of groundwater scarcity, for example Gujarat, where, since 1967, a certificate of no objection needs to be obtained for wells deeper than 150 feet (Mukherjee 2007a). In this case though, rules have become less stringent and authorizations are mostly dealt with politically and the certificate remains a mere formality (ibid.). A third indirect way to potentially reduce the abstraction of groundwater is to incentivize the change of crops towards less water-thirsty crops (via subsidies, improving access to markets, etc.) (ibid.).

3.4 Implementation issues of groundwater regulatory measures

Cullet's assessment of the different groundwater Acts across India emphasizes its lack of implementation and enforcement, due, according to this author, to the fact that the Acts adopted "are not tailored to their actual needs and particular challenges they face." The adopted Acts follow the 'command and control' approach and regulate only notified areas

(Water Governance Facility 2013). The provisions to involve users are lacking as well (ibid.). Cullet (2012a, 2012b) however also notes a general apathy from government officials, lack of data and outdated scientific understanding. In Uttar Pradesh for instance, the Groundwater Authority is dominated by senior civil servants from a variety of departments and only one NGO is represented (Cullet 2012b). The lack of implementation could also be due to the fact that the Acts were introduced following the initiative of union policy makers and not so much as a reaction to a policy need coming from each state. The fact that at the state level no policy maker wants to upset the status quo and tip the balance in favor of more implementation also limits the scope and powers of these bills. As Cullet (2012a: 65) notes, until recently "State governments often preferred opening up their coffers to ensure that sufficient groundwater could be pumped up in a context of falling water tables, rather than tackling the issue upfront by starting allocate, restrict, and take a broader view of groundwater governance." As the author also reflected in another publication, the acts avoid any confrontational approach in tackling groundwater over-abstraction and incentives for individual landowners to use water responsibly are non-existent (Cullet 2010).

The 2011 Model Bill builds on some of the shortcomings of the current legal regime but has not yet been implemented across India. The Model Bill emphasizes the recognition of a unitary approach towards water (unlike before where surface and groundwater were differentiated) and builds on legal developments that have taken place in India since 1970 (Cullet 2012b). It puts forward groundwater as a public trust and introduces the principle of subsidiarity, recognizing that aquifers should be regulated at the local level (following India's 73rd and 74th constitutional amendments (ibid.)). It also recognizes the creation of groundwater committees and the use of district groundwater councils to coordinate the application of measures. It also recognizes groundwater protection zones demarcated to protect recharge and discharge in aquifers from the threats of deterioration (ibid.). Despite these proposed changes, the different iterations of the Model Bill are based essentially on the 1970 Model Bill and the different subsequent versions "are not new essentially" (Cullet 2014, pers. com.). The Model Bill remains for its most part not implemented, with no concert for aquifer-level management as the overall management of the resource is still very much focused on structures (i.e. wells) (ibid.).

As seen in Maharashtra, one of the Acts used to regulate groundwater abstraction, the Maharashtra Groundwater (Regulation for Drinking Water purposes) Act from 1993, provided for abstraction restrictions, permits, well spacing, and granted the Collector the right to ban further uses in overexploited aquifers (Water Governance Facility 2013). However, years after the Act was passed it was found that the state "lacked political will to enforce it". Between 1993 and 2001 only 10 percent of groundwater abstractions had been declared in scarcity-affected areas and that only 15 actions had been carried against offenders and only 16 abstraction restrictions had been imposed on wells (ibid.). These implementation failures caused the state to rethink the existing management regime, setting up a Groundwater Regulatory Authority stressing the need for independent data collection and water usage conflicts to be solved at the local level. Even though decentralization of water resources management had been emphasized, these decentralization moves were however not very successful as they lacked enforcement, as illustrated by the almost complete absence of social support for the legislation in a study in 15 water-stressed villages in the west of the state (Phansalkar and Kher 2006). Local communities lacked understanding of the dispositions in the law and efforts from project partners (UNICEF) to raise awareness on the rights of users had not often been executed. Officials and politicians also did not want to upset the farmers' perception about their rights to irrigate their fields (ibid.). Government officials do not have many incentives to do an effective job, as in Bangalore and Karnataka, where according to Grönwall (2008), board officials are not very enthusiastic

with the implementation of groundwater regulation as they know users will tamper with meters and find ways to avoid the law.

The lack of effective implementation of Government rules within the states could also be associated to wider and deeper issues related to India's political history. The conflicts between a centralized state and local communities were perpetuated after India's independence as the country decided to inherit Britain's colonial administration (Mollinga 2010). The elite's project of Indian democratization constructed 'from the top' allowed new landowning elites to retain the traditional structures of power in the rural social hierarchy (ibid.). The state became exterior to rural social dynamics where relationships of patronage abound. This reinforced the dichotomy between local communities (rural) and the state and increased the gap between these two poles of governance (ibid.). The creation of intermediate levels of government (e.g. district councils) have had a low success record as "both the executive and political arms of the state seem to be keen on assuring the maintenance of their control and to be adverse to the power sharing that the establishment of governance arrangements at intermediate levels would imply" (Mollinga 2010: 425-426).

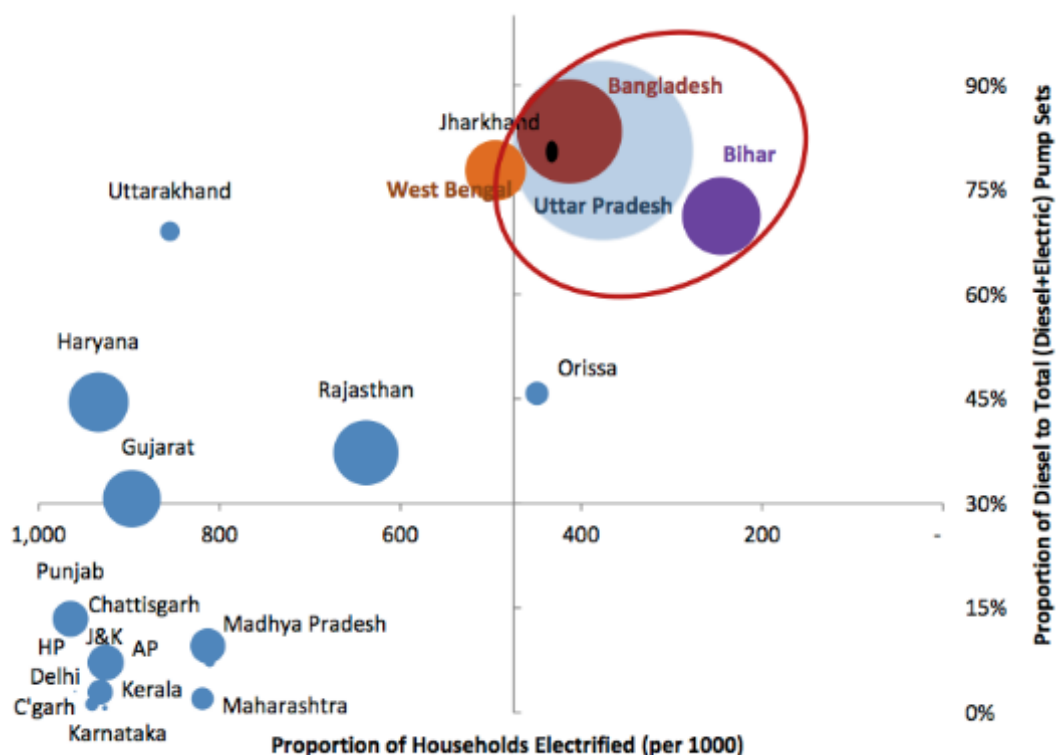
A lack of proper groundwater legislation, and control and the implementation of regulatory measures at the state level of groundwater over-abstraction has also led to distributional inequity amongst landholders and groundwater users (Nayak 2009). Research carried out by Mukherji (2006) in India highlights tensions between state public powers and farmer communities. In Gujarat, contextual and structural factors can explain the level of mobilization of farmers to counter state politics to control groundwater abstraction. According to Mukherji (2006), the high dependence on groundwater and the state's history of groundwater abstraction have created a common awareness around this resource, deeply engrained in rural farming communities. Private rights associated with land ownership are very strong and presuppose the ownership of groundwater beyond any change in the regulatory framework. Additionally, this is coupled with a widespread lack of trust of public officials and negative perceptions by urban elites of farmers' claims. These high levels of political mobilization, which could be seen as positive and reflecting healthy community dynamics and social capital, have in turn impacted the resource even further in places such as North Gujarat, as farmers have been able to maintain their control over the resource fighting back state attempts to reduce groundwater abstraction (ibid.). This strong sense of community and high levels of mobilization found by Mukherji (ibid.) have positive results though. Dubash's (2002) research in Gujarat found how the need for irrigation triggered entrepreneurial investment by local non-farming developers and the creation of informal market institutions to buy and sell groundwater across caste and class.

4 The groundwater/energy nexus

Direct management of groundwater in South Asia is challenging due to the sheer number of groundwater users (up to 25 million wells and tubewells according to some estimates) (Scott and Shah 2004). The supply of power to agriculture has been a primary force that has enabled farmers to switch to groundwater irrigation, and diesel and electricity alike, as well as pump irrigation equipment, have benefited from generous subsidies enabling farmers to develop groundwater abstraction (ibid.). Electricity-powered wells (including shallow and deep wells) represent around 55 percent of all wells in India whilst diesel-powered wells represent around 32 percent (CGWB 2013a). These data can differ geographically however, as suggested by data collected and studied by Deloitte and the World Bank (2014). Eastern states such as Bihar, Uttar

Pradesh, or West Bengal have high proportions of diesel pump sets in operation, which correspond to low levels of rural electrification (Figure 41).

Figure 41. Electrification and dependence on diesel pumps in India



Note: original study included Bangladesh. The size of the bubbles indicates the number of diesel pump sets (e.g. 3.75 million in Uttar Pradesh, 0.67 million in Bihar).

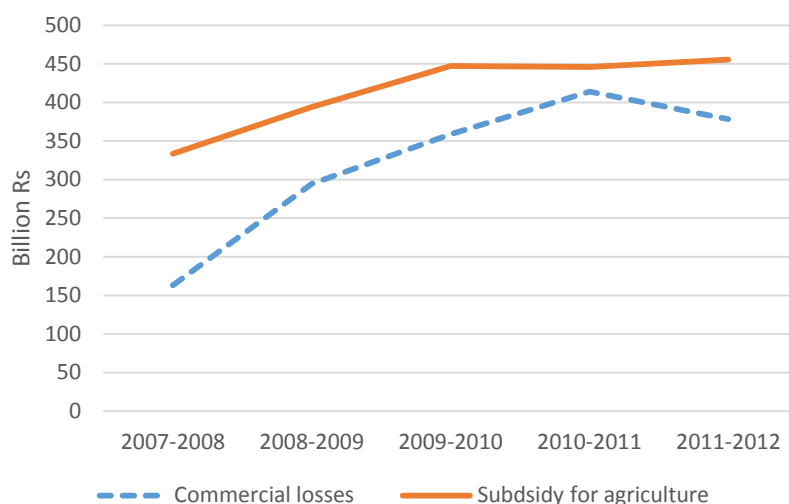
Source: Deloitte and the World Bank 2014.

Highly subsidized, and sometimes free, power available to farmers in India has however created highly inefficient electricity boards with decaying infrastructure and poor quality power, with estimated annual operation losses of 260 billion INR (around 4 billion USD) (Bassi 2014). Electricity utilities have poor financial performance which can be attributed to important commercial losses (theft through direct tapping or meter tampering) (Figure 42) (Planning Commission 2011). Some states, such as Andhra Pradesh provide 100 percent subsidized electricity to farmers whilst in Rajasthan or Maharashtra there are no meters for agricultural power consumption, electricity being charged on the basis of connected load (Bassi 2014).

As Dubash (2007) wrote, the lack of metering has led to a culture of un-accountability in the sector, leading to theft and line losses. Metering agricultural consumers and revising the management and operational rules of utilities is essential according to this study, as energy utilities do not have the necessary audit systems and operational practices to monitor and calculate commercial losses (not accounted for in these schemes) (World Bank 2013). Calculations of power transmission and distribution losses in Andhra Pradesh were underestimated according to Dubash (2007) by about 6 percent, while agricultural energy load was overstated in order to book the residual loss as agricultural consumption. Following this author, it would seem that agricultural use was in fact between a quarter and a third less than

reported in Andhra Pradesh, and that commercial losses or thefts accounted for an equivalent greater share of total consumption (ibid.).

Figure 42. Commercial losses and agriculture subsidy for power utilities and electricity departments in India



Source: Planning Commission 2011.

In the Indus-Ganges Basin for instance, Scott and Sharma (2009) found regional and state disparities of growth rates for electric pumps linked to electricity supply and pricing policies, varying markedly from state to state. On the eastern side of the basin (including India's eastern states, Bangladesh and Nepal Terai), the authors have identified an 'energy-groundwater paradox'. This is a region rich in energy sources but with inadequate electricity supply. This has led to an increased reliance of farmers on diesel pumps, which in turn limits the development of groundwater, "one of this region's most abundant and agriculturally productive resources" (Scott and Sharma 2009: 119). In places where electricity rates for groundwater pumps have been experiencing a gradual increase, in Punjab in Pakistan for instance with an increase of 126 percent between 1989 and 1993, this caused a shift of energy source in favour of locally manufactured and cheaper high-speed diesel engines (Steenbergen and Oliemans 2002).

For Dubash (2007), the real complexity in India lies in the way the use of electricity has evolved overtime, with its roots in the Green Revolution strategy of agricultural intensification. Accompanying the groundwater revolution, subsidized electricity is largely responsible for the large increase in electric pumps in the 1980s and 1990s, benefitting at the same time millions of farmers (Scott and Shah 2004). As the Planning Commission (2011: 9) put it in its 2011-2012 annual report, agricultural gains during the Green Revolution and free electricity was translated into "vote banks and this started the process of a close correlation between the power sector and politics" but in turn "completely destroyed the financial position of the SEBs [State Electricity Boards]" in many states. Additionally, the use of flat electricity tariffs and the promise of 'free electricity' has been used as a political tool to appease rural communities (Birner et al. 2007; Dubash 2007; Mukherji et al. 2010). With the added complexity to individually meter each groundwater abstraction point, this situation led to the development of water use patterns and cropping decisions bearing no connection to the scarcity value of either water or the real cost of electricity (Dubash 2007). Rural electrification brought the means to abstract groundwater more effectively, as farmers had access to water without the usual complications of the diesel supply

chain (Scott and Shah 2004) but it also made them vulnerable to power cuts and infrastructure breakdowns. With time, these contextual and historical factors have developed into a rigid political economy trapping electricity use for irrigation in a low-level equilibrium (ibid.).

4.1 Potential energy policy reforms in India

Taking a wider approach to the electricity/groundwater nexus, Dubash (2007) sustains that going beyond technocratic approaches to policy-making would provide a fuller appreciation of the intrinsic political nature of the problem and the way in which policies can be implemented (Birner et al. 2007). Different types of solutions put forward have tended to be either economic (raising the prices) and/or technical (installing meters) but have usually under-estimated the role politics play in such reform contexts, mainly seen as characterized by a lack of 'political will' to such reforms (Dubash 2007).

Tariff increases and metering are conventional solutions based on "straightforward neoclassical economic interpretations", but farmers receive distorting incentives via subsidies that lower the price of electricity and water (Dubash 2007). These interventions assume that electricity can be treated as a commodity, thus disregarding half a century of political alliances shaped by energy policy, monetary gains, and entrenched farmer practices and investments. As Mukherji et al. (2009) found out in West Bengal, electric pump owners represent less than 2 percent of the agricultural households in the state and happen to be the larger and wealthier farmers. Farmer perceptions and decisions also need to be understood, as their logic, based on short-time horizons and lack of credibility in the electricity reform process, perpetuates the electricity-groundwater conundrum (Dubash 2007).

As Mukherji et al. (2009) wrote about electricity reforms in West Bengal, new metering policies could benefit from local government structures (Gram Panchayats) which could act as regulators and set price limits at which pump owners can sell water in the village. Some villages have already started playing this regulatory role but corruption and local elite capture are challenges affecting the potential scaling-up of this proposition (ibid.). Moreover, the government should also, according to Mukherji et al. (2010: 305), "ease the process of electrification of tubewells and provide one time capital subsidy for constructing tubewells, especially for the small and marginal farmers" in order "to safeguard the interest of the water-buying farmers". This would, according to the authors, lead to an increase in the number of electric tubewells whilst fostering competition in water markets.

To tackle these problems, Dubash (2007) puts forward a solution that directly involves a democratic process through which policy-making and implementation takes place and that can sustain a workable political bargain between all users and stakeholders. This author puts forward ideas such as deepening the understanding of farmer perspectives, negotiating efforts towards a transitional path away from party politics, and finally "crafting a multifaceted implementation strategy" based on a multi-stakeholder dialogue moving beyond perspective sharing and toward consideration of concrete implementation steps (Dubash 2007: 54). But part of this solution has to come also, as Shah et al. (2004) wrote, from decision-makers, from the groundwater economy and from the energy sector, talking to each other in order to provide joint options for the co-management of groundwater and energy economies.

4.2 The politics of energy reform and their implementation

Despite the potential energy reforms in India, policies face many implementation problems. In India, the promise of 'free power' for agriculture wins votes (Narendranath et al. 2005). In Tamil

Nadu Palanisami et al. (2008) point out that the free electricity policy for farmers should be reconsidered in order to reduce groundwater over-abstraction. Energy consumption should also be recorded at the farm level and a cap on electricity consumption per hectare should be fixed according to either the pump set horsepower or the size of the farm.

Scott and Sharma (2009) contend that the coordination of energy and water management policy represent the most effective policy option to ensure the sustainable use of groundwater. Targeted and judicious energy supply, pricing and efficient management of the power infrastructure at the substation and transformer levels could further encourage sustainable groundwater practices as well as reinforce the financial position of power utilities in rural areas. However, the question of dealing with the energy/groundwater nexus is complex, intertwined with farmers' perceptions and mistrust, development of surface irrigation in the case of India, quality and reliability of power supply and sustainability of groundwater abstraction.

The regulation of electricity connections is also subject to the will of local and partisan politics. In West Bengal, local village councils control new electricity connections for submersible pumps. The issuing of new permits is co-opted by local elites such as village council heads refusing to forward new applications either because applicants did not pertain to their party or because a new permit would harm the interests of party supporters. Villages with stronger representatives also obtained disproportionately higher numbers of permits (Mukherji 2006).

Agricultural subsidies generate considerable additional income for farmers and power subsidies are also partly passed through to small farmers through exchange arrangements of groundwater services⁶⁵ (the proof being that when tariffs are reformed groundwater buyers are affected by price increases). This situation suggests that the stakeholders in the status quo are numerous and varied and that the 'micro-politics' of the status quo related to the groundwater-energy nexus are therefore important for reformers (Birner et al. 2007). The ramifications of the impact of subsidies on rural populations undermines the argument that subsidies exist only to satisfy a bunch of small and wealthy landowners (ibid.).

Additionally, discursive elements reflecting the farmers' rural ethos present a more complex picture of the different stakes at play surrounding the subsidy regime. The social fabric of the rural economy is in constant flux and although the agricultural elite exercises its power, small and medium farmers have also been able to increasingly exert pressure on local authorities and governments via their political voice, whether it is by voting or through agrarian movements (Birner et al. 2007; Mukherji 2006). The success or failure of reforms will have to take into account electoral competition and the local and state level, events such as public protests, party politics and ideology. As the case of Andhra Pradesh shows, political parties frequently change their position towards reform (as the case of the Congress Party) and their positions can also vary in different states depending on strategic considerations. Policy discourses are also important as the debate around farmers' suicides helped farmers establish themselves as a group that needs and deserves subsidies (Birner et al. 2007).

4.3 Solar powered pumps for India

Due to India's infrastructure deficiencies and lack of access to electricity, coupled with an expected increase in energy demand and in population, the use of solar energy to power

⁶⁵ Also called by some authors 'groundwater markets' (See following section).

irrigation pumps has been put forward by the central government as a potential solution to provide the agricultural sector with reliable and sustainable energy. With irrigation being the second most important direct commercial energy end use in Indian agriculture after land preparation, the amount of energy required for the sector amounted to 19 percent of the total consumption of electricity in the country (2014 data) (Purohit and Michaelowa 2005). Pump sets can be oversized in many cases in order to avoid burnout due to voltage peaks and frequency fluctuations as well as to pump higher amounts of water during the short periods when electricity is available (ibid.).

As a result of a program initiated by the Ministry of Non-Conventional Energy Sources (now known as the Ministry of New and Renewable Energy), the deployment of solar photovoltaic powered water pumps was initiated in 1993-1994 and implemented by the Indian Renewable Energy Development Agency (Purohit and Michaelowa 2005). The government aimed to provide financial assistance for subsidizing capital and interest costs and the target was to install 50,000 solar-powered pumps over a period of 5 years but by December 2004 only 6,780 solar pumps had been installed and only another 554 by March 2010 (with a total of 7,334 sets) (Desai 2012; Purohit and Michaelowa 2005).

In 2010, the Jawaharlal Nehru National Solar Mission (JNNSM) program re-launched the solar water pumping program, integrating it to the Ministry's off-grid and decentralized component of the JNNSM. The mission of this program is to achieve the target of 22 GW of solar generation capacity installed in India by 2022 (primarily by commissioning Mega Watt scale solar photovoltaic plants as well as solar thermal plants) (Shah et al. 2014). The realization however is the huge potential of farmers and their inclusion in this program as they have a strong comparative advantage because they own the land where the solar panels could be fitted (ibid.). Under this program, solar water pumping systems are eligible to a 30 percent financial support scheme (GIZ 2013). In 2014, as part of a new 3-billion rupee subsidy package,⁶⁶ the Ministry of New and Renewable Energy launched the installation of 17,500 new solar photovoltaic water pumping systems in the states of Rajasthan,⁶⁷ Tamil Nadu, Andhra Pradesh, Uttar Pradesh, Maharashtra, Chhattisgarh, Madhya Pradesh, Bihar and other selected states willing to contribute not less than 15 percent of the project costs as state shares.⁶⁸

The potential of solar-powered pumps should be seen as an energy/water intervention according to Shah and Kishore (2012) which can provide additional rents to producers and offer attractive prices for other users buying surplus energy. This is due to the fact that the economies of scale of such systems and cost structure make them interesting for small farmers wanting to double up as energy providers at a small scale (ibid.). However, this potential can also unlock further groundwater abstraction, increasing stress on the resource in parts of India as external control will be more difficult to implement once off-grid and subject to free-energy charges and

⁶⁶ Bloomberg, 'India approves 3 billion rupees in solar pump subsidies', March 6th 2014, www.bloomberg.com/news/2014-03-06/india-approves-3-billion-rupees-in-solar-pump-subsidies.html (Accessed 20th October 2014).

⁶⁷ The state of Rajasthan brought in 2011-2012 new momentum to the development of solar-powered pumps in India by introducing a 3 horsepower submersible pump through an 86 percent subsidy scheme in 16 districts with the aim to install 1,600 pumps (Tewari 2012).

⁶⁸ The aims of this new project include the reduction of diesel consumption for diesel pumps in irrigation, avoiding farmers to travel long distances to procure diesel as well as increasing cropping intensity. Government of India, Ministry of New and Renewable Energy, <http://mnre.gov.in/file-manager/UserFiles/scheme-SPV-water-pumps.pdf> (Accessed 20th October 2014).

farmers running the pumps almost limitlessly as they would not be dependent on the grid anymore (Shah and Kishore 2012; Shah et al. 2014).

5 Aquifer recharge programs

Aquifer recharge is a technique used in several states in India. It aims at augmenting groundwater resources by "constraining surface runoff and encouraging infiltration to aquifers through the construction of earthen field bunds. A large percentage of schemes are developed to store water for future use, especially with respect to agriculture" (Gale et al. 2002: 3). More generally, aquifer recharge is seen as a tool using conjunctive surface water and groundwater aiming to optimize the resource, productivity, and equity as well as attaining environmental sustainability and meeting water demands (Shah 2006). This conjunctive use can refer also to practices such as modifications of canal lining in river diversion systems and operating rules to promote groundwater recharge with monsoon floods such as in Uttar Pradesh (ibid.).

Following India's IX Five year Plan (1997-2002), a Central Sector Scheme aimed at studying groundwater recharge was undertaken. Recharge structures were built in various states in coordination with the different states through 165 different projects.⁶⁹ During the XI Five Year Plan (2007-2012), demonstration aquifer recharge projects have been undertaken by the CGWB in over-exploited and critical areas in 22 states,⁷⁰ as well as urban areas and areas affected by water quality problems. The 133 projects planned to be built are expected to contribute with 75 Mm3 of surface runoff for aquifer recharge and raise by 0.5 to 5 meters water levels in the vicinity of the structures.⁷¹ The plan aimed at building 1,661 structures of which 1,348 were finally built. Structures built included percolation tanks (152), check dams (410); recharge shafts (321).

In the state of Punjab for instance, India's 2013 master plan for artificial groundwater recharge in Punjab developed by the CGWB identified an area of 43,340 km² for recharge (CGWB 2013b). The area shows declining water levels and the vadose zone is of sufficient thickness to store recharged groundwater. Studies calculated that within this area, a potential volume of 1,201 Mm³ per year could be stored 3 meters below ground level (ibid.). Non-committed water for this plan was obtained from surface run-off in drains and spare canal water, as well as rooftop water. Long trenches were installed with recharge wells and check dams in 21 pilot projects in 9 different districts in Punjab (CGWB 2013b; Gupta 2009).

Previously though, from 1960 to 1990, "both the public and government had started realizing the importance of recharging aquifers to arrest groundwater decline and maintain groundwater levels" (Sakthivadivel 2007: 198).⁷² This was done in view of large-scale groundwater extraction depleting many aquifers. Back then, pilot studies were carried out by a number of agencies, state and federal, water supply and drainage boards, as well as research institutes (Sakthivadivel

⁶⁹ CGWB, http://www.cgwb.gov.in/Artificial_recharge.html (Accessed 3rd of February 2015).

⁷⁰ Andhra Pradesh, Arunachal Pradesh, Bihar, Chandigarh, Chhattisgarh, Delhi, Gujarat, Himachal Pradesh, J & K, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Nagaland, Orissa, Punjab, Rajasthan, Tamil Nadu, Telengana, Uttar Pradesh & West Bengal (http://www.cgwb.gov.in/Artificial_recharge.html, Accessed 3rd of February 2015).

⁷¹ CGWB, http://www.cgwb.gov.in/Artificial_recharge.html (Accessed 3rd of February 2015).

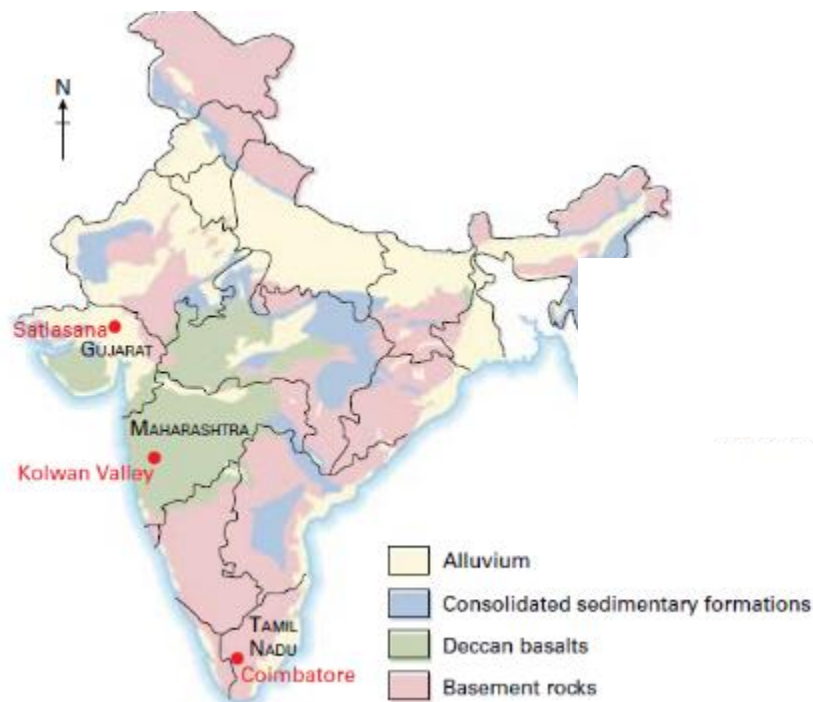
⁷² Up until the 1960s, according to Sakthivadivel (2007), groundwater recharge had been done via traditional water collection infrastructures and schemes (e.g. tank systems). This was un-organized and spontaneous driven by local communities, kings, and religious leaders to meet local needs.

2007). After the 1990s, the "spontaneous uprising and cooperation from the public supported by religious leaders, philanthropists and committed individuals to take up artificial recharging through dug and borewells, check dams and percolation ponds and, later – with the government joining hands with the local community – in implementing such schemes on a mass scale" (Sakthivadivel 2007: 198-199). States themselves have also undertaken projects to increase their aquifer recharge capacity, by enacting legislation and promulgating groundwater regulation acts ordering communities to develop rainwater harvesting schemes and artificial recharge (e.g. Tamil Nadu, Gujarat, Kerala, and Maharashtra) (Sakthivadivel 2007).

Shah (2009) has examined the potential of aquifer recharge in hard-rock aquifers, while Gale et al. (2006) and Kulkarni et al. (2005) looked at the possibility to develop community management strategies for recharge with dug-wells and percolation tanks.⁷³ With a more regional view, some of his examples illustrate success stories based on community management and cooperation. For Shah (2009), success in groundwater recharge entails the de-localization of its management and operations, as these structures have to run on the same energy that created atomistic groundwater-fed irrigation in the first place. Findings from Gale et al. (2006) about three study sites in India (Figure 43) however suggest that recharge interventions alone will not halt or reverse longer-term groundwater depletion problems. The scale of regional groundwater abstraction in areas of India such as Satlasana, Gujarat, and Coimbatore, Tamil Nadu, is far larger than any additional contribution managed aquifer recharge could provide. Moreover, aquifer recharge activities can have perverse effects and encourage investments in unsustainable farming systems, such as sugar cane production in the Kolwan Valley in the state of Maharashtra in central-west India.

⁷³ A typical percolation tank used for aquifer recharge consist of a bund of 8 to 10 metres in height, and a catchment area of about 10 to 50 km². Water stored in the tank should infiltrate within the first 3 to 4 months of the dry season to recharge the aquifer (Limaye 2010). Dug wells used for recharge are the same wells used for irrigation. Water is pumped or carried by a pipe into the well. The pipe outtake can be placed below or above the water table level.

Figure 43. Location of aquifer recharge projects in relation to geology in Gale et al (2006) study



Source: Gale et al. 2006.

Assumptions on the effects of managed aquifer recharge, which form part of a wider set of watershed development activities, include the support of livelihoods threatened by groundwater overdraft and agricultural contraction and lead to increased aquifer recharge and an improvement in groundwater availability. However, general assumptions based on 'one-size-fits all' aquifer recharge approaches are flawed according to Gale et al. (2006) as they assume they will work everywhere and benefit everyone. The use of participation mechanisms is also limited. Although interventions in the Kolwan Valley and Coimbatore areas included community participation and consultation, these were restricted to the provision of labour and information and not a true engagement and management of the project by the community. The quality of participation was also linked to an already existing presence of NGOs working in the area.

Gale et al. (2006) also referred to common coordination problems arising from the operation and maintenance activities of newly built recharge structures. Even in Satlasana and in the Kolwan Valley where more participatory programs were being implemented, the duties and obligations of different stakeholders (community committees, individuals, implementing agencies) remained a grey area. The drop-off in associative activities at the community level resulted in the involvement of only motivated individuals, the project implementing agency or no one at all. This is, according to Gale et al. (2006) due to the lack of clear incentives linked to the upkeep of recharge structures by communities. As Shah (2009) pointed out, watershed programs with aquifer recharge components have an incentive compatibility problem as they seek community-based action to create groundwater recharge but the groundwater gets captured largely by well owners.

Aquifer recharge also needs to be accompanied by basic scientific research to allow for more informed decision making at the local level. The implementation of this type of projects needs to be informed by an understanding of the local hydro-geological conditions before the projects can start. The need for incorporation of local knowledge reflects the need as suggested by Shah

(2009) for finding a common ground between 'formal hydrology' and 'popular hydrology'. Communities studied by Gale et al. (2006) were uncertain about the availability of water recharged and showed a lack of understanding and awareness of groundwater hydraulics, which acted as a major impediment for the success of aquifer recharge. This suggested the need for more education programs at the local scale as one of the goals of these practices was to transfer the management of the recharge structures to the local communities. Managed aquifer recharge projects in India also proved to be temporary solutions to redress both groundwater quantity and quality but do not represent a sustainable solution for groundwater depletion (Gale et al. 2006; COMMAN 2005).

Additional challenges to the adoption of aquifer recharge programs stem from the fact that costs and benefits may be unevenly distributed or difficult to appraise as part of the intervention (Kulkarni et al. 2005). Households and geographical areas can be differently affected and this needs to be considered from the outset of the project (Gale et al. 2006). These characteristics require avoiding easy assumptions as to what benefits aquifer recharge can bring to local communities. The impacts of aquifer recharge programs on livelihoods proved to be difficult to assess due to the lack of baseline longitudinal data on the situation 'before' the recharge. The combination of aquifer recharge with other activities part of a wider watershed management program make it difficult to single out the benefits connected to that particular aspect of the project. External factors, changes in economic conditions and access to infrastructure may also have an impact on livelihoods thus influencing equally the outcomes of the project. Kulkarni et al. (2005) found "virtually impossible" to attribute a direct correlation between the physical effects of recharge and changes to livelihood conditions in Kolwan valley. Livelihood changes are a consequence of a multiplicity of factors such as proximity to cities offering employment of non-agriculture livelihood options which also contribute to increased incomes but are unrelated to recharge activities.

In all cases studied by Gale et al. (2006), the additional recharge generated for the aquifers by purpose-built structures has been minor in relation to irrigation demand. In the Kolwan Valley for instance, aquifer recharge interventions had no direct impact on farmers' livelihood except for the direct use of impounded water for irrigation, negotiated amongst users independently of the project. In Satlasana and Coimbatore, recharge activities have helped mitigate but not reverse growing water scarcity.

Last, but not least, water harvesting projects, when developed on a large scale, have unsurprisingly redistributed the resource spatially, with downstream users in the watershed finding themselves gradually deprived of their resource. In closed/over-exploited watershed such projects are tantamount to a mere re-allocation of resource, not to supply augmentation when seen at the level of the basin (Kumar et al., 2008). Research by Everard (2015) in Rajasthan has showed that groundwater recharge projects carried out by the NGO Tarun Bharat Sangh rebuilt traditional village governance structures and user participation in community-designed and maintained water harvesting structures. This was achieved by re-constructing and managing water harvesting systems following the requests of villages and the resurrection of traditional village decision-making bodies with deliberating powers over water management (Everard 2015). Cohesion and coherence is achieved at the regional level through a water parliament established in 1998 and meeting twice a year to determine water sharing and management issues across the catchment (including dispute resolution and other activities such as reforestation) (ibid.). Work and activities are dependent on international funds (e.g. the Swedish Cooperation Agency, contributing during some years for over 77 percent of the NGO's budget) to reconstruct the structures. Nevertheless, over 30 years of work and with more than 8,600

structures built by 2008, water availability has increased raising the water table during dry seasons from 100-120 meters to 3-13 meters and with an increase in agricultural area from 42 percent to 54.9 percent (ibid.). The forested area equally increased, from 7 percent to 40 percent (ibid.).

6 Groundwater use and social arrangements

6.1 Service exchange arrangements for irrigation in India

In India, arrangements to access irrigation water, called by some authors 'groundwater markets' (Mukherji 2008; Mukherji et al. 2009; Mukherji et al. 2010), represent local institutions whereby owners of irrigation means either directly sell water (groundwater market) or rent out their pumps (service market) to neighbors (depending on whether well drilling and/or the purchase of a pump/motor is the limiting factor to using groundwater), against a pecuniary or symbolic gain (Villholth et al. 2009; Mukherji 2008). The informality of these exchanges is due to the fact that they are established outside the purview of any legal framework, as water rights are not separately defined from land ownership (Mukherji 2008). These 'markets' present wide variations in terms of organizational arrangements and behavior of buyers and sellers according to the region and to the local context (Tamuli and Dutta 2015). Markets are also linked to other rural markets such as informal credit markets, pump markets, and land tenancy markets (ibid.).

The country-wide study by Mukherji (2008) on groundwater exchange arrangements in India showed a very large increase in the area irrigated through pump rental markets between 1976 and 1988, and an ubiquity of these types of exchanges not only in the country but also in the region (Mukherji and Shah 2005). The area irrigated through these exchanges in India increased from less than 0.09 million hectares in 1976 to 2.4 million hectares in 1998 (with some 25 million farmers out of a total of 82 million farmers, reportedly hiring this type of irrigation equipment, or around 30 percent of India's farming households) (Table 8). Farmers owning between 1 and 2 hectares and 2 to 4 hectares represent 50 percent of pump owners. Using national census data Mukherji (2008) found that these exchanges were no longer a localized small-scale phenomenon but had become a pervasive feature of India's agricultural landscape. Later research however (Shah 2009, 2012b) found out that many of these 'markets' are actually shrinking, driven by the accumulative behavior of larger farmers, becoming monopolistic and an instrument of exploitation of smallholder farmers by the wealthier. Additionally, the 'energy squeeze' suffered in parts of India with increasing diesel prices, or a reduction in electricity connections authorized by some state governments (West Bengal), has affected the spread of these 'pump irrigation markets' which had boomed in the 1980s and 1990s (Shah 2007b). This latter tendency has caused farmers in some cases to return to rain-fed farming by the agrarian poor (who are hit the most by the energy squeeze), or the exit altogether out of inviable irrigated farming (ibid.).

Table 8. Number and percentage of households hiring irrigation services in India (1997-1998)

Operational land holding category (ha)	Number of households within the operational land holding category who reported hiring irrigation services (millions)	Percentage distribution of households within the operational land holding category who reported hiring irrigation services
Below 0.50	12.4	49.5
0.51–1.00	6.0	24.1
1.01–2.00	4.1	16.6
2.01–4.00	1.8	7.2
4.01–10.00	0.6	2.4
10.01 and above	0.1	0.2
All	24.9	100.0

Source: Mukherji 2008.

Groundwater exchange services have provided access to irrigation water for resource-poor farmers, whilst also improving efficiency of water use (Manjunatha et al. 2011). These 'groundwater markets', as Mukherji (2008) wrote, gradually expanded in Karnataka in southern peninsular India. Unlike Gujarat, where a few sellers enjoy monopoly power over buyers (Shah 1993), the market characteristics in this area are close to that of a 'bilateral monopoly' with bilateral bargaining between a seller and a buyer mostly favouring groundwater buyers. Groundwater sellers tend to be larger farmers than groundwater buyers (their average farm size is 3.2 hectares and that of buyers is 1.5 hectares on average), something that substantiates Villholth's et al. (2009) findings about the domination of groundwater selling activities by larger farmers.

Farmers with shallow tubewells in Bihar, northern India, abstract water from the aquifer down at 5-6 meters (pre-monsoon levels) and connected to diesel pumps (Islam and Gautam 2009). Water buyers are charged an hourly rate by sellers for the use of the well and conveyance pipes are laid out across the fields (up to 300 meters) or through lined channels from community tubewells (ibid.). In some instances, water buyers have also to pay for the use of the plastic pipes (ibid.). Pump owners without tubewells can use the well free of charge in exchange of lending the pump to the well owner free of charge (ibid.). In northern West Bengal, shallow tubewells with centrifugal are predominant as they are less capital intensive and, fitted with fuel efficient Chinese pumps, more economical (Anantha et al. 2009). Farmers without wells buy water from these wells, but in kind payments (e.g. labour days) for the operator or well owner. In Gujarat, owners of deep tubewells selling groundwater also own conveyance pipes (up to 2 and 3 kilometres long). Farmers owning tubewells would talk to their neighbors and get an idea about the need for groundwater or whether people are willing to buy water. Every water buyer would then have different outlets onto the field from different 'providers' and switch depending on the necessity and availability (Shah 2014, pers. com.).

Groundwater exchanges in resource-abundant Murshidabad District, West Bengal, have been prosperous in the region with more than 80 percent of farmers participating in private groundwater markets with payment conditions involving cash or kind exchanges (Anantha et al. 2009). Cash payments are most common for buyers obtaining water from government tubewells and kind payments for operators safeguarding the crops and allocating water. For diesel pumps, kind payments in terms of labour days or crop sharing are also common (ibid.).

According to Villholth et al. (2009), groundwater markets studied in the Indo-Gangetic plain tend to be quite competitive and without important price distortions negatively affecting groundwater buyers. These authors found a lack of significant difference between buyers and sellers which may indicate "that the price charged to the water buyer for the energy consumption in connection with pumping for water extraction may not be significantly higher than the well/pump owner has to pay for himself" (Villholth et al. 2009: 11). However, in spite of the fact that in many cases groundwater sellers also act as buyers purchasing water from other well owners due to land fragmentation, which can equalize prices across farmers, sellers have an additional income source which favours them economically to groundwater buyers (Villholth et al. 2009).

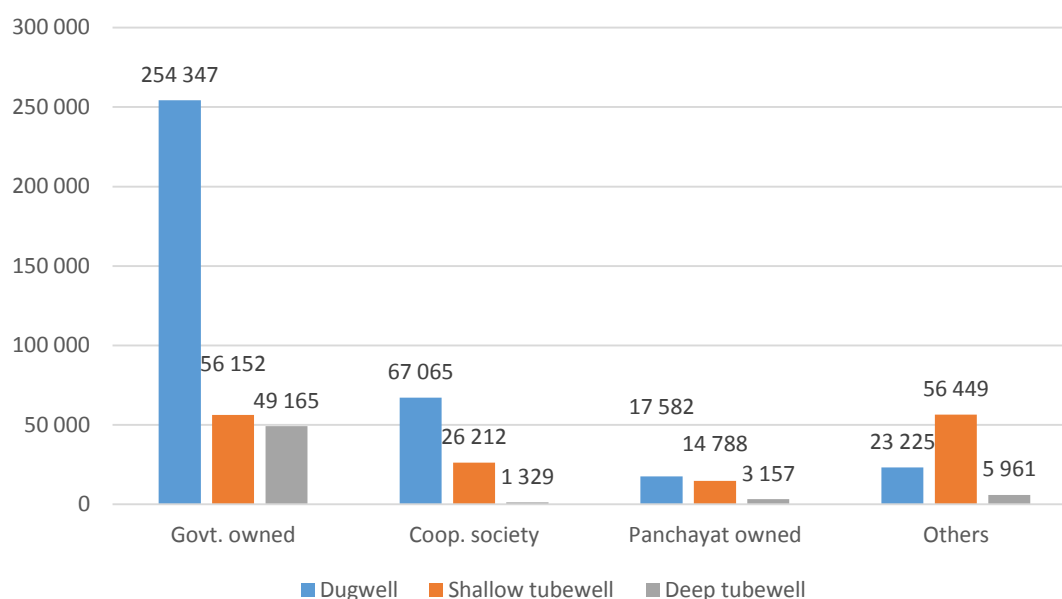
In contrast, Aubriot (2013) observed in Sorapet, a village in Tamil Nadu, that decisions regarding the price of groundwater can become a monopoly, as they only depended on the collective consensus of well owners without consulting the buyers and according to rainfall before the harvest of monsoon rice. This raises equity issues, as indicated by Mukherji (2007b) in West Bengal, where the net irrigation surplus generated through water market transactions can be accumulated by pump and larger land owners, reinforcing the positions of these users as 'water lords' in detriment of small and marginal farmers without access to natural resources.

In groundwater-abundant Assam, Eastern India, Tamuli and Dutta (2015) have studied the factors influencing water buying decisions of farmers and the operational features of these 'groundwater markets'. Based on the different types of payment arrangements possible: 1) hourly rates; 2) area based rates; and 3) volumetric rates, the authors found out that in Assam payments are based on an area approach, contrary to the dominance of hourly rate payments in other parts of the country (Tamuli and Dutta 2015). The area-based approach the amount of groundwater paid for is based on the amount of land irrigated and expenses (diesel) are paid by the buyer. Transactions are both cash and kind (as output sharing and fixed charges, or additional services rendered to water sellers such as pump operation and irrigate the well owner's field) (ibid.). Groundwater selling in this area is used as an additional source of income for farmers owning a well. Research by Tamuli and Dutta (2015) found that own farm size, the distance of the buyer's plot from the nearest source of irrigation, education, and age have significant influence on water purchasing decisions. The study also verified that small farm plot tenants are mostly water buyers and found out that when farmers have better contact with the government extension services the probability of a farmer buying water is less. This indicates according to the authors that government support in the form of information on farming technology, "helps farmers to gain more control of irrigation water" as "the farmer is more likely to own a tubewell rather than resorting to water purchase (Tamuli and Dutta 2015: 21-23).

6.2 Community and user participation for groundwater management in India

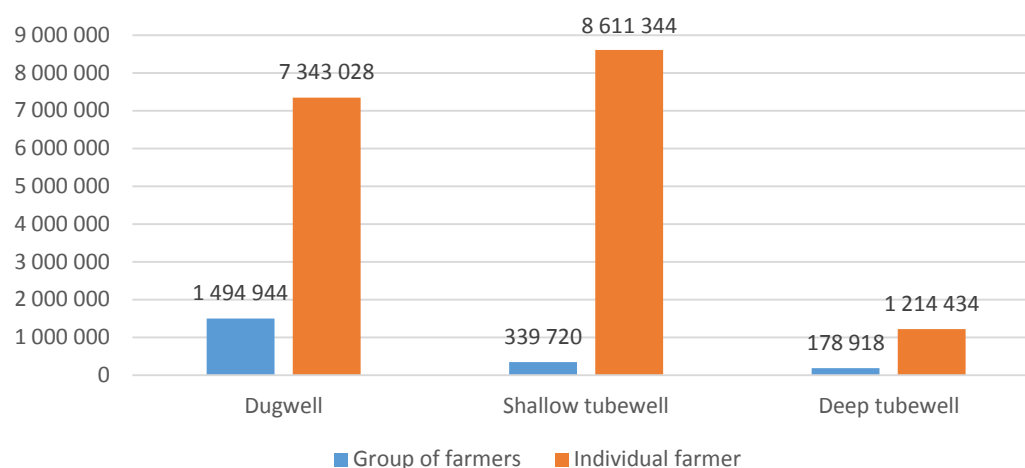
Despite the fact that most wells in India are owned individually, there are however some instances of collectively owned wells (owned publicly by the government, cooperatives or panchayats or privately owned by groups of farmers) (Figure 44 and Figure 45). There are around 254,000 dug wells owned by the government (representing 2 percent of the total number of dug wells in India) and around 56,000 shallow tubewells (which represent 0.6 percent of the total number of shallow tubewells in India) (Ministry of Water Resources 2010). As data from the 4th Minor Irrigation Scheme Census indicates, 16 percent of dug wells, 3 percent of shallow tubewells and 12 percent of deep tubewells are owned by a group of farmers (ibid.).

Figure 44. Types of ownership for publicly owned wells in India



Source: Based on data from Minor Irrigation Schemes Census 2010, Ministry of Water Resources, Gov. of India

Figure 45. Types of ownership for privately owned wells in India



Source: Based on data from Minor Irrigation Schemes Census 2010, Ministry of Water Resources, Government of India.

As part of a wider program of political and administrative decentralization, India's groundwater planning commission has been seeking a greater reliance on community resource management, supported by adequate technical inputs, complementary institutional changes and appropriate incentives (such as a subsidy regime for micro-irrigation), rather than on 'controls by state' (Planning Commission 2007). State legislations can of course strengthen such strategy by endorsing community action, supportive institutions and use of technical inputs and incentives (ibid.). However, as Aggarwal (2000) found in Andhra Pradesh, community members need assurances, especially in joint and risky ventures entailing a long-term commitment and where the obligations of each member are poorly defined and enforcement is costly (ibid.). Certain activities requiring informal cooperation are low-risk, low-contribution, and need close

monitoring (everyday allocation and routine maintenance). But for new wells the stakes are so high that a large majority of group members studied by Aggarwal preferred to undertake those new investments in individual rather than shared wells. The author added that group investments in shared wells "has been widespread only in areas where the government or a highly committed voluntary agency has intervened" (Aggarwal 2000: 1494).

In the Bist Boad area region in the Indian Punjab, kinship relations among households are used amongst community members to share well access, define rules for water sharing, maintenance costs, crop selection, and the inheritance of rights, as observed by Aggarwal (2000) in cooperative arrangements for sharing wells in Andhra Pradesh. In Punjab, Tiwary and Sabatier (2009) found that out of the 44 tubewells found in the village, 40 are shared by more than one household and all of them are kinship-based, started as shared wells by immediate ancestors. Water is shared according to the land ratio and is allocated by turns reflecting the right of the shareholder (*ibid.*). In Rajasthan, Birkenholtz (2009) has also observed farmer partnerships organized around the ownership of wells following patrilineal relationships where the eldest member is usually the decision-maker (for crop decision, rotation, and conflict resolution).

Communities can also be organized in order to collectively manage aquifers. Following a study on participatory groundwater management in Andhra Pradesh by Das and Burke (2013), these authors raise the argument that "[t]he people nearest the groundwater can best manage this resource, not agencies that visit every now and then. Therefore, the nature, occurrence and behavior of aquifer systems need to be understood by those most affected by changes in the system. Local organizations, government, civil society and the private sector all have important, and often unique, roles to play in participatory groundwater management (PGM)." (Das and Burke 2013).

Participatory groundwater management comes as a 'package' for these authors which includes the following components: (1) well irrigation system; (2) hydrological unit; (3) participatory hydrological monitoring; (4) farmer data management; (5) Crop–water budgeting; (6) artificial groundwater recharge; (7) Farmer Water Schools; and (8) community based institutions (Das and Burke 2013). After a decade, the results of this approach in India, according to Das and Burke (2013), show that community-based institutions occupy a central position in the smallholder approach. Through training and participation, farmers are capable of collecting hydrological data and they are able to understand the seasonal occurrence and distribution of groundwater levels near their habitats and they are able to estimate recharge, withdrawal and water balance. They have also understood the concept of groundwater as a common resource.

As the quantitative results quoted by these authors showed,⁷⁴ "the proliferation of boreholes was not possible to stop and (...) a direct regulatory approach [by the state] is impossible to

⁷⁴ Following official assessments, the success of APDFAMGS has meant its potential replication across the country (Das and Burke 2013; Garduño et al. 2009). More than 4,000 farmers were trained to read maps and more than 10,000 were trained to handle hydrological equipment (Reddy et al. *in press*). Quantitative results for the project suggest that the development of participatory groundwater management have mixed impacts. The groundwater-fed irrigation area increased in the project area in Andhra Pradesh by about 62 percent between 2006 and 2010 in spite of a reduction in active wells. The average area cultivated using wells also rose from 0.90 ha in 2006 to 1.69 ha by 2010. This may be attributed to crop–water efficient practices, i.e. suitable irrigation methods and water-saving devices – or simply more pumping from fewer wells (Das and Burke 2013). Additionally, of the 63 hydrological units 43 show a decrease in the withdrawal compared to the base year, while the remaining 20 show an increase in groundwater abstraction levels (*ibid.*). For these authors though, the important point about this approach is that it aims to demystify science and technology and provide access to scientific

implement because of the lack of resources for policing abstractions and the absence of substantial support for penalizing defaulters" (Das and Burke 2013: xxxii). These authors suggest that voluntary regulation by users themselves is a viable management option, driven by the users' improved understanding of aquifer systems and accompanied by demonstrations of the positive impacts of improved natural resource management on ecosystems and livelihoods (ibid.). Verma et al. (2012) however present a more critical picture as their post-implementation evaluation showcases deficiencies in the remnant practices from the project after support for local organizations withdrew when the project ended. Additionally, as Taylor (2013) wrote, the project conceptualization was founded on the basic and reductionist premise that groundwater over-abstraction is produced primarily due to a lack of information prohibiting farmers to make rational decisions about what crops to plant.

The overall evaluation by Verma et al. (2012) of the APDFAMGS project shows the abandonment of practices such as rainfall collection, discharge and groundwater level data in most of the habitations and Hydrological unit networks (Figure 46). The maintenance and operation of discharge and observation wells was only sustained in less than 30 locations out of more than 150 studied. At the time of the project, groundwater level data was reported to be collected in 43 out of 49 habitations. However, according to Verma et al.'s (2012) post-implementation survey, only 15 were found to be continuing with this data collection.

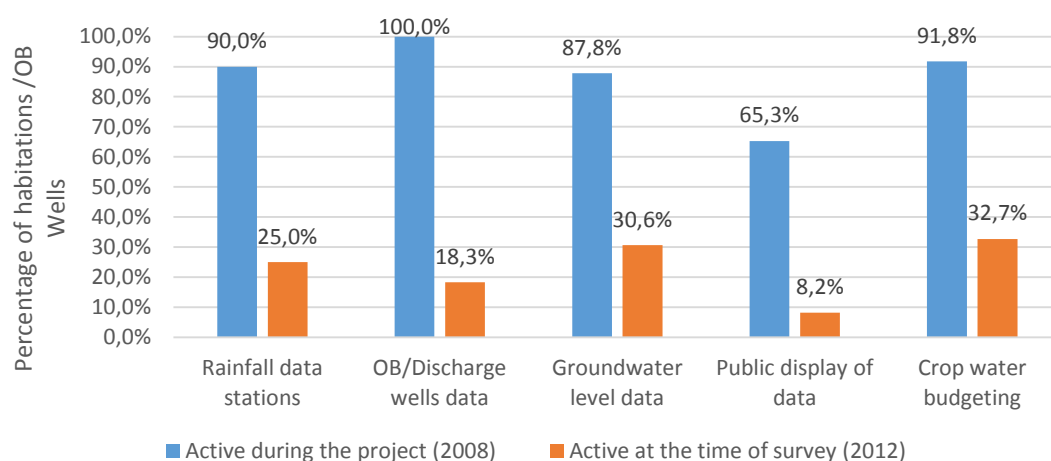
The original survey and study by Reddy and Reddy (2012 in Verma et al. 2012) also observed that data monitoring was discontinued in some households due to the need for repair or replacement of the equipment. In some cases, the authors also found that farmers would be reverting to traditional heuristics about the nature of the aquifer and behavior of wells as opposed to using the new methods of data collection and interpretation to inform farming decision-making. Farmers also felt no need to continue with the data collection once the project finished, as they felt obligated to do it in the first place due to the constant visits and encouragement by the implementing NGOs.

The lack of universal legitimacy (as per Ostrom's rules) was compensated by regular visits to the project sites and farmers relied on local NGOs to carry out monitoring practices and to organize workshops. This created a sense of obligation for farmers to participate in these prescribed activities and they doubted that anyone would follow community decisions after the NGOs leave (Verma et al. 2012). This lack of implication is reflected in the conduction of monthly meetings: at the time of the project, 42 of the 49 habitations studied by Verma et al. (2012) used to conduct them but at the time of the post-implementation assessment, 31 households were reported not having any meetings at all and 16 of them had reported quarterly meetings. This was attributed to the absence of implementing NGOs (ibid.). The fact that there is an absence of external authority and lack of sanctions for defaulters is likely to further increase the discontinuation of monitoring mechanisms within the APFAMGS model. This lack of external authority can also further deteriorate the legitimacy of community-based associations set up during the project. As observed by Verma et al. (2012), the exception to this general trend in Andhra Pradesh can be found in communities with continuous NGO support after the finalization of the project and also where the APFAMGS initiated institutions found anchorage in strong pre-existing associations such as credit and dairy cooperatives.

information at the user level, striking the balance between scientific management of hydrological units and inculcating groundwater users with a sense of shared responsibility (ibid.).

The development of new forms of participation and community management can also negatively affect traditional or more ancient forms of natural resource management and community organization. Where power and inequality have played a significant role in granting access to groundwater it is not surprising to find a lack of self-governing institutions regulating the use of groundwater though it is possible to find partnerships involved in sharing the cost of access to groundwater (Rajasthan and Gujarat) (Birkenholtz 2009; Dubash 2002).

Figure 46. Status of practices initiated by the APFAMGS project during and after



Source: Verma et al. 2012.

7 Groundwater abstraction and social impacts

7.1 The disruption of traditions

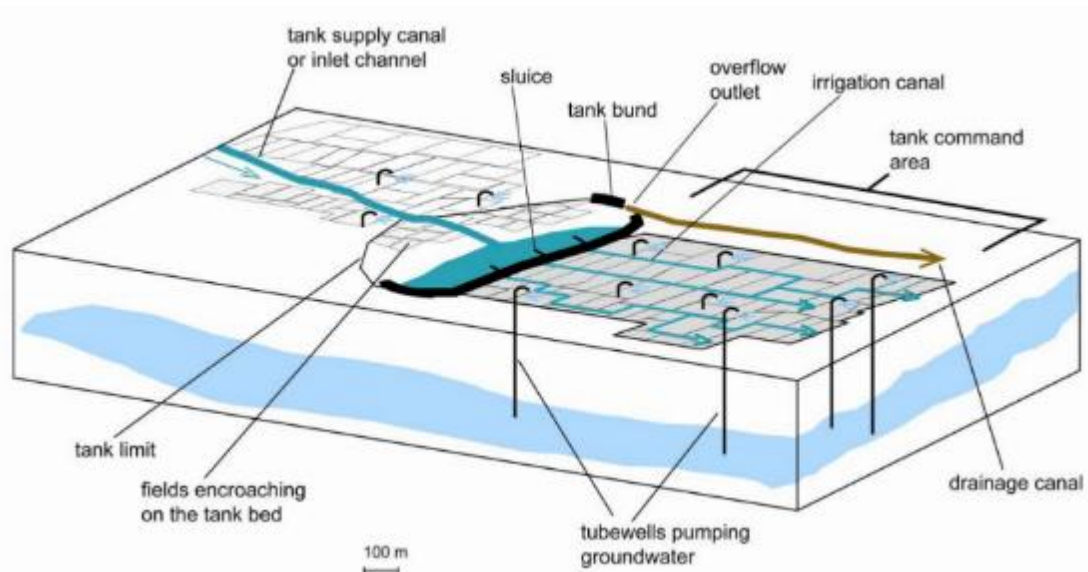
Groundwater abstraction through modern individual wells can disrupt community traditions. In Tamil Nadu, the replacement of traditional and communal tank irrigation systems by private wells (Kajisa 2012) brought the deterioration of communal tank systems with negative impacts on rice yields of farmers relying solely on traditional irrigation systems. For Rosin (1993) as well as for Mosse (2006), the traditional system of hydrologic conceptions and practices found in Rajasthan in north western India or in Tamil Nadu was extremely important for social and hydrological reasons. Surface runoff impoundments helped aquifer recharge, groundwater storage, and groundwater lifting technologies, as well as affirmed social roles and community cohesion through the rules of use developed around the communal maintenance and use of these structures (Figure 47).

In Puducherry, the rapid development of tubewells has also affected traditional tank irrigation systems. Farmers having invested in individual pumps have been 'freed' from the constraints of collective irrigation systems, progressively losing interest in collective irrigation management (Aubriot and Prabhakar 2011). However, changes in traditional irrigation systems also mirror technical, environmental, and social factors. Changes in control of tank management and maintenance (removal of siltation) and the fragmentation and the access to farming to lower casts has opened new opportunities for agriculture but also changed the social makeup of rural villages and contributed to the decline of tanks as social and communal institutions (ibid.). The redistribution of land from upper strata of society by the Government after the 1970s as they moved out of farming activities gave access to land to tenants, permanent labourers and lower

castes (Jegadeesan and Fujita 2009). Conversely, decreasing groundwater levels due to overexploitation have fostered a recent revival of these systems in some areas in order to increase rainwater harvesting and aquifer recharge (Aubriot and Prabhakar 2011).⁷⁵

Traditional tank systems in Karnataka have been disrupted by increasing numbers of wells in their catchment areas (Chandrakanth and Romm 1990). The individual ownership of wells affected community-owned systems and eroded the social fabric organized around the collective management and repair of these structures (ibid.). Government rules further disrupted these systems as it was dictated that the government and not the communities would ensure tank repair and maintenance (ibid.).

Figure 47. Command area of a tank irrigation system and interactions with groundwater



Source: Aubriot and Prabhakar 2011.

7.2 Social differentiation

Despite the fact that the Green Revolution has had positive impacts across India giving access to increasing sources of income for millions of farming families, distributional inequity amongst landholders and groundwater users has also appeared to be linked with groundwater over-abstraction. This has led to serious physical groundwater depletion as well as increasing pumping costs limiting the abstraction of groundwater for poorer farmers and thus inequity in access to groundwater, also connected to the inequity of access to land for farmers (Nayak 2009). Although in some areas of India communities have been able to adopt shared groundwater management practices,⁷⁶ in many other parts these inequities have increased. Elites and wealthier farmers are more likely to benefit from this situation as they have access to networks of power which can control the decision-making processes which can "legitimize the rules for allocation and distribution of water" which are unfair to poor farmers (Nayak 2009: 91). Large farmers have been increasing their share in resource co-optation and extraction, as they

⁷⁵ The revival of these systems is not possible everywhere, especially in areas where traditional tank institutions are socially defunct or where villagers have lost interest in tank water use (e.g. in parts of Tamil Nadu or also Puducherry) (Aubriot and Prabhakar 2011).

⁷⁶ In Andhra Pradesh (See Aggarwal 2000, Reddy et al. 2014).

can negotiate better water rights and bypass legislation and regulation, as well as buying pumps and selling water or irrigation services at higher prices (Dubash 2002; Mukherji 2008; Nayak 2009). Mukherji (2007b: 2549) found in West Bengal that in many cases cooperative institutional arrangements "have superior equity outcomes than pure private water market transactions", "especially so in the initial stages of groundwater irrigation development when pump capital is scarce and monopoly power of the water sellers considerably high".

In states such as Rajasthan and Gujarat, the accumulation of wealth and power can be established via the proxy of groundwater control, social and economic capital and land ownership (Bhatia 1992; Birkenholtz 2009; Dubash 2002). In Tamil Nadu, differences in land ownership mean different costs for irrigation (Palanisami et al. 2008). According to their research, many small and marginal farmers reported differences in access to groundwater due to the fact that they would have one borehole and pump for four hours per day compared to large farmers with four to six boreholes, pumping simultaneously from more than one well (ibid.). Thus, via this type of mechanisms, equity and access to groundwater by poor farmers is not ensured due to existing power structures in the communities. Research by Nayak (2009) showed how medium farmers, constituting 17 percent of the total number of irrigation holdings, possess nearly 48 percent of the total area operated by irrigation schemes in India.

In Rajasthan, Birkenholtz (2009) has studied the role tubewell irrigation technologies play in altering existing social power relationships and environmental practices. Tubewells have exacerbated social differentiation, as the area studied by Birkenholtz is already socially stratified, with marginal castes having the smallest landholdings and with less access to this type of technology (ibid.). The tubewell is viewed as a symbol of status and some farmers adopt it in order to increase or maintain their social status (ibid.). Moreover, according to Cullet (2014), the current legal provisions for groundwater management in India, linking groundwater rights to landownership, indirectly assume that it is only landowners who have a stake in groundwater management thus excluding more than 30 percent of the population in India who do not own any land from the purview of groundwater rights (even if groundwater is their main source of drinking and livelihood as tenants or labourers).

Research in Rajasthan by Birkenholtz (2009) also found that intermittent access to electricity can also affect the gender division of labor. It is usually women who have to stay awake at night in the event that electricity becomes operational so that the groundwater pump can be switched on. Females in these families have to work in the fields and also for other farmers and daughters do not attend school beyond fifth grade (ibid.).

Access to credit and finance for farmers wishing to abstract groundwater can also have social consequences. In Andhra Pradesh, marginal and smallholder farmers find accessing institutional credit to pay the investment for a well as a limiting factor for tapping into the water table (Taylor 2013). Micro-credit is actually too 'micro' to pay for the investment, drilling costs, and pumps (ibid.). As a consequence, informal loans from money lenders at exorbitant rates are common and in some extreme cases, are a contributing factor to farmer suicide rates in parts of India (ibid.).⁷⁷ Additionally, given the dependence of small farmers on debt (e.g. for well

⁷⁷ This is one of the factors associated with high suicide rates amongst farmers in parts of India. High levels of debt, but also internal inefficiencies of lending institutions, malpractices and unethical operations to maximize their profits are all contributing factors for farmers' high levels of debt (Hossain 2013; Taylor 2013). Other factors associated with this phenomenon cited in the literature are crop failure due to pest attack, high reliance on the monoculture of hybrid cash

deepening or pump reparation), credit markets represent a significant mechanism of economic surplus extraction between agrarian classes, as money lending is a key source of income for social classes holding capital (ibid.).

Status linked to age or knowledge can attribute power to community members in order to influence groundwater management. In Tamil Nadu, farmers still rely on water diviners to find groundwater and mixed results can erode farmers' hope for mobilizing further expenses for local diviners (Palanisami et al. 2008). Drilling wells can also be a matter of social status and linked to social pressure. For farmers planning to marry their daughters, well drilling failure can be a social stigma. Social pressure compels them to remain in agriculture even with lesser earnings and encourages them to deepen or drill new wells as a way to keep their social status (ibid.). In some instances, pledging jewelry or lands and borrowing money from relatives are common practice in order to meet the cost of drilling new borewells (ibid.). In Gujarat, tubewells form the backbone of the agrarian economy and with the decline in electricity availability and restrictions on new connections, control over a tubewell brings enviable power and prestige (Mukherji and Kishore 2003).

Research by Shekri (2012) has found out that the incidence of poverty amongst farmers using groundwater in Uttar Pradesh is significantly higher wherever groundwater requires more capital-intensive submersible pumps. This technology option is much more expensive than centrifugal pumps which are widely used in areas where groundwater is shallower than 8 meters. Due to decreases in water table levels as a result of groundwater pumping, farmers can no longer use this technology and have to use more expensive groundwater lifting technologies. Instances of rural poverty in areas where groundwater is under 8 meters are 10 to 12 percent higher than in areas where it is more accessible (Shekri 2012). In Gujarat however, where the state of groundwater depletion is much more severe, this trend is not observed as wells are already too deep and being abandoned or face low discharge rates causing a reduction in irrigated land surface (7 percent and 17 percent respectively during winter and summer) (Kishore 2014).

Aquifer recharge practices have also raised significant equity questions in the areas studied by Gale et al. (2006). The beneficiaries of aquifer recharge in Satlasana and Coimbatore were those with existing land holdings (a minority group) and access to groundwater with wells (an even smaller minority) close to recharge structures whilst there was no evidence of poorer households benefiting indirectly via trickle-down effects. In Coimbatore, recharge ponds built in the 1970s were built in existing common lands and in recent years this type of land has also been leased for quarrying by the district authorities. However, this situation raised significant poverty issues as poor people are reliable on common lands for grazing or the collection of firewood and other materials.

Social inequalities are also exposed when looking at patterns of rural-urban migration in regions facing water scarcity such as northern Gujarat (Fishman et al. 2013). Migration trends and employment shifts are more likely to occur in groundwater stressed areas (ibid.). However, caste type, land holding size, and social networks spurring from family connections are also relevant factors explaining migration (ibid.). Migration patterns are dominated by the Patel

crops after seed sector liberalization, climatic change and drought (Mukherjee 2009). According to data from the 4th Minor Irrigation Scheme census, there were 581,451 wells in India financed through money lenders. Bank loans had financed 2.3 million wells and own savings from farmers 14 million wells (Ministry of Water Resources 2010).

caste (dominant landowning caste in the region) and castes with traditionally no or very small landownership display much lower migration rates (ibid.). This combination of 'pull' (better income prospect in urban areas) and 'push' (droughts or water scarcity) factors co-exists in parallel in the study area (ibid.).

8 A typology of wells in India

Following this analysis, a preliminary and simple typology of wells in India can be drawn in order to summarize the different characteristics of groundwater abstraction, management and regulation, combining it with the varied geology of India. As shown in Table 9, different geological formations will correspond to certain types of groundwater abstraction technologies as well as allocation and sharing mechanisms and rules that can be developed more easily. Individual wells are pervasive across India, however, specific geological formations facilitate private and atomistic groundwater development. In alluvial and sedimentary basins with important recharge (monsoon), groundwater is fairly easily accessed and there is less need for collective bargaining and association. However, depending on a series of parameters (the farmers' access to capital, caste, access to land, access to water, etc.), arrangements for the sale and purchase of services surrounding groundwater can be found (e.g. pump and/or pipe rental, or water purchase). Collective structures are more easily found where groundwater is scarcer (in hard rock formations) and also where economies of scale prevent individual farmers from accessing the resource (too deep and therefore too expensive to drill an individual well or to buy a pump).

Table 9. Well typology and examples

		1) Northern alluvial basins	2) Arid alluvial aquifers	3) Salinity-prone aquifers	4) Hard rock aquifers
Individual wells	<i>Atomistic individualism</i>	Eastern Uttar Pradesh, North Bihar, North Bengal	N.A.	Coastal areas in Gujarat	Maharashtra, Telangana, Andhra Pradesh
	<i>Resource accumulation and opportunistic behavior (with possible exchanges)</i>	West Bengal, Bihar	Western and north-western India, Punjab, Haryana, parts of Rajasthan, northern Gujarat	N.A.	Karnataka
Collective wells	<i>Collective wells and cooperation</i>	N.A.	N.A.	N.A.	Gujarat, Eastern Rajasthan, Andhra Pradesh
	<i>Collective structures</i>	N.A.	N.A.	N.A.	Gujarat (Saurashtra Peninsula), Maharashtra
State initiated or sponsored wells	<i>Retained ownership</i>	N.A.	Gujarat	N.A.	N.A.
	<i>Transferred ownership</i>	Uttar Pradesh	Gujarat	N.A.	N.A.

Source: Authors with complementary information from Shah (2009, 2012b).

Groundwater management and regulation in Australia

1 Groundwater resources and use in Australia

The geology of Australia presents a mix of large sedimentary areas and fractured rocks. Sedimentary areas with porous materials can be consolidated (sandstones) or unconsolidated, made of sands such as the coastal aquifers of New South Wales and Queensland (covering typically small areas of shallow deposits) (Figure 49) (Harrington and Cook 2014). Sedimentary areas with alluvial aquifers are also found as part of the sedimentary areas containing extensive deep aquifers (the Canning Basin in northern Western Australia or the Great Artesian Basin) (ibid.). Fractured rock aquifers, prevalent throughout the Great Dividing Range of eastern Australia with basalt aquifers and fractured metamorphic rocks with low or moderate productivity (ibid.). The large presence of groundwater bodies in Australia however does not mean that all of it can be used or abstracted for drinking supply or agriculture. Much of it has high concentrations of salt (particularly in internally draining arid areas with high evaporation levels) (ibid.).

In Western Australia, groundwater is mostly found in extensive sand or sandstone deposits covering 40 percent of the territory's surface.⁷⁸ These are sedimentary basins and fresh groundwater generally occurs in the shallower few hundred meters. Groundwater is mostly found in confined aquifers in these sedimentary basins. The largest source of confined groundwater is the Canning Basin (with an estimated storage of 12 trillion m³) running from the northern part of Western Australia towards the centre of the country.⁷⁹ Annual renewable groundwater in the sedimentary basins are estimated at around 2,500 Mm³ per year (of which around 1,400 Mm³ are found in the unconfined Perth groundwater basin). In the East, the Great Artesian Basin, one of the largest groundwater systems in the world, underlies one fifth of Australia comprising regions of Queensland, New South Wales, South Australia, and the Northern Territory (Powell et al. 2015; Smerdon et al. 2012). Consisting of sedimentary rocks (sandstones), it is a confined aquifer system where groundwater is found mostly in artesian conditions supporting pastoral industries, population centres, and mining (ibid.). More than 4,700 boreholes have been mining the Great Artesian Basin since the 1880s but heavy use for livestock and urban supply and more recently for mining and oil had dried 1,368 wells by 2000 (Fensham et al. 2015; McKay 2007).

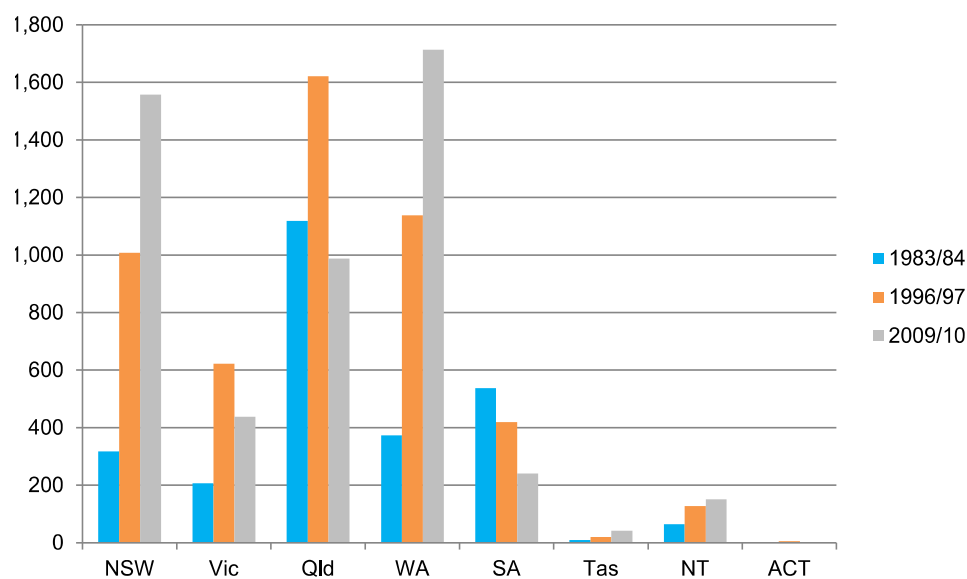
Australia's dependence on groundwater varies greatly according to the state and region (Figure 50). Of all states and territories, the Northern Territory and Western Australia are the areas that most depend on groundwater compared to surface water (Harrington and Cook 2014). The Northern Territory obtains 90 percent of its water from aquifers (ibid.). Western Australia and Queensland are also heavily dependent on groundwater. The South-East of Australia presents a more mixed situation. New South Wales, South Australia and Victoria have the highest concentration of groundwater use and their reliance on the resource has been increasing over the years (abstracting an average of 1,795 Mm³ per year) in order to support expanding irrigated agriculture (ibid.). In the Murray Darling Basin, groundwater represents 16 percent of the total water use in the basin (ibid.).

⁷⁸ Water and Rivers Commission, Water Facts 9, December 1998, <http://www.water.wa.gov.au/PublicationStore/first/10088.pdf> (Accessed 12th February 2015).

⁷⁹ Ibid.

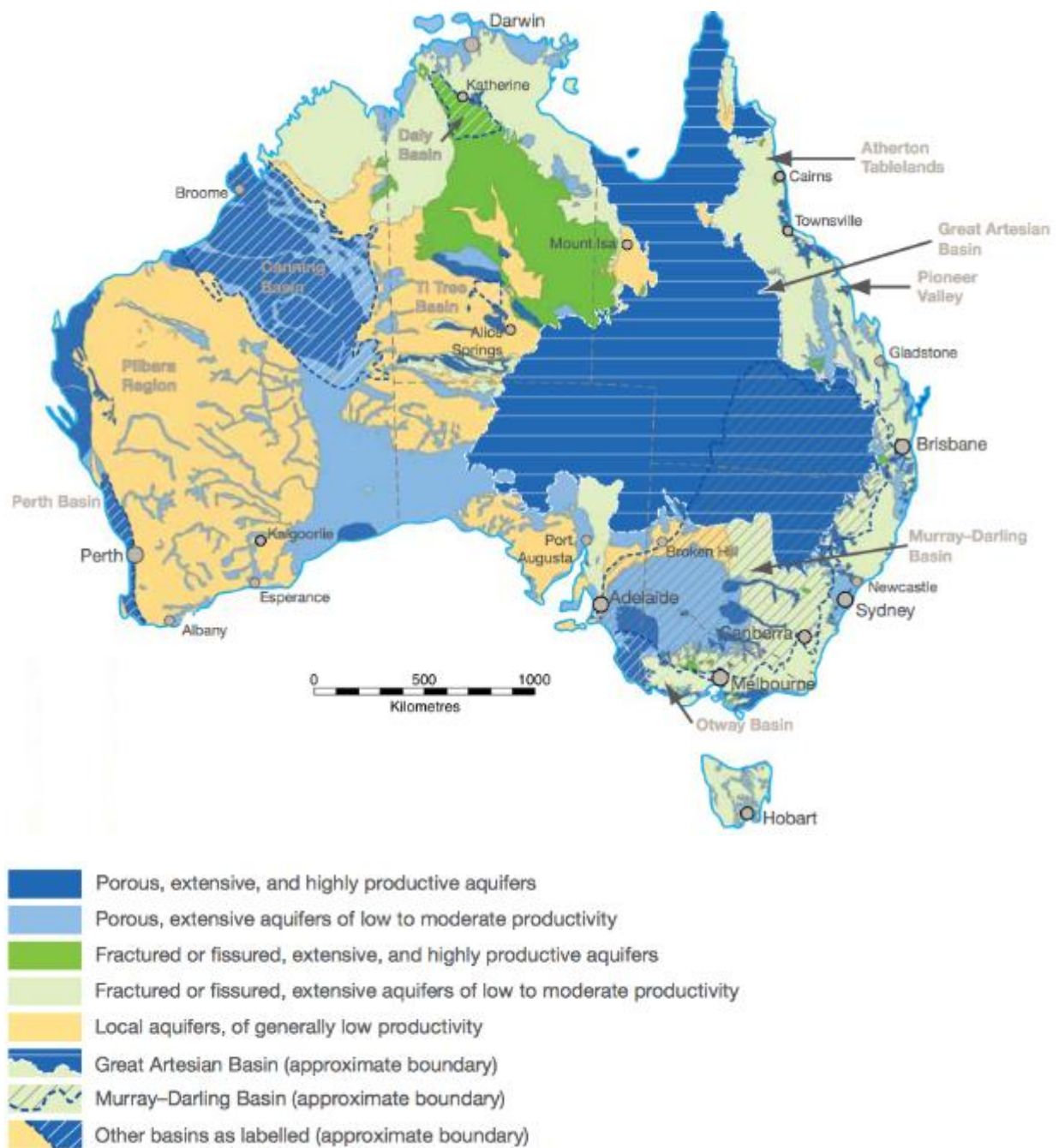
Approximately one third of Australia's annual water use comes from groundwater (5,000 Mm³) (Harrington and Cook 2014). Agriculture uses around 70 percent of all groundwater abstracted in Australia (ibid.). The mining industry uses 12 percent, manufacturing and other industries use 17 percent and household water supply 5 percent (Deloitte 2013). This varies however depending on the region. New South Wales and South Australia use more than 60 percent of their groundwater for agriculture whereas in Western Australia agriculture uses 21 percent of groundwater use and mining 38 percent (Harrington and Cook 2014). Economic estimates for such reliance establish that 29 percent of the total value of agricultural production from irrigation is dependent on groundwater (Deloitte 2013). The total value of production dependent on groundwater has been valued at 3.7 billion dollar. For metal and ore mining activities, the proportion of production directly dependent on groundwater is 37.6 percent (ibid.).

Figure 48. Total groundwater use in Australia (per state)



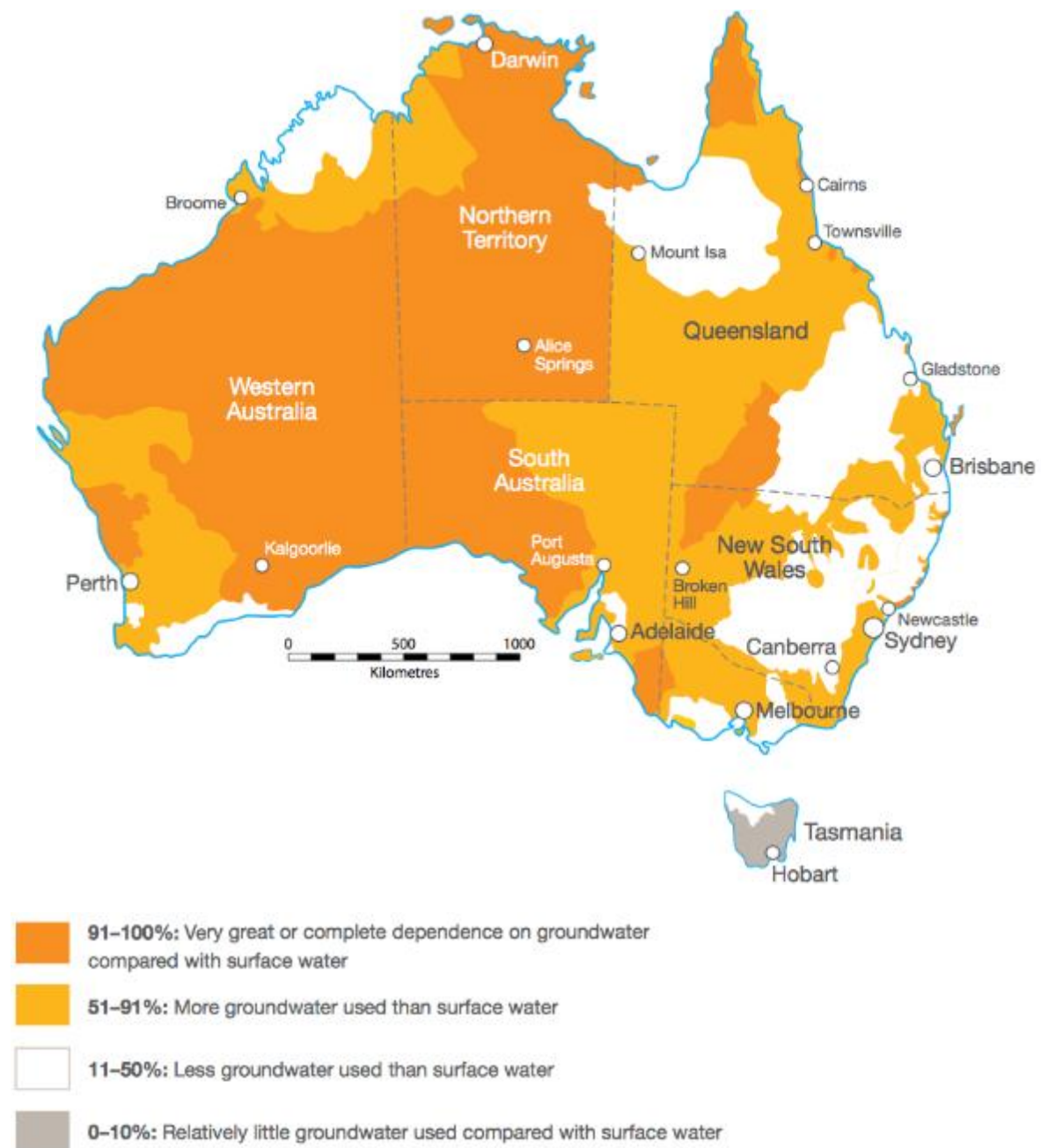
Source: Harrington and Cooke 2014.

Figure 49. Australia's groundwater resources



Source: Harrington and Cook 2014.

Figure 50. Australia's reliance on groundwater



Source: Harrington and Cook 2014.

2 Groundwater regulation in Australia

2.1 Groundwater regulation, policies and tools

According to McKay (2007), groundwater has historically been the Cinderella of Australian water laws, policies and planning until the regional drought crises in Victoria in the 1960s and the Great Artesian Basin in the 1990s. The 'wholesale transfer' of English common law to Australia was the initial start of the problem as it allowed for resource exhaustion by each landowner (right to groundwater linked to right to land) leading to the tragedy of the commons (McKay 2007). An additional problem driving the depletion of groundwater was the transfer of the management and control of groundwater to each of the states and the subsequent lack of control by the Federal Government of state regulation and implementation (ibid.).

The reforms that Australia faced in the water sector in 1994-1995 are linked to previous inquiries led by the Federal Government Industry Commission in 1990 and 1992, which questioned the performance of the water industry, calling for change and pricing reforms. These competition reforms were however "set against a background of concern over water resources management – in particular, environmental problems noted by the Senate in 1970s [...] and the view that an important part of the solution to environmental problems lay in policy and institutional change" (McKay 2001: 50). These water reforms "aimed to promote national sustainable development in the long term by telling the States what to put in their laws. Some had already moved in the desired direction but now all had to. State Water Policies in Australia in the past tended to be very idiosyncratic [...], insular and introspective. Common law did not impose any limits on groundwater use (as it treated surface and groundwater differently) and all groundwater was not subject to the riparian doctrine (applied for surface water). This situation was maintained until 2004 with the National Water Initiative specifying that consumptive use of water requires an entitlement, described in the legislation as "a perpetual share of the consumptive pool of surface or groundwater" (McKay 2002).

General legislation enables each jurisdiction (i.e. state) to delineate a specific area or aquifer, determined under statutory power or in accordance with a policy initiative (e.g. water resources management plan), and establish it as a 'Groundwater Management Unit' (GMU) (different states have different nomenclatures: e.g. water management area; water control district; prescribed wells area; groundwater management area). GMUs are defined following aquifer as well as administrative and management boundaries (Harrington and Cook 2014). They are "a hydraulically connected groundwater system that is defined and recognized by State and Territory agencies. This definition allows for management of the groundwater resource at an appropriate scale at which resource issues and intensity of use can be incorporated into local groundwater management practices." (Sinclair Knight Merz 2003: 4). Those areas outside GMUs in each jurisdiction are referred to as 'Unincorporated Areas' (UAs).

According to Sinclair Knight Merz (2012), all jurisdictions require licenses (or an equivalent authorization) for groundwater abstraction within the delineated GMUs. Metering is inconsistent however, with levels reaching 100 percent in Victoria or South Australia to 0 percent in Tasmania. In New South Wales, groundwater abstractions can be monitored by

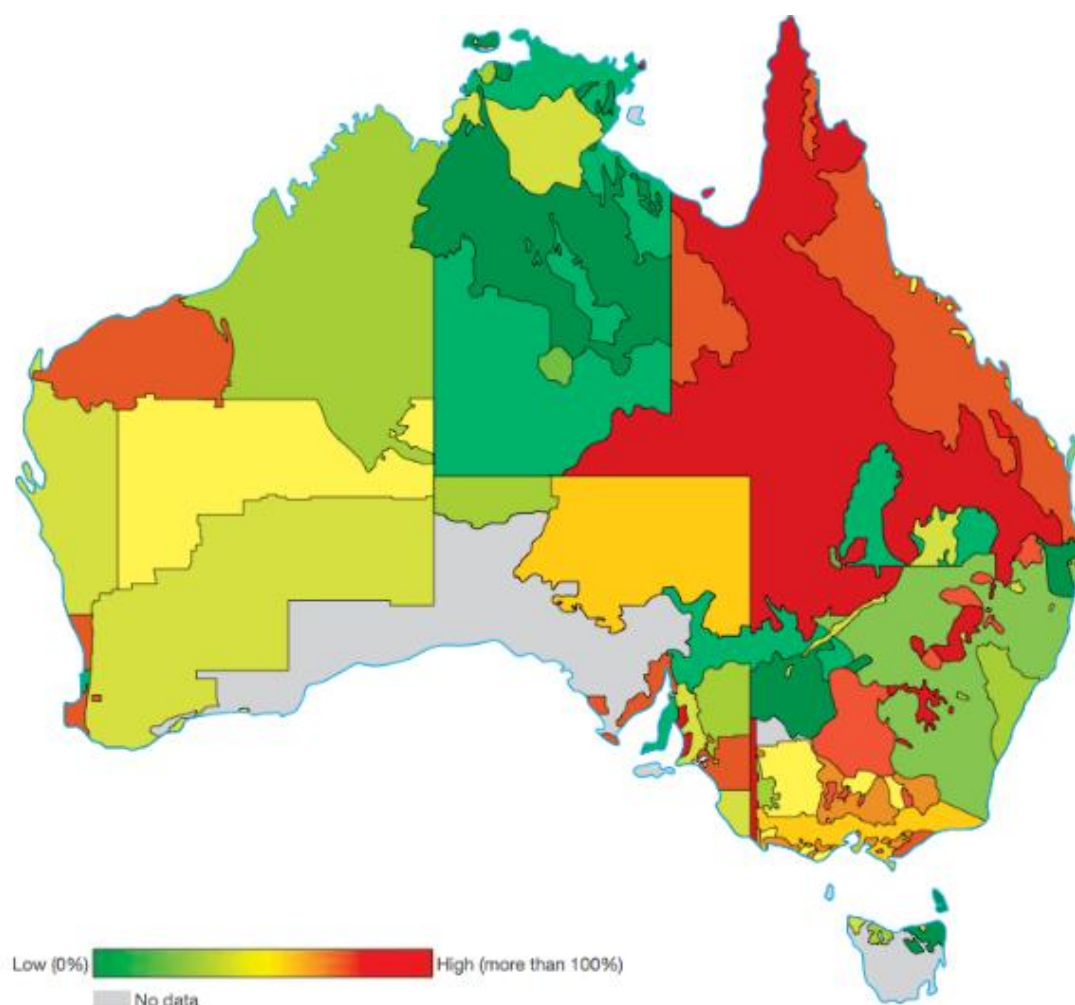
government inspectors (who are few) but also via remote sensing equipment, feeding meter data back to the Department of Water via the mobile phone network (Valli 2015, pers. com).⁸⁰

Even though the legislation requires that groundwater abstraction for commercial uses is to be licensed if a well is located within a proclaimed or prescribed management area, for most jurisdictions "licensing and direct metering of all groundwater extraction is not deemed to be practical, [...] particularly of low-volume extraction such as for stock and domestic use" (Sinclair Knight Merz 2012: viii). The implementation of licensing and metering across Australia varies and there are "differences in licensing requirements outside GMUs [groundwater management units], and between threshold volumes triggering metering" (ibid.) (Table 10).

A loose definition and use of the concept of 'sustainable yield' also drives part of the regulation and management of groundwater resources. As part of the water policy reforms enacted in Australia in the late 1990s and early 2000s, the concept of 'sustainable yield' was adopted in order to define sustainable abstraction limits. The level of sustainability was defined as 'the social acceptable level of the impact of groundwater abstraction'. The definition used by the National Groundwater Commission was: "the groundwater extraction regime, measured over a specified planning timeframe, that allows acceptable levels of stress and protects dependent economic, social, and environmental values" (NCC 2004 in Turrall and Fullagar 2007: 335). Authors have claimed that this definition allows for groundwater mining to happen as it leaves it to the states to decide and administer how trade-offs are made between the stress caused to the system and the benefits arising from the abstraction (Turrall and Fullagar 2007). There is also a great deal of inconsistencies and flexibility in the definition and estimation of safe yield across states (Harrington and Cook 2014), with high variability "in how the definition is put into practice" (Sinclair Knight Merz 2003: 15).

⁸⁰Data is centralized by the Department of Water and Energy through a computer-based system which continuously monitors and archives data. Information is received via various telemetry systems (landline phones, mobile, satellite, radio). As stated by Malone et al. in 2009, the system had over 650 sites with data accessed daily. As described by Malone et al. (2009: 5), the "[d]ata is collected by hydrographic personnel or relayed through telecommunications networks to the regional offices where it is processed and stored onto the corporate HYDSTRA and delivered to clients through a range of channels including the Internet. The data relayed through communications networks are processed automatically in near real-time and updated to the Internet. In the case of some radio systems (such as the Hunter Integrated Telemetry System), real-time data is available online within minutes." The DWE has also information on over 100,000 boreholes in New South Wales (those licensed), with data such as completion date, intended purposes of abstraction, final depth drilled, Groundwater Management Area, salinity levels, yield, GPS location (Malone et al. 2009). In addition, a pilot project was launched in 2012 with the objective to meter the majority of abstractions (regulated and unregulated surface water and groundwater) in the Upper Murray Darling Basin. Via a system of telemetry, meter data is relayed back to the NSW Office of Water to monitor usage and manage unregulated surface water and groundwater systems. Water users not willing to participate in the scheme were liable to penalties (as it would be a breach of the water license conditions). The pilot project was completed in 2013 and saw the installation of 600 meters in the Upper Murray catchment. The project was extended in 2013 to the Murrumbidgee sub-basin (with another 600 meters installed) and in 2014 to the Mid-Murray basin (with 70 meters installed by 2014) (NSW Metering Scheme, <http://www.statewater.com.au/current+projects/nsw-metering-scheme>, Accessed 23rd June 2015).

Figure 51. Ratio of use to sustainable yield in Australia's groundwater management units



Note: this figure uses data from 2005 updated with more recent data (2010) where possible. It does not show the effects of management changes in the Murray-Darling Basin since then. A number of basins with high use would no longer be in red.

Source: Harrington and Cook 2014.

Of Australia's states and territories, the Australian Capital Territory (ACT) and New South Wales (NSW) have reached almost full coverage of licenses for all groundwater uses (irrigation, livestock, domestic use) (Sinclair Knight Merz 2012) (Table 10). In NSW, authorizations are issued for drilling, altering, or "de-commissioning groundwater boreholes (ibid.) In the ACT, a license is required first to extract groundwater and another one for constructing, altering, or de-commissioning groundwater boreholes (ibid.). Also, in the case of the ACT this high level of management is due to the demand from predominantly urban population. Meters in the ACT cover 100 percent of licenses. The Northern Territory has few Groundwater Management Units and there are areas with high levels of allocation but without allocation plans and little metering and data available on abstraction levels. In the GMUs, all irrigation uses are licensed. Mining leases benefit from license exemptions. These do not have to provide metering nor report abstraction levels to the agency responsible for water management (ibid.).

In Queensland, 28 sub-artesian resource areas have been declared in the regulations (requiring licenses and meters). The lack of data however from meters in priority aquifers impedes capturing significant consumptive uses. In South Australia, groundwater is a widely used

resource and 21 prescribed areas have been delineated. All Prescribed Areas require a license for groundwater abstraction (except for livestock and domestic uses). There are two exceptions however: the Eastern Mount Lofty Ranges and Northern Adelaide Plains Areas are highly allocated and therefore require that wells for livestock and domestic uses are also licensed. Sixteen of these 21 prescribed areas have water allocation plans. Of those considering metering in their water allocation plans, all but one of them require metering in their respective water allocation plans.

In Tasmania, groundwater resources are not widely developed and the level of management is low. In Victoria, legislation requires licenses for all abstractions (excluding livestock and domestic use) as well as meters for entitlements higher than 20,000m³/year. Areas with increasing development of groundwater are named 'Groundwater Management Areas' and those requiring closer management and regulation due to more intensive abstraction are delineated as 'Water Supply Protection Areas' leading to subsequent statutory plans. There are 62 Groundwater Management Areas.

As an example, in the Lower Murrumbidgee Valley in New South Wales, policy on groundwater management has been developed since the mid-1950s. Licenses were applied then and various rules and regulations since then have been put in place to control groundwater abstractions, whilst slightly modifying groundwater abstraction allowances for entitlements as well as a new Water Sharing Plan for the Lower Murrumbidgee after 2003 (for shallow and deep groundwater sources) (Table 11 and Table 12). The deep groundwater source of the Lower Murrumbidgee is fully allocated and used (with 311 licenses for irrigation) and the shallow groundwater has a small number of granted licenses (30).⁸¹ The continuous abstraction and the increasing in trading (outwards of the valley) caused abstraction levels to exceed the long-term average extraction limit after the mid-1990s (Kumar 2013).

As Table 11 shows, the different policy developments in the Lower Murrumbidgee Valley, NSW, indicate an increase in controls and a reduction of entitlements for groundwater licenses from 514 Mm³ to 270 Mm³ in 2006. Following the Water Sharing plan for the valley, at the start of every year, an available groundwater determination (from shallow and deep sources) is made, setting the allocation of groundwater for the different categories of access licenses. Supplementary water licenses⁸² have been reduced every year from 900 m³ in 2006-2007 to 100 m³ allowed in 2014-2015 (Kumar 2013; NSW 2015). Even though in 2010-2011 the low precipitation spell receded and levels and aquifer recovery occurred during this period due to flooding and rainfall events, groundwater abstractions were at its lowest during this year (Figure 53 and Figure 54), probably due to the inertia of the accumulated pressure on the resource due to the existing drought during the previous years and the reductions of license abstractions (with nine years of rainfall below average) (Burrell et al. 2012; NSW 2015).

⁸¹See also Section 3.3.

⁸² Supplementary water licenses are defined as additional water that becomes available during wet periods outside the regulated framework of established and granted water licenses. The additional volume of water available during wet periods that exceeds the environmental requirements and other granted water needs can be made available to license holders on regulated rivers. (New South Wales Government, Advice to Water Management Committees, http://www.water.nsw.gov.au/_data/assets/pdf_file/0003/549417/policy_advice_2-supplementarywater.pdf, Accessed 19th November 2015).

Table 10. Groundwater licensing and metering in Australia

<i>Jurisdiction</i>	<i>Main legislation regulating groundwater</i>	<i>Groundwater licensing</i>	<i>Groundwater metering</i>	<i>Progress required</i>
Australian Capital Territory (ACT)	Water Resources Act 2007	Licenses are required for all groundwater abstraction including livestock and domestic purposes	Meters are required for all groundwater abstraction including livestock and domestic purposes. Meters have to be recorded at the end of every month and the information must be provided to the licensing agency (upon request, usually once a year)	Management plans have not been prepared for Water Management Areas (envisaged as part of the water resource planning process required under the Murray-Darling Basin Plan)
New South Wales	Water Resources Act 2000 and the Water Act 1912	A license is required for the extraction of all groundwater (with the exception of livestock and domestic use). An approval is however required for constructing, altering or de-commissioning all groundwater wells (including livestock and domestic purposes).	Meters are enabled under the legislation and policy directions clearly intend to expand metering programs	Metering needs progress outside the Murray-Darling Basin. In July there were 30,000 licenses for which meters should have been installed but only 9,300 were actually metered.
Northern Territory	Water Act 1992	Licenses are required for groundwater extraction for commercial uses within Water Control Districts. Outside, threshold extraction rates determine the need for a license. A license is needed for abstraction over 15l/s.	Metering is required under legislation alongside abstraction licenses of the abstraction rate exceed a certain threshold volume outside planning areas (>15l/s) (unless the abstraction is from within a mining lease area).	Threshold abstraction rates outside planning areas have to be clearly articulated. Regulatory arrangements have to be considered within mining lease areas
Queensland	Water Act 2000	Licenses (or equivalent authorization) is required for the abstraction of groundwater for commercial purposes within proclaimed/declared areas (Water Resource Plan areas). A license is also required to take artesian water for any purpose.	Metering is enabled under legislation with regulatory provisions requiring a meter for each abstraction license. Meters are being installed in existing wells in selected high priority management areas	Stronger regulatory arrangements outside Water Resource Plan areas should be considered
South Australia	Natural Resources Act 2004	Legislation requires licenses for the abstraction of groundwater for commercial purposes (not including livestock or domestic) within	Metering is required for all licensed abstractions (not including livestock or domestic uses)	Stronger regulatory arrangements outside Prescribed Well areas should be considered

<i>Jurisdiction</i>	<i>Main legislation regulating groundwater</i>	<i>Groundwater licensing</i>	<i>Groundwater metering</i>	<i>Progress required</i>
		proclaimed/declared areas (a Prescribed Wells Area). Licenses are not required outside these areas unless it is through an artesian well		
Tasmania	Water Management Act 1999	Licensing dependent on the water planning process (not yet finalized)	Metering dependent on the water planning process (not yet finalized)	Licensing and metering regulatory arrangements have yet to be initiated
Victoria	Water Act 1989	A license is required for groundwater abstraction (except for livestock and domestic use)	Metering is enabled under legislation but it is implemented according to entitlement thresholds. Meters shall be installed in all wells for which the annual entitlement is >20,000 m ³ . Since groundwater management is delegated to Rural Water Corporations and affected in some cases by Water Management plans, more stringent metering thresholds are in place (across the southern region, meters are required for entitlements higher than 10,000 m ³ per year).	Some existing meters are likely to need upgrading to meet national standards
Western Australia	Rights in Water and Irrigation Act 1914; Rights in Water and Irrigation Exemption (Section 26) Order 2011	Licensing is required for the abstraction of groundwater from all artesian wells and from sub-artesian wells in groundwater management areas (with the exemption of livestock and domestic uses). Drilling of non-artesian wells for livestock and domestic uses is also exempt	Metering is required for the abstraction of groundwater from all artesian wells and sub-artesian wells in groundwater management areas. Regulation is established following metering thresholds. Thresholds vary however. Low priority areas they are required for wells abstracting 50,000m ³ per year or more and in priority areas wells abstracting 5,000 m ³ per year or more (this position was however based on the expectation of national funding support. Without the support, department staff have indicated that thresholds are likely to be set at 500,000m ³ per year)	Stronger regulatory arrangements for groundwater abstraction to be considered outside water planning areas

Source: adapted from Sinclair Knight Merz 2012.

Table 11. Policy developments in the Lower Murrumbidgee Valley, New South Wales

Period	Description
1955	All water bores constructed required a licence. Licences were issued in perpetuity with no area or volume based restrictions.
1972-1984	Licences became renewable on a 5-year basis and were issued initially based on authorised area for irrigation, and later on a volumetric basis.
1984-1991	Licences in the Lower Murrumbidgee GMA were issued on a revised volumetric allocation basis.
1991-1997	Licences in the Lower Murrumbidgee GMA were issued on a further revised volumetric allocation basis.
1997	A 12-month moratorium preventing the issue of groundwater entitlement for irrigation use was put in place in September 1997 for the Lower Murrumbidgee GMA.
1998	The moratorium was extended for an additional 18 months in September 1998.
1999	The above moratorium was replaced by a statutory embargo in September 1999
2000	In May 2000 a moratorium was placed on all new bore licenses for irrigation and Industrial purposes. This prevented the drilling of additional bores even where entitlements existed.
2001	Conjunctive bore licenses were converted to fixed groundwater entitlements.
2003	Water Sharing Plan (the Plan) for Lower Murrumbidgee Groundwater Sources was developed.
2006	Plan implemented in October with total entitlements reduced from 514.6 GL to 270.0 GL
2007	Implementation of local impact management.

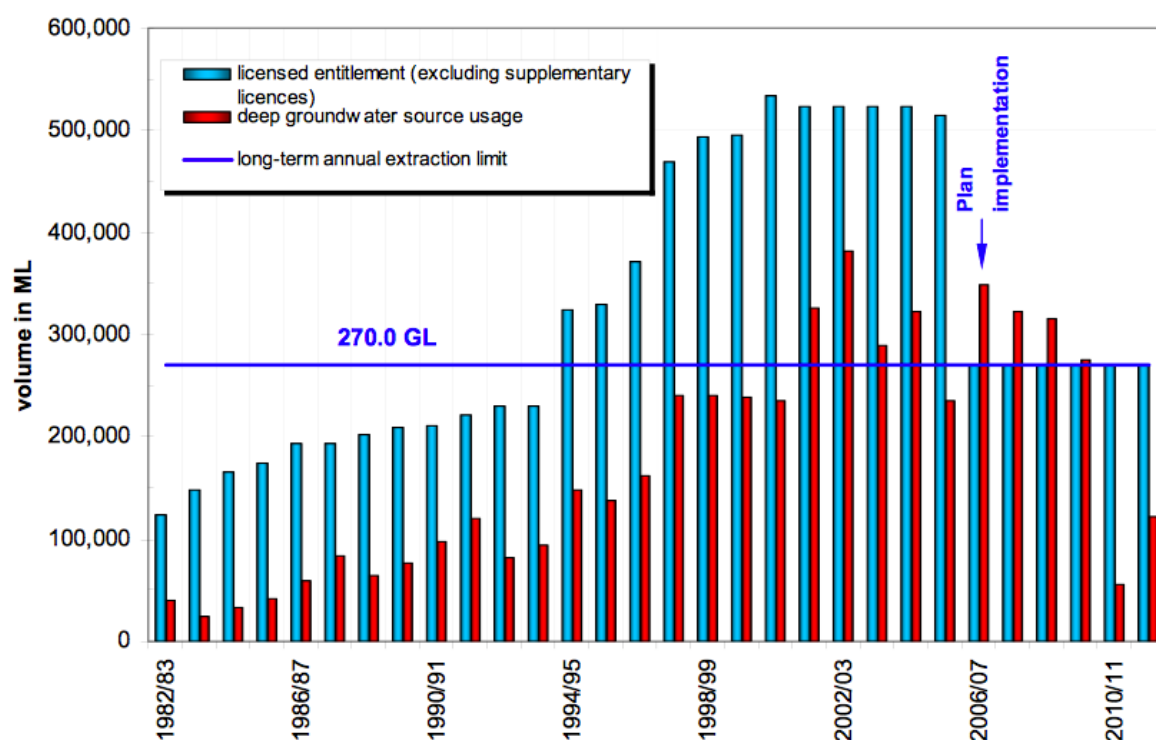
Source: Kumar 2010a.

Table 12. Groundwater abstraction rules in the Lower Murrumbidgee Valley

Period	Access Limit	Reason
pre-1982	Unlimited.	Low level of groundwater usage.
1982/83 – 1990/91	Access to 100% of Entitlement.	Low level of groundwater usage.
1991/92 – 1997/98	Access to 150% of Entitlement.	Relatively low level of groundwater usage and rising groundwater pressures.
1998/99	Access to 100% of Entitlement.	Prevent over use.
1999/00	Access to 95% of Entitlement.	Prevent over use.
2000/01 – 2001/02	Access 90-100% Entitlement, based on zones.	Prevent over use.
2002/03- 2005/06	Access limited to share of extraction limit or maximum history of use.	Manage within the extraction limit of the system.
2006	Access limited to new reduced entitlements or share components.	Plan rules.

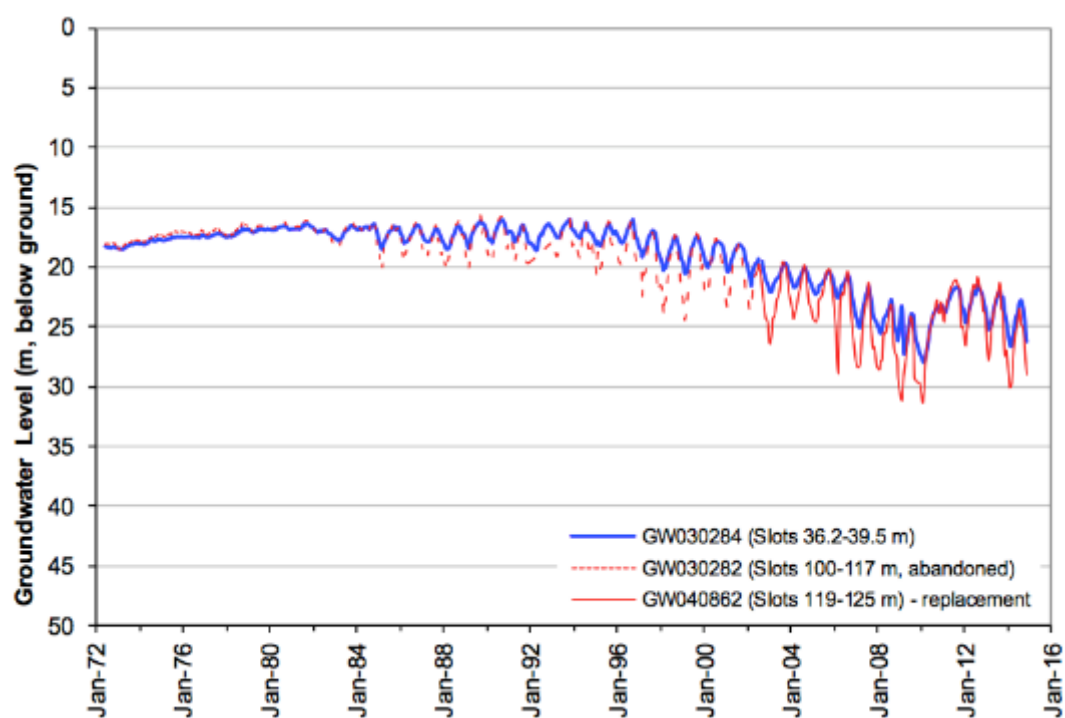
Source: Kumar 2010a.

Figure 52. Licensed entitlements and groundwater use in the Lower Murrumbidgee (1982-2012)



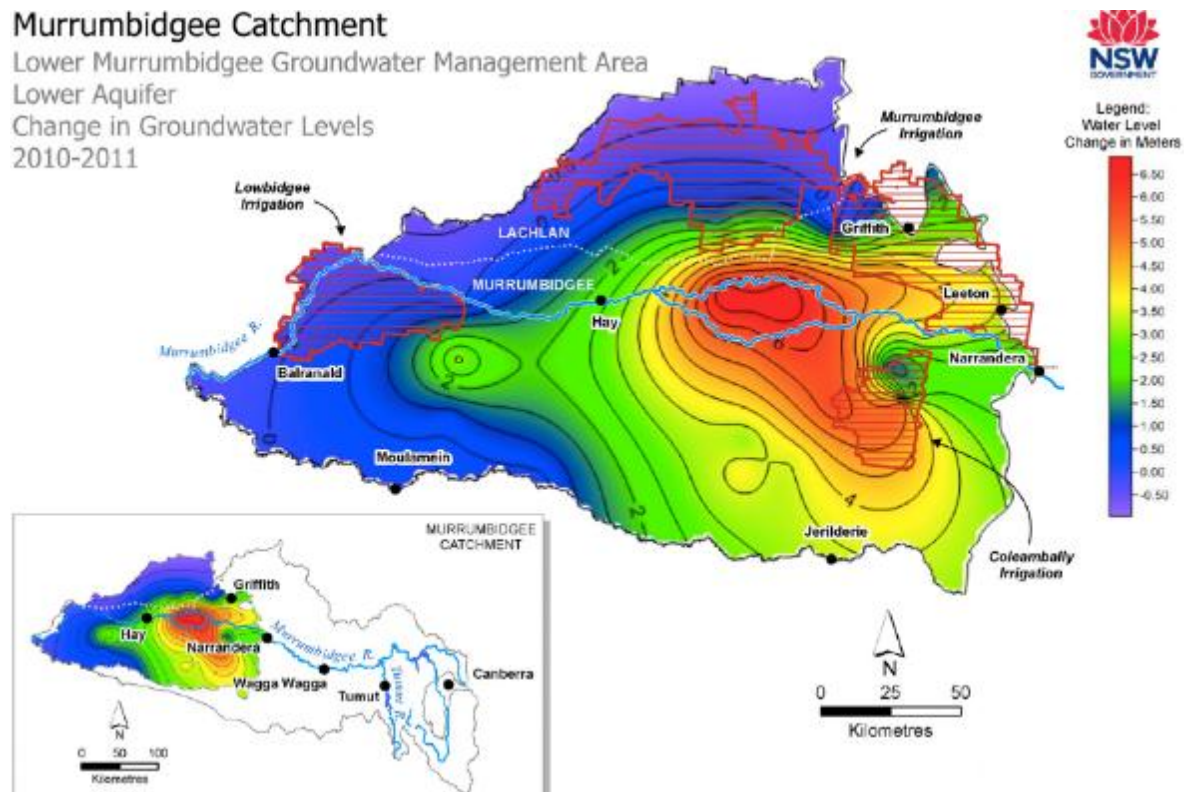
Source: Kumar 2013.

Figure 53. Groundwater levels for Belvedere monitoring site, Lower Murrumbidgee



Source: NSW 2015.

Figure 54. Change in groundwater levels in the Lower aquifer of the Lower Murrumbidgee catchment (2010-2011).



Source: Burrell et al. 2012.

Trades (permanent and temporary) are recorded in a water register and are audited (with onsite visits), something which is not that hard in Australia given the smaller number of groundwater irrigators) (Turrall 2015, pers. com.). When groundwater rights are bought from wells, new wells can be drilled or abstraction increased from the existing well. In some instances, since the cost of drilling a new well is high, buyers sometimes install pipes (for neighbors not very far apart) to convey water from the well supplying groundwater to the land plot. As described by Turrall (ibid.), if groundwater rights are purchased in South-east Australia it is rare that the entire right is sold by sellers. If that is the case however, the well will be decommissioned but not backfilled. Control a posteriori is exercised centrally through metering and inspections (additionally, individual users keep also control of neighboring irregular activities happening and can report them to the authorities). Fines are a serious financial burden and using groundwater without a right a punitive offence. This however does not mean that illegal pumping does not occur (ibid.). In the Werribee Irrigation District (west of Melbourne) for instance, a 7-8 year drought episode led to a drastic reduction of aquifer recharge and a blanket pumping ban was imposed in 2007-2008.⁸³ Despite emergency measures (such as substituting irrigation water with treated urban wastewater from Melbourne for agriculture), Turrall (ibid.) refers to "clear instances of people

⁸³ The Goulburn-Murray Water Corporation (entitled to manage the portion of the Murray-Darling Basin in the State of Victoria) developed during that drought water saving programmes which saw the decommissioning of meters (700 outlets) and new installed meters (194) as users were opting for new farm layouts and purchasing arrangements (http://www.gmwater.com.au/downloads/gmw/Annual_Reports/2008_09_G_MW_Annual_Report_Low_Resolution_File.pdf, Accessed 26th of October 2015).

continuing to pump" and problems with controls and verifications by the authorities (with on occasions, users threatening with guns). In the end however, wells were forcefully decommissioned and dismantled and users prosecuted. Additional control measures include monitoring information from Catchment Management Authorities through aerial photographic inspection of rice areas (routinely for the last 20 years) with the aim to enforce limits on groundwater recharge (in saline shallow aquifers especially). Water use audits are however less of a routine compliance mechanism and more a one-off control activity (ibid.).

User participation for groundwater management in South East Queensland: In Queensland, the proposed co-management for the Lockyer Valley is aimed at developing effective sharing institutions among groundwater users supported by the regulating agency within the context of self-governing institutional arrangements. This is consistent with Australia's water reform agenda from 1994 and the Australian National Water Initiative of 2004 aiming to restore environmentally sustainable extraction levels in overused ecosystems and use community partnerships to promote transparency and ensure information access for decision-making (Sarker et al. 2009). Following this policy initiative, the Lockyer Water Users Forum began negotiating with the Queensland government to develop a co-management approach to groundwater, motivated largely by the desire of water users to avoid an imposed and inflexible regulatory approach from the government (ibid.). This process is therefore driven by the perception that users want to retain control over the resource that is key to their livelihood and show an interest in controlling and participating in the planning process so that the interests of the groundwater users are respected (ibid.).

The Lockyer Water Users Forum is a group of water users created in 2001 during a meeting of all representatives of all irrigation groups and which comprises representatives of 17 sub-catchment irrigator groups (Baldwin 2008). The government-led water resource planning process at the time caused users to decide to foster a 'more collaborative approach' to determine their future. Lockyer irrigators were trying to "manage decreasing availability of water on an individual basis with little scientific information" and submitted in its co-management proposal "to supplement State government data acquisition with funding for additional groundwater monitoring of use (through meters) and aquifer levels and three dimensional aquifer modelling in conjunction with irrigators to produce credible independent data on groundwater use and its impacts" (Baldwin 2008: 119).

The government of Queensland has been in discussions with the Lockyer Water Users Forum for over 10 years over the supply of water for irrigation. They have developed a co-management proposal for the sustainable management of the Lockyer Valley surface and groundwater but their effort lapsed, as the Australian government "was not forthcoming", with progress in the implementation of groundwater management slowing down and being overtaken by the implementation of pricing reforms (SEQWater 2013: 9).

One of the main issues discussed by the groundwater users was the ownership and monitoring of groundwater abstractions. The proposal by the Lockyer Water Users forum was that government would provide an overall allocation to each of the 18 management areas within the basin and that the forum would own, maintain and monitor meters directly. This was considered important as the irrigators wanted to monitor directly and more often than the state, in order to better understand the relationship between water use and aquifer levels (ibid.). The forum of groundwater users also showed interest in implementing a system of small management zones, nested within an over-arching governance framework under the auspices of a general board (ibid.).

2.2 Groundwater management in South Western Australia⁸⁴

2.2.1 Groundwater resources and water supply in South Western Australia

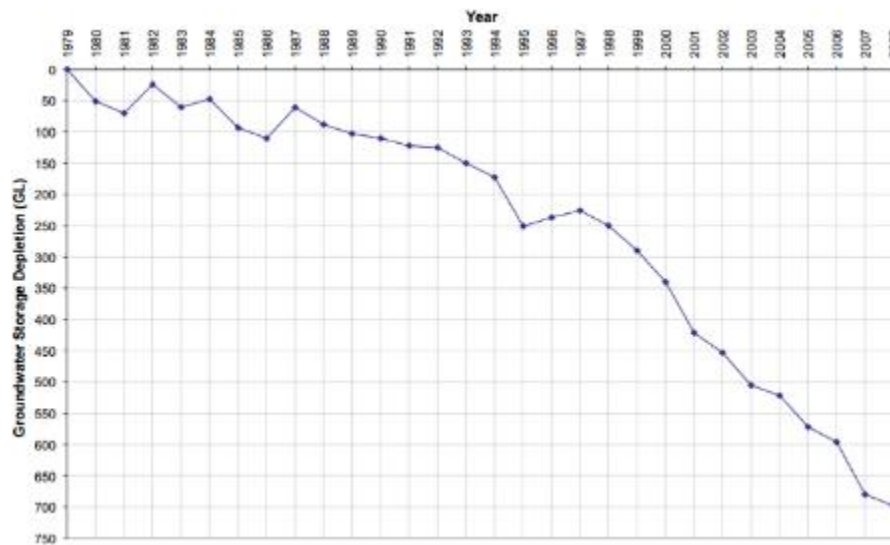
The South West of Western Australia is an area covering 62,500 km² and containing around 2 million people located along the western coast of Australia between Albany in the south, Perth in the centre, and up to Geraldton in the mid-west region of Western Australia. Groundwater is the most important resource for consumptive use in the South West (estimated at 850 Mm³ per year for drinking water supply in urban areas and self-supply for gardens, horticulture, and industry). Perth is the largest groundwater-dependent city in Australia (Turral and Fullagar 2007). It is estimated that groundwater self-supply via wells represents 700 Mm³ per year, with the remaining 150 Mm³ used by water utilities to supply drinking water. The Department of Water estimated in 2009 that there are around 176,000 garden bores in the Perth-Metropolitan area alone (Sinclair Knight Merz 2012). These wells are exempt from usual licensing requirements.⁸⁵

The South West of Australia has experienced a significant decrease in winter rainfall over the last decades (17 percent decrease since 1970) leading to a decline in streamflow into reservoirs (over 50 percent). This has also caused decreasing recharge in aquifers and increasing demand for groundwater to substitute surface water. It has been estimated that reductions in recharge have caused water table drops of up to 4 meters between 1979 and 2005 in the Gnamptara shallow aquifer north of Perth (covering approximately 2,200 km²). The aquifer system comprises the unconfined superficial aquifer, the semi-confined Mirrabooka Aquifer, and the confined aquifers of Leederville and Yarragadee. The shallow aquifer consists of quaternary and tertiary coastal sediments (sands, limestones, and clay) and is between 45 and 75 meters thick. The confined aquifers consist mostly of cretaceous sandstones. The middle aquifer is mostly recharge from the downward through-flow coming from the shallow aquifer. Resources in the Gnamptara aquifer system are also over-allocated (with pine plantations unregistered but heavily affecting the recharge of the aquifer) (31 percent of management units are declared over-allocated – defined when the "total volume of water able to be extracted by entitlement holders at a given time exceeds the environmentally sustainable level of extraction for that system" (Bennett and Gardner 2014: 27)).

⁸⁴ Source: Bennet and Gardner 2014, 2015 unless referenced otherwise.

⁸⁵ The heavy use of groundwater at the household level started after the Second World War when water consumption increased with newfound affluence in the suburbs with gardens. Total water restrictions in 1978 were seen as a shock to many families. The introduction of user-pays water rates at the same time outraged them even more, provoking a wide public backlash which caused the government to back down. In 2005, the Labour government made the pledge to reduce the likelihood of water-sprinkler bans to just one year in two hundred. Seawater desalination and wastewater recycling have become the centre of Western Australia's Water Corporation for more than three quarters of the state population with the 10-year strategy approved in 2008 (Morgan 2015).

Figure 55. Decline in groundwater storage levels in the superficial Gngangara aquifer (1979-2008)



Source: Bennett and Gardner 2014.

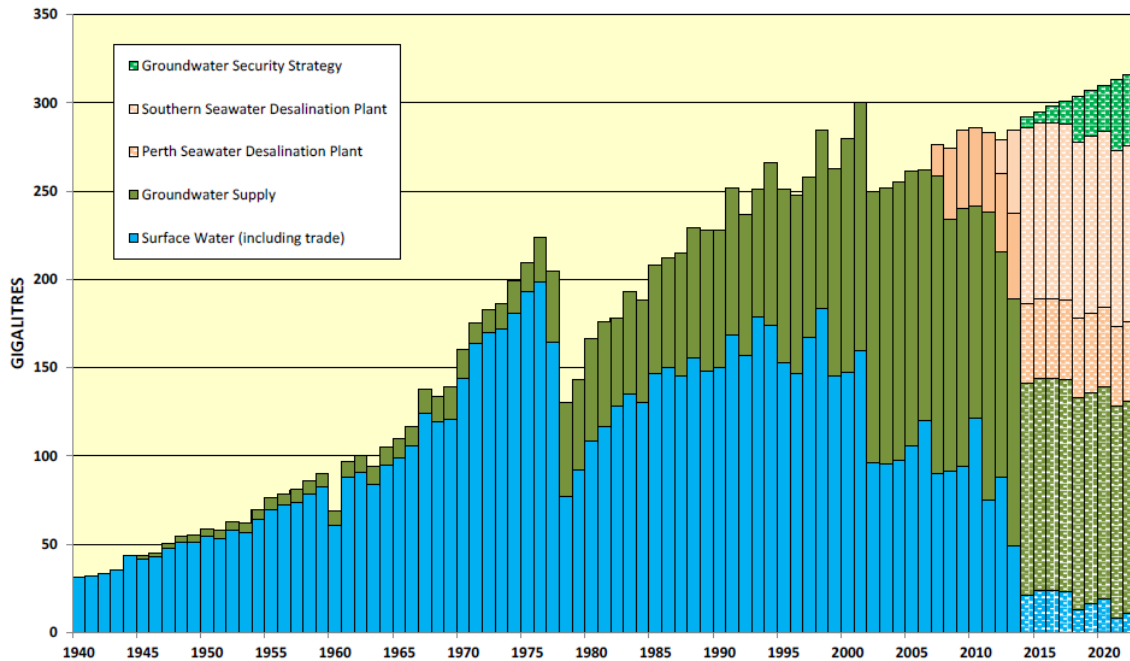
Alternative groundwater sources to replace reduced surface water stream-flows were found in the Gngangara Mound (north of Perth) and the Jandakot Mound. The use of groundwater for public water supply increased since then, first from these two more superficial reserves since the 1960s, and later from deeper more confined aquifer layers. By 1998, according to Bennett and Gardner (2014: 23), "the Water Corporation was using oil-field technology to draw water more than one kilometer from the Yarragadee aquifer beneath Perth".

The Gngangara Groundwater Allocation Plan (2009) recognized that some management sub-areas were over-allocated and designed a number of responses aimed at reducing the level of licensed abstractions. The plan stated that no new water entitlements in over-allocated areas would be granted, reduced Perth's water utility company (called Water Corporation) allocation, and recouped unused water entitlements. The Water Corporation's allocation was reduced as its licenses expired in 2012 and the renewed ones were granted with a reduced entitlement. Licensed entitlements decreased in 2013 and 2014 (due also to the fact that rainfall recovered after the very dry winter of 2010 and increasing desalination production). The maturation of pine plantations in the basin also contributes to reduced recharge in the superficial aquifer layers (Bennett and Gardner 2014; Skurray et al. 2013).

As part of Perth's future integrated plans to increase security in water supply by 2022, the city's water utility established in 2013, a 'Groundwater Security Strategy' which includes the development of groundwater recharge projects in the Leederville and Yarragadee aquifers with treated wastewater (the goal is to recharge 14 Mm³ per year), allowing the city to abstract the same equivalent of groundwater and use it in its water supply (Water Corporation 2013). The plan also included transferring groundwater abstraction to the deeper aquifers surrounding the city to protect the groundwater-dependant ecosystems and secure groundwater supply by using these deeper groundwater sources. Desalination has also been used to compensate for the lack of surface water and to relieve pressure on groundwater resources since 2006 when the first desalination plant for Perth was completed and became operative (producing 45 Mm³). Also, as part of this 10-year plan, the city of Perth and the Water Corporation envisage to expand the city's existing desalination potential by building an additional plant (designed to be built in two phases, each one with a production capacity of 50 Mm³, bringing to 145 Mm³ the total

desalination production capacity of the metropolitan area of Perth after completion). Stage one of this plant became operational in 2012 and stage two was commissioned in 2014 (Water Corporation 2014).

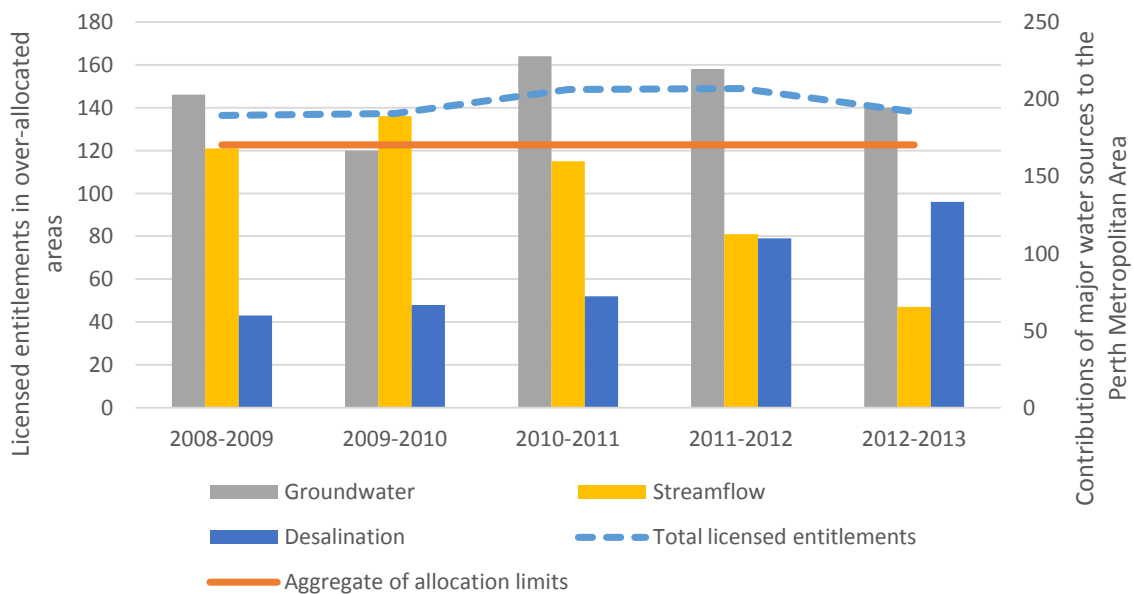
Figure 56. Water supply sources for Perth Metropolitan Area and projections of supply



Note: after 2014, values are projected estimates (hence the change in colour).

Source: Bennett and Gardner 2014.

Figure 57. Licensed entitlements in the Gnangara Groundwater system and contributions from major water sources to the Perth Metropolitan Area water supply



Source: Based on data from Bennett and Gardner 2014.

2.2.2 Regulation of groundwater abstraction in Western Australia

The historical common law of the rule of capture has been replaced in Australia by a statutory 'regulated access' model for groundwater. In Western Australia, the *Rights in Water and Irrigation Act 1914* is the principal legislation covering groundwater management. There, groundwater entitlements are volumetric (licensees are granted a specified volume of water to abstract each year). During severe dry spells, these entitlements can be reduced by ministerial decree. Even though these groundwater volumetric entitlements can also be reduced permanently without any compensation if the reduction "is fair and reasonable", in fact, this power has rarely been used in groundwater over-allocated areas in the South West. This is due, according to Bennett and Gardner (2014: xii), to the fact that "it would be administratively onerous to amend a large number of licenses individually and deal with resulting merits appeals to the State Administrative Tribunal." Furthermore, water legislation in South West Australia does not provide how the risk of loss from entitlement reductions made by water plans and their amendments will be assigned between water users and government. Water users investing on the basis of already defined water management plans and entitlements "may legitimately anticipate some security of entitlement during the term of the plan" but as it stands now, periodic adjustments from a consumptive pool will be made and will apply equally to all entitlement holders without compensation. Abstraction licenses are also "not fully 'unbundled' from land in Western Australia. In order to hold a license, a person must ordinarily be an owner or occupier of the land to which the license relates, or have the agreement of the owner and occupier to be on the land and do the things that may be done under the license" (Bennett and Gardner 2014: 13).

The Department of Water in South West Australia identifies cumulative allocation limits for groundwater abstraction. But before an allocation limit is set, the department estimates the environmental water requirements and assesses the 'resource yield' needed to meet these requirements. These allocation plans drawn by the Department of Water identify in practice: a) the allocation limit for the total consumptive use of the relevant resource (i.e. groundwater) in a sub-area/aquifer; b) an estimate of unlicensed use; c) any water resource reserve as a source for future public water supply; d) the remaining component available for license allocation.

Legislation reforms in 2004 signed by an Intergovernmental Agreement arising from a National Initiative on Water Reform brought new commitments towards changes in water planning and regulation measures.⁸⁶ Statutory water plans had to be directed at achieving environmentally sustainable levels of abstraction as well as aiming to return over-allocated and over-used water resources to sustainable levels. After these changes, the Department of Water requires a license in order to abstract groundwater (whether it is artesian or non-artesian in a proclaimed area or in an area prescribed by regulations).⁸⁷ Users do not need a license to abstract non-artesian groundwater if an order to this effect has been approved by the Governor. Exemptions from licensing include: 1) firefighting; 2) watering cattle or other livestock (not raised intensively); 3) watering gardens smaller than 0.2 hectare; 3) other domestic uses; 4) short term dewatering; 5) taking water for monitoring purposes. The use of groundwater for domestic gardens remains

⁸⁶ The National Water Initiative addressed overuse and over-allocation issues by requiring the development of comprehensive water plans (surface and groundwater), the restoration of over-allocated basins to 'environmentally sustainable levels' and the provision for environmental water supplies (Ross 2012).

⁸⁷ No areas in South West Australia have been prescribed by regulation but approximately 90 percent of Western Australia's groundwater resources are within proclaimed areas. Areas outside proclaimed areas tend to be isolated fractured rock aquifers (Bennett and Gardner 2014).

unlicensed. State government policy "does not favor the licensing of domestic garden bores" but does "identify large areas of Perth that are unsuitable for such bores" (Bennett and Gardner 2014: 35).

Licenses can be granted for a determined period of time but also indefinitely. In practice, licenses are usually issued for up to 10 years. Common conditions under which licenses are granted include: 1) the installation of an approved meter for each water point;⁸⁸ 2) the licensee must record the reading from each meter required under the license at the beginning and the end of the water year; 3) licensees must provide a groundwater monitoring summary to the Department of Water; 4) license conditions can also impose water efficiency requirements (directly by requiring for example a golf course to only use its sprinklers at a certain time of the day or by requiring a water conservation or efficiency plan as part of its operating strategy).

Licensees are prevented from abstracting the full volume of water entitled when:

- 1) Conditions already specified in the license;
- 2) Other laws restricting abstraction (e.g. abstraction causing environmental impacts assessed under the Environmental protection Act 1986 such as affecting wetland water levels or nationally threatened species or ecological communities; or under the Contaminated Sites Act 2003 when abstraction is deemed unsafe as the site has been classified as contaminated);
- 3) A restriction (issued by the minister or departmental delegate) is issued restricting groundwater abstraction if it is determined that the volume of groundwater abstracted "is, or is likely to be, insufficient to meet demand, including any demand made by the needs of the environment; or where the Minister has made, and published in the Gazette, an order declaring that a water shortage exists in the area in which the water resource is situated" (Bennett and Gardner 2014: 11-12);
- 4) The license can also be amended to reduce the annual volume of groundwater allowed to be abstracted in order to protect the resource or associated environment or to prevent an inconsistency arising from a water allocation plan (only under this pretext compensations can be made).

The Rights in Water and Irrigation Act 1914 also regulates the construction and alteration of wells. It is considered an offense to construct or alter a well in a proclaimed area. The construction or deepening of wells has to be reported within one month. The report will include: the driller's name; coordinates of the well; intended use; well depth; water level; field samples (e.g. salinity). Penalties for abstracting water without a license or for breaching a condition of a license can be up to 10,000 USD for individuals and 50,000 USD for corporations (plus a daily penalty of up to 1,000 USD for individuals and 5,000 USD for corporations).

However, according to Bennett and Gardner (2014: 61), it is difficult to address groundwater over-allocation through the use of license amendments. For certain activities (e.g. mining)⁸⁹, there have been deliberate policy decisions to allow continued over-allocation "in order to

⁸⁸ Existing legislation states that meters are compulsory for abstraction levels of over 500,000m³ per year, so many users with domestic wells do not fall under this condition.

⁸⁹ In the Collie groundwater area found in the Collie Coal Basin, groundwater abstraction for mining activities have had significant impacts on aquifer levels, with water table drops of up to 50 metres compared to pre-mining state (Bennet and Gardner 2014).

facilitate the ongoing operation of coal mining and coal-fired electricity generation in the area." It is also administratively onerous to address over-allocation via the revision of license and amendments, as they have to be done on an individual basis. Licensees have the right to review and comment and the legal fees for the Department of Water could be very high (as it would have to be overseen by the State Administrative Tribunal). Additionally, compensations would have to be paid in case water reductions were imposed.

With the new system of water entitlements in place, "giving the holder of the entitlement a perpetual share of a consumptive pool and identifies a 'risk assignment framework' for changes in that consumptive pool" (Bennett and Gardner 2014: 17). These reforms also aimed at increasing the use of market-based mechanisms to release water entitlements and reduce barriers to trade with them.⁹⁰ Following these legislative changes, water was allowed to be traded separately from land (but not separated from its water license), enabling permanent and temporary trades of entitlements. From July 2002 to June 2007 there were a total of 58 permanent groundwater entitlement trades in 24 separate groundwater management sub-areas (totaling 2.9 Mm³) and 12 temporary agreements (representing 14.6 Mm³).⁹¹ In 2010-2011 the volume of groundwater traded had however increased substantially to 716 Mm³ (with 1,956 new and renewed groundwater licenses) (National Water Commission 2011c) thus demonstrating the erratic and highly fluctuating market conditions.

2.3 The Murray-Darling Basin, Southeast Australia

The Murray-Darling Basin (MDB) covers 1.043 million Km² in south-eastern Australia and has a population of 2.1 million people (Ross 2012). Its agricultural activities supply around 40 percent of the gross value of Australian agricultural production (ibid.). Groundwater supplies about 16 percent of water at the level of the whole basin but the share can rise to 27 percent in the north of the basin (ibid.). Nearly 75 percent of irrigated agriculture in Australia occurs in the Murray-Darling basin (Chartres and Williams 2006). Additionally, about 75 percent of the basin's mean annual flow is diverted and more than twice its average flow is stored (ibid.). Groundwater dependence can locally be higher, such as in rural communities or in metropolitan areas, with cities such as Newcastle relying on coastal aquifers by up to one-third for its water supply (Malone et al. 2009).

The MDB has over 50 surface water management units and 100 groundwater management units. Superimposed to these are 18 river catchments (Turrall and Fullagar 2007). In the MDB, 40 percent of GMUs are highly used or overused (70 percent or more of sustainable yield abstraction) (Sinclair Knight Merz 2003). In the MDB, the total groundwater sustainable yield as calculated by Sinclair Knight Merz (2003) is 7.4 Bm³ per year, 67 percent of which lies within UAs where there is little demand for groundwater. This groundwater is, following Sinclair Knight Merz (2003) of poor quality and saline (with values of over 3,000 mg/L of total dissolved solids). There is actually 2.4 Bm³ per year available for extraction under sustainable development practices (ibid.).

⁹⁰ A State Government Discussion Paper from 2009 was published detailing a set of reform proposals mirroring the commitments reached by the National Initiative and Intergovernmental agreement and signed by Western Australia in 2006. In September 2013 the Government released a position paper on reforming water resource management with a view of drafting new legislation on water resource management in 2014.

⁹¹ Data from the Water Trading Information for the Economics and Industry Standing Committee, [http://www.parliament.wa.gov.au/parliament/commit.nsf/\(Evidence+Lookup+by+Com+ID\)/2F59FD83CFBEAA75482578310040CF0D/\\$file/Submission+No+46+Dept+of+Water.pdf](http://www.parliament.wa.gov.au/parliament/commit.nsf/(Evidence+Lookup+by+Com+ID)/2F59FD83CFBEAA75482578310040CF0D/$file/Submission+No+46+Dept+of+Water.pdf) (Accessed 24th June 2015).

Surface water extractions from the Murray-Darling were capped in 1995 to 1993-1994 levels in order to limit the amount of water that could be diverted for consumptive uses. Regulation of surface water entitlements had started during this decade, arising mainly from concerns in states downstream (e.g. South Australia) about the salinity impacts of irrigation development further upstream (Marshall et al. 2013). The negotiations that started about salinity eventually resulted in a more encompassing arrangement on the whole basin (ibid.).

The decision on the cap came out of an agreement in 1994 when all state and territory governments agreed on a series of reforms aimed at finding an equilibrium with supply and demand of water resources in the country (which included water prices, allocations and trading, environmental and water quality) (Chartres and Williams 2006).⁹² Under this agreement, groundwater however was not capped and while the imposition of the cap, surface water use has remained stable, groundwater has continuously been on the rise (between 1993-1994 and 1996-1997 groundwater use tripled in New South Wales and Victoria states) (Ross 2012). The cap was also implemented, according to Williams (2011: 26) "with the water-management rules that operate separately in each State and that are counter-cyclical. Namely, they provide for a greater proportion of inflows to irrigators in dry years than in wet periods."⁹³ Additionally, groundwater abstraction continued to increase in the early 2000s by up to 50 percent in two years due to the decrease in surface water availability due to the cap on surface water and drought (Nevill 2009). This provided irrigators with a significant buffer but led to drops in the hydraulic head of wells of 10 to 20 meters (ibid.). After a general review of the surface water cap in August 2000, several recommendations on groundwater were issued, such as its management "on an integrated basis with surface water within the spirit of the Cap" and a strategy in order to manage groundwater through sustainable yields and include studies on how groundwater management practices can impact the integrity of the cap (Sinclair Knight Merz 2003).

Groundwater had been mainly dissociated from surface water in the MDB until 2001 when the review of the operation of the water cap recommended the development of a groundwater management strategy for the MDB (Ross 2012; Turrall and Fullagar 2007). This was reinforced by the separation between surface and groundwater science (hydrology vs. hydrogeology), hindering the development of integrated water management. Water management is also highly centralized in the hands of ministers and departments, and surface and groundwater policy and planning are coordinated at the highest decision-making level but separated at the lower implementation levels (Ross 2012). Although consultation is included within state water legislation, this process often occurs after policy changes have been made or does not take fully into account the different stakeholders' views (Ross 2012).

Work that began in 2001, to revise the principles of the Cap in the MDB and provide more detail and guidance in water planning, was never completed (Anderson et al. 2014). Following a series of legislative initiatives to recognize and establish agreed sustainable management objectives during this period (1994-2001), the Council of Australian Governments agreed in 2003 to

⁹²Interstate water shares across the basin had originally been agreed in 1915 (without much knowledge of the actual river flows and science). Additionally, these limits "were not tested by water resources developments until it was realized (in the late 1970s) that the licensed volume exceeded the available resource" (Turrall and Fullagar 2007: 324). Managers subsequently realized that "the existing licensed volume already exceeded the sustainable water resource and that, at the prevailing rates of irrigation expansion, the actual diversion would exceed sustainable limits by 2020" (ibid.).

⁹³This rule was justified, following Williams (2011: 26) under the belief that "the environment would get its 'fair share' of the water during flood events, and this would be consistent with the natural flows to which the Basin's ecosystems had evolved."

consolidate and update the 1994 Water Reform Framework and established in 2004 the National Water Initiative (ibid.). Even though the National Water Initiative was national in scope, it "was strongly shaped by the need to manage political conflicts in the MDB. (This was reflected in the NWI's minimal coverage of water quality, groundwater and urban issues)" (Marshall et al. 2013: 243).

The management plan for the MDB was enabled by the Water Act of 2007 approved by the Australian Parliament. This piece of legislation redefined the priorities for water policy for the Basin and required the preparation of a plan alongside the creation of the Murray-Darling Basin Authority (Weir 2011). Aquifer management in the MDB is complex as in many instances aquifers overlap different catchments (thus different catchment management units) and also different states. Aquifers are therefore sometimes into different management zones causing poor coordination in planning uses and allocations. Monitoring and measurement is also incomplete leading to data gaps affecting modeling and management (Turrall and Fullagar 2007). The delay in the implementation of specific groundwater reforms to be added to the MDB Framework in 1996 meant the magnification of the basin's environmental and water problems in 2009.⁹⁴ Some states were quite relaxed in the implementation and compliance with the new rules (e.g. Queensland State maintained a causal attitude vis-à-vis the development of floodplain water harvesting, allowing catchment farm dams to increase by 90 percent) (Nevill 2009). For Nevill (2009), given the level of over-allocation and over-use in some areas, reductions in abstractions should have been put in place rather than a cap (due to inconsistencies in data). The cap was however the political acceptable solution, not the scientifically or environmentally sound one (ibid.).

A Guide to the Proposed Basin Plan was issued in 2010 stating that between 3 and 7.6 Bm³ per year were required to be returned to the river to achieve the environmental goals of the Water Act (Wahlquist 2011). The guide's recommended conservative estimate was between 3 and 4 Bm³, short of the at least 4.4 Bm³ required by the vocal and influential group of scientists (the Wentworth Group of Concerned Scientists) for a healthy and working river basin (Leblanc et al. 2012; McKay 2011; Wahlquist 2011). These savings were to be achieved through a large buy-out of surface water rights from users (by 2010, 0.9 Bm³ had already been purchased by the Federal Government, and the MDB plan aimed to extend this work and proposed that an additional 2.1 Bm³ be purchased from farmers to reach the target of 3 Bm³ (Weir 2011). An initial budget allocation from the State's purse had been secured in 2008 through the Water for the Future Initiative for 0.7 Bm³ of surface-water entitlements and the Government had USD 1.8 billion remaining for future entitlement purchases, indicating "a willingness to draw deeper into the public purse to close the environmental watering gap if required" (Bjornlund et al. 2011: 291). These sales however happened, according to Bjornlund et al. (2011), by irrigators "forced to sell as a last resort due to financial stress, not least as a result of the current prolonged drought" and that "few regard themselves to be willing sellers of water entitlements" (ibid.).

In the MDB, the Basin Plan sets out the 'sustainable Diversion Limit' (SDL) resource units within the Basin with their corresponding SDLs (based on the sustainable yield for groundwater) (Sinclair Knight Merz 2014). Groundwater SDLs are specified as particular volumes of water per year and are based on assessments of a defined 'Environmentally Sustainable Level at Take'

⁹⁴These finished abruptly in 2010 when, after ten years of below average rainfall (the so-called 'Millenium drought'), a very strong La Niña event in 2010-2011 produced the highest annual rainfall mean recorded in the Murray Darling Basin (Leblanc et al. 2012).

(ESLT) for each SDL resource unit (Anderson et al. 2014). The ESLTs are to provide the SDLs with an environmentally, social, and economically sustainable limit on the volume of water that can be taken for consumptive use from the basins water resources (Sinclair Knight Merz 2014). SDLs define the long-term average volume of water that can be taken from the resource unit, replacing the existing basin-wide cap on surface water diversions and will take effect on 1 July 2019 (National Water Commission 2013).

2.4 The Great Artesian Basin

2.4.1 Groundwater resources and use in the Great Artesian Basin

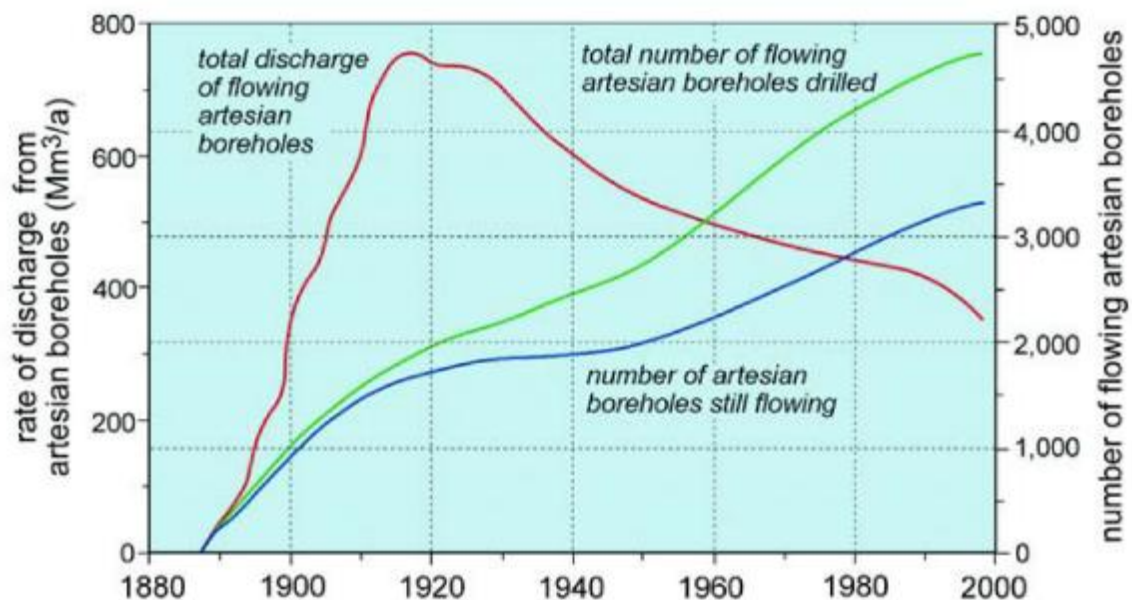
The Great Artesian Basin (GAB) of Australia underlies approximately one fifth of Australia's land surface (1.7 million km²) stretching to parts of Queensland, New South Wales, South Australia, and the Northern Territory (Habermehl 2006). Its estimated groundwater storage is around 8.7 million megalitres (8,700 Bm³) (Cox and Barron 1998). This confined basin is up to 3,000 metres thick, consisting of alternating layers of water bearing sandstone aquifers and non-water bearing layers of siltstones and mudstones and confined by shales above and by basement rocks below (Bhp Biliton 2015; Cox and Barron 1998; Queensland Department of Natural Resources and Mines 2005). "Springs occur near the margins of the Basin where the aquifer is shallow and the shale aquitard is thin, enhanced by structural weaknesses (faults) providing low-conductivity conduits that transmit the pressurized GAB groundwater upwards" (Bhp Biliton 2015: 2). Springs form permanent aquatic environments supporting plants and animals adapted to these habitats (ibid.). Before the 1870s there were around 3,000 flowing artesian springs, mostly in South Australia and Queensland (Ponder 2002). Recharge in the Basin occurs mainly along the eastern edge, and a smaller recharge area along the western edge through rainfall infiltration, spring recharge, and lateral groundwater flow along the western slopes of the Great Dividing Range in Queensland and New South Wales (Bhp Biliton 2015; Government of South Australia 2014). Groundwater flows slowly (about 1 to 5 metres per year) and naturally from these recharge areas toward springs in the West and southwest because of gravity (Queensland Department of Natural Resources and Mines 2005). The Great Artesian Basin contributes to spring discharge in the Darling River Basin in New South Wales through direct leakage through outcrop areas (Herczeg 2008).

Groundwater is used for urban supply, irrigation, livestock intensive industries (sheep, cattle, and pigs), mining, and power generation. For example, in the State of Queensland in 2005 there were 63 industrial licenses (representing 26 percent of total nominal entitlements), 352 irrigation licenses (28 percent of total nominal entitlements), 5 mining licenses (5 percent of total nominal entitlements), and 3,799 livestock and town supply licenses (40 percent of total nominal entitlements) (ACIL Tasman 2005). As the report by ACIL Tasman (2005) stated, at the time of writing, licenses can cover more than one bore and licenses for livestock and domestic purposes do not have a volumetric entitlement associated with them. Most irrigation is for small areas of fodder production for supplementary livestock feeding during the dry season or to boost fodder quality for particular classes of stock (ibid.). Recent additional challenges found in the GAB come from coal seam gas (an unconventional gas) and fracking. Groundwater is abstracted to reduce the pressure in the coal seam, and gas is subsequently allowed to flow to a surface well or injected via fracking technology to release the gas (de Rijke et al. 2016). Although a Federal Senate Inquiry recommended stopping any further approvals for production of coal seam gas, given the lack of evidence of its impact on water resources, the pro-extractive Queensland government seems to have little interest in enforcing such recommendation (ibid.).

Continuous groundwater abstraction over more than a century has created large-scale drawdowns and reduced artesian borehole discharges and spring flows (Habermehl 2006). Artesian water was discovered in 1878 and since then, more than 4,700 artesian boreholes have been drilled. By 2006, about 3,100 remaining were still flowing, producing artesian flows of more than 100 litres per second (Habermehl 2006). These artesian boreholes can reach depths of up to 2,000 metres although average depth remains shallowed (500 metres) (ibid.). Non-flowing artesian waterbores numbered 20,000 in 2006, with depths between the tens to the hundred meters. They are generally powered with windmills and supply about 300 million litres per day in total (ibid.).

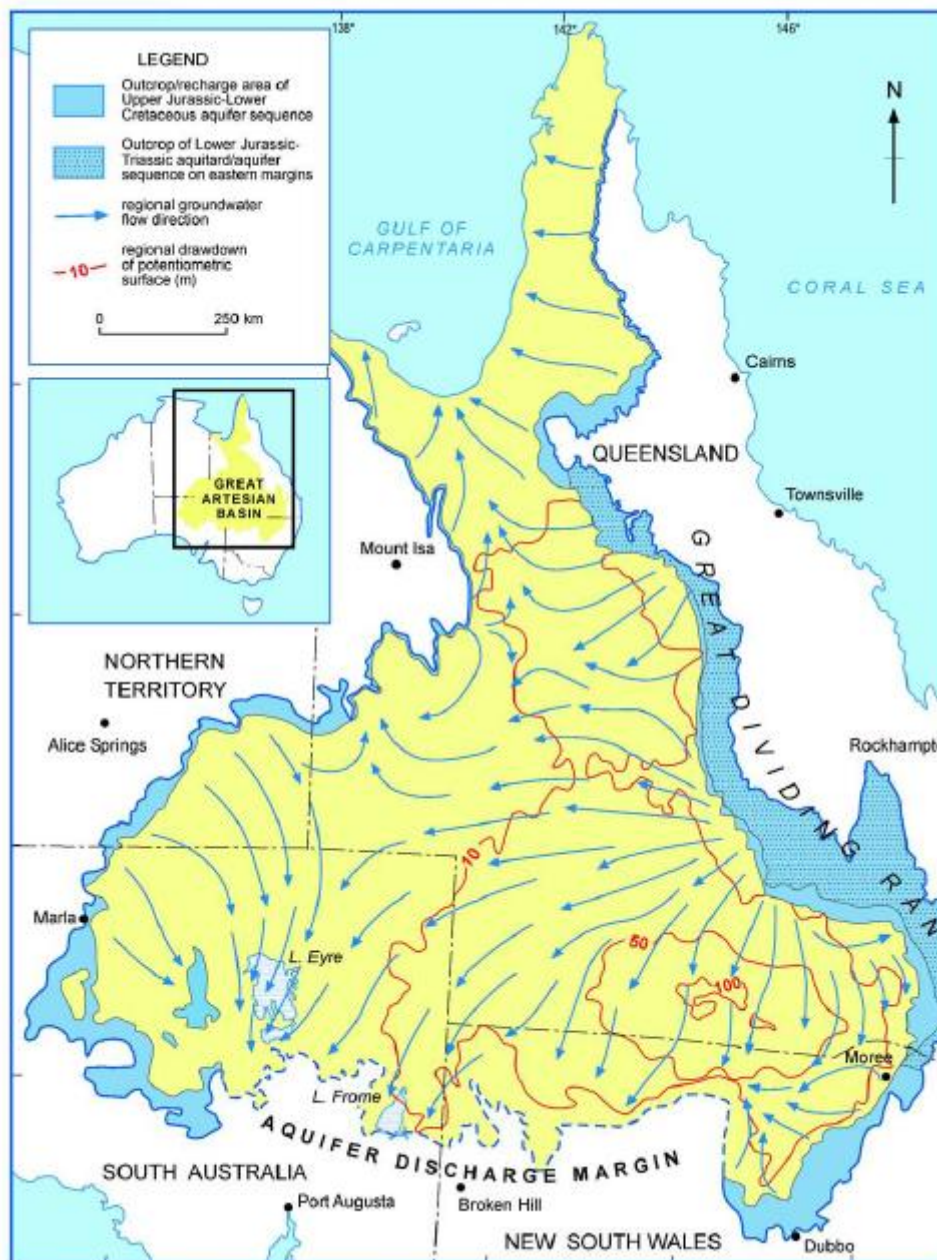
The intensive use of groundwater for pastoral uses created the first main groundwater drawdowns, affecting the industry itself, town water supply, and homesteads (ibid.). The high volumes of groundwater used in the pastoral sector have also created an abundance of surface water and the inefficient bore drain distribution systems, with wastes of up to 95 percent of groundwater produced, have resulted in land degradation, erosion, salinization, and spread of introduced weeds and shrubs (ibid.). The use of groundwater for mining and oil industries over the last quarter of the twentieth century has exacerbated pollution and drawdown problems (ibid.). In the Eastern Recharge source of the New South Wales portion of the Great Artesian Basin (covering about 207,000 km² or 12 percent of the total area of the Great Artesian Basin), groundwater entitlement exceed "the sustainable yield by approximately 300%. While annual extraction has in the past exceeded the sustainable yield, it has been reduced to around the sustainable yield by restricting annual allocations to 80% of entitlements" (State of New South Wales 2009: 10).

Figure 58. Artesian groundwater use in the Great Artesian Basin



Source: Habermehl 2006.

Figure 59. The Great Artesian Basin of Australia



Source: Habermehl 2006.

2.4.2 Groundwater management plans in the Great Artesian Basin

According to Habermehl (2006), interstate cooperation by Federal and State Governments to manage the Great Artesian Basin has occurred since the early 1900s. These attempts have been piecemeal however and each of the states addressed the problem of groundwater over-abstraction separately (Quiggin and Tan 2004). Queensland enacted in 1910 *The Rights in Water and Water Conservation and Utilisation Act*, "the first Australian legislation to declare that the right to the use and flow of water in artesian bore and subterranean supply was vested in the Crown for all purposes whatsoever" (Quiggin and Tan 2004: 11). According to this new legislation, "[n]o new artesian bore could be constructed or existing artesian bore deepened except pursuant to a license. Bore Water Supply Areas and Boards were created. If the Minister

was of the opinion that water from any artesian bore was being improperly used or wasted, the Minister could order partial closure of the bore, or such other precautions deemed necessary to prevent improper use of the water. This particular provision applied only after 10 years from commencement of the Act. There is no record that these powers were ever used. However the licensing scheme put some control on the drilling and construction of new artesian bores, headworks and drains and was subsequently extended to cover sub-artesian bores in proclaimed areas." (ibid.).

In the early 1900s, state governments already saw groundwater over-abstraction as a problem, and in 1908 the New South Wales governments convened a conference to seek federal action to tackle the problem of excessive abstraction, but only the South Australian government sent a delegation (Quiggin and Tan 2004). The neighbouring state of New South Wales promoted the development of boreholes with its Artesian Wells Act in 1897, enabling groups of settlers to obtain assistance from the government to drill wells and serve collective properties. It was not until the Water and Drainage Act in 1902 that provisions were made to constitute bore trusts to administer the boreholes (GABCC 2010). In 1912 the Water Act of New South Wales required the licensing of boreholes and wells in order to acquire appropriate hydrogeological data. Legislation only applied however to boreholes in the western half of the state (ibid.).

Much later, state and federal programs aimed to redress groundwater depletion in the Basin. The Great Artesian Basin Bore Rehabilitation Programme (1989-1999) was funded by State and Federal governments as well as borehole owners and aimed to provide a basis for better management of the Basin and reduce groundwater waste (Habermehl 2006). The programme aimed to rehabilitate boreholes in bad conditions and install control valves on free flowing artesian wells (ibid.). The Great Artesian Basin Sustainability Initiative started in 1999 as a follow up of the programme, aiming to accelerate further the rehabilitation of boreholes and achieve partial recovery of artesian pressure in some strategic areas of the Basin (ibid.). A legislative reform at the national level in 1996 provided a framework for sustainable groundwater management, and requested all boreholes in the Great Artesian Basin to be licensed (ibid.).

In 1997 the Great Artesian Basin Consultative Council was created, with representatives from the federal, state, and local governments. It also included as members, livestock owners, petroleum and mining companies, traditional landholders, and community and conservation groups (ibid.). This is a voluntary project jointly funded by federal and state governments and pastoral bore owners. In 2000, the Consultative Council developed a Strategic Management Plan for the entire basin, addressing basin-wide management issues "aimed at achieving the sustainable use of artesian groundwater for optimum economic, environmental, and social development" (Habermehl 2006: 86). Its role also started with the rehabilitation of uncontrolled boreholes and replacing bore drains with polyethylene pipes, tanks, and troughs for livestock under the Great Artesian Basin Sustainability Initiative (GABSI) (Quiggin and Tan 2004). Set up as a whole-of-Basin investment programme and partnership, the federal government committed funds to projects delivered through state agencies aiming to implement the management plan of the Consultative Council. The GABSI provides subsidies for well rehabilitation (up to 80 percent, including investigation, project plan and design, materials and contract work) (GABCC 2010). The GABSI is at its fourth phase, with an extension from 2014 to 2017. In total, the GABSI has received close to 160 million dollars AUS up to its third phase (ending in 2015) (ibid.). By June 2013, 650 additional boreholes had been rehabilitated, and a total of more than 19,000 km

of bore drains had been eliminated, and more than 28,000 km of additional piping had been installed in total since 1999.⁹⁵

The first management plan for the Basin in the State of Queensland was drawn in 2006, providing the framework for the sustainable management of groundwater including groundwater supply security for current and future water uses, and protection of groundwater flows for springs and watercourses (State of Queensland 2012). In Queensland, the Water Management Plan divided the state in 25 management areas (State of Queensland 2012). The Plan is implemented through the Great Artesian Basin Resource Operations Plan (first written in 2007). This Operational plan specifies day-to-day management and monitoring arrangements developed following the Water Resource Plan for the Basin (*ibid.*). The Operations Plan aimed to make up to 23,4 Mm³ of unallocated groundwater available across the Basin in Queensland and an additional 10 Mm³ of unallocated water for projects of state or regional significance (e.g. town supply) (State of Queensland 2007). The Plan defined criteria for the protection of spring flows and baseflows to watercourses that have to be taken into consideration when dealing with water licenses (*ibid.*). Moreover, the Plan also set the conditions for the water licenses, specifying processes for dealing with unallocated water and granting new licenses for unallocated water (*ibid.*). Protection areas around springs were established, with a ban on licenses that would increase groundwater abstraction within 5 km of a spring (*ibid.*). Carryovers were also defined in Queensland for groundwater. Unused groundwater becomes carryover at the beginning of the new water year and can be accumulated to a maximum volume of twice the volumetric limit

In the Darling River Basin (DBR), "[c]urrent and proposed water extraction limits of the GAB water sharing plan are likely to reduce baseflow in these areas in the DRB. Interventions such as the GAB bore rehabilitation program will likely have little impact on the DRB systems in New South Wales because of time lags between bore rehabilitation actions and attainment of new equilibrium bore pressures by virtue of large distances from the artesian bores and the intake beds and corresponding impacts on connectivity with surface water systems" (Herczeg 2008: 1).

3 Surface and groundwater trading in Australia's South-East

3.1 Water markets features

As defined by the National Water Commission, water trading schemes refer to the buying and selling of rights to take water out of a system (rather than buying or selling water itself) and these rights can be expressed as water access entitlements, or water allocations. According to Australian legislation, there are two types of trade possible: 1) water entitlement trading;⁹⁶ and 2) water allocation trading. All water trading is done by paper transactions and trades are recorded on a government register (Valli 2015, pers. com.). Water allocations are credited to

⁹⁵ Great Artesian Basin Coordinating Committee, Great Artesian Basin Sustainability Initiative (GABSI), <http://www.gabcc.gov.au/basin-management/sustainability-initiative-gabsi> (Accessed 24th February 2016).

⁹⁶ Water access entitlements have different nomenclatures in Australia (e.g. water allocation in Queensland; water share in Victoria; water license in Western Australia) (National Water Commission 2011a).

users' water accounts (surface and groundwater users alike) and the volume granted per user depends on the ownership of permanent water entitlements and shares.⁹⁷

Water entitlement trading refers to the "transfer of ownership of the right to a perpetual share of the consumptive pool" and can generally be driven by "changes in long-term demand and in the nature and location of water-using industries. Entitlements can be purchased as an investment or risk management tool" (National Water Commission 2011a: 10).⁹⁸ Water allocation trading is a "transfer of ownership of the right of a specified volume of water allocated to a water access entitlement" and is generally used to assist users "to respond to seasonal conditions and other short-term events by reallocating water between users within a particular year" (ibid.). For groundwater specifically, the National Water Commission acknowledges that most groundwater trades arise predominantly from changes in the location of groundwater extraction (GHD et al. 2011). For allocations, the original groundwater title holder can sell their allocation in subsequent years or retain it for their own use (National Water Commission 2011a).

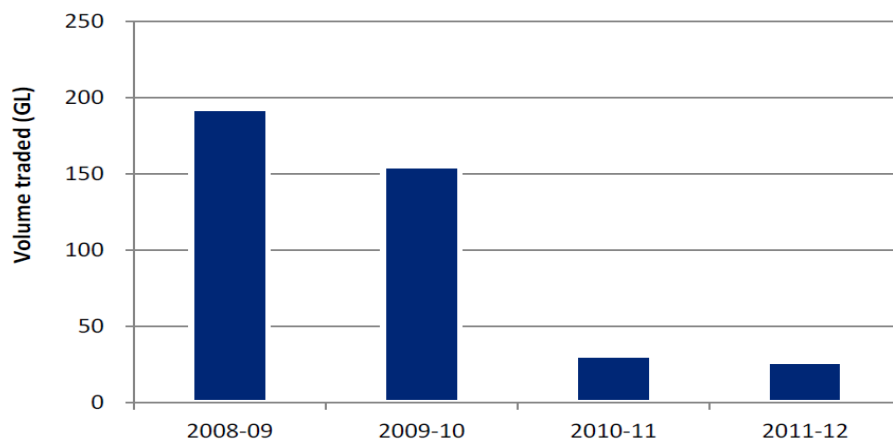
Water trading was made possible in Australia by separating water (and groundwater) rights to land so that, even though total abstractions were capped, individual users could increase the volume they abstract if they purchased water entitlements from other users (Williams 2011). Water trading therefore came into being as part of the National Water Initiative in 2003, which was part of "an accord to return water to over-allocated rivers. When water licenses of various durations and forms were converted to indefinite water entitlements which became a tradeable water right this represented a large transfer of public assets to the private sector. The accord and social contract was in light of this transfer to be a return of water to the public to provide the water for over-allocated river systems in the Basin. The nature of this social contract is the foundation for the water reform process in which we are currently involved" (Williams 2011: 25).

Even though Australia is an often-quoted case of functioning water markets in the literature (Skurray et al. 2013), the country has relatively few well-functioning groundwater markets (Deloitte 2013). Available data studied by the National Water Commission shows that of all water entitlement trading in Australia, groundwater only represents 12 percent, whilst groundwater allocation trading (occurring only in New South Wales and Victoria in the Southern Murray Darling Basin) accounts for around 1 percent of total allocation trading (National Water Commission 2011b) and with heavy fluctuations every year (Figure 60). Of all entitlements issued in Australia, around 49 percent by number are groundwater entitlements (21 percent by volume) and of all groundwater entitlements issued in Australia, 68 percent of issued entitlements (by number) are in New South Wales (representing 30 percent by volume) (National Water Commission 2011a). Additionally, the vast majority of trade is still through the temporary trade market and the largest buyer of permanent allocations remains the Australian government (Leblanc et al. 2012).

⁹⁷If an aquifer has for example 1,000,000 shares in existence capped by a Water Sharing plan, and a user owns 1,000 shares, then the user will be allocated 1/1000 of water from the aquifer each year (Valli 2015, pers. com.).

⁹⁸Surface water entitlements are further differentiated between 'high-reliability entitlements' such as vineyards and orchards and expected to reach 100 percent of their allocations between 89 and 98 years out of 100; and 'low-reliability entitlements', available to irrigators when river levels are exceptionally high (e.g. flooding) (National Water Commission 2011a; Maddocks 2013).

Figure 60. Groundwater allocation trade volumes in New South Wales



Note: values are in GL (Giga liters). One Giga Liter is equivalent to 1 million cubic meters.
Source: Deloitte 2013.

As Kuehne et al. (2010: x) have studied in the Murray River in South Australia, farmer attitudes towards selling and buying water entitlements (surface water) differ, and are influenced by a number of non-profit maximizing values. These are: "1) whether the farmer wishes to continue farming in the future, 2) years left to retirement, 3) whether succession has been arranged, 3) whether they are full-time, part-time or hobby farmers, 4) future employability, 5) whether the sale includes land or not, 6) the conditions of the exit grant package, and 7) the price on offer." These drivers are therefore context and individual specific. Even though these authors found that external influences "such as the on-going need for structural change in response to increased water scarcity, and changing market condition tend to steer the farmer towards considering the sale of water" it would seem that farmers are conditioned by the former internal forces acting on them and ultimately determining whether they will sell (ibid.).

Additional factors for selling include part-time or full-time farming occupation (part-time farmers are more likely to sell, as they would be less reliant on the use of water for irrigation to generate income or also as they are "on the way out of irrigation", having "sold water in the past and taken off-farm work" (Kuehne et al. 2010: 15)). The fact that prices are negotiated through a tender process between the government and the willing seller, represents a concern for farmers. In the study, selling farmers would prefer "a stated price provided for water" with "more transparency in the price setting process" and a revision, at the time of the study, of the conditions of the government buy-back scheme (which had, until April 2009, an upper limit of 15 hectares for eligibility for participation) (Kuehne et al. 2010: 20).

Groundwater markets in Australia can cause varied, unpredictable, and sometimes non-compensable externalities (Skurray et al. 2013; Wheeler et al. 2014). In 2004, the National Water Initiative established an integrated framework of entitlement and allocation specifications, water planning and water trading and in 2011, a specific framework for managing and developing groundwater trading was put forward in order to encourage the efficient distribution of scarce water between competing users (GHD et al. 2011). Different jurisdictions are applying specific approaches to developing and implementing trading rules. These rules can include "constraints on the direction of groundwater trades, minimal distances to other groundwater users and dependent ecosystems, and zonal density or total extraction limits."

Trading rules can also determine "whether an application can be approved or not, or whether it may proceed subject to individual technical assessment" (GHD et al. 2011: xii). In New South Wales for instance, groundwater licenses based on entitlements have now been converted from what was previously a bundled form (whereby the authorization for groundwater access and abstraction is dependent of that for works and use) to a fully unbundled form. This format provides according to GHD et al. (ibid.) "a high degree of mobility for groundwater access and is a contributing factor to the high levels of market activity in these areas." Information is however lacking on guidelines and impact thresholds to support individual assessments.

A wide range of factors, which include market size, groundwater access, scarcity, and market confidence, affects groundwater market activities in Australia. Market size can be affected by the physical size of groundwater management units, and also subject to the criteria for and placement of aquifer unit boundaries. Confidence in trading can also be influenced by how tradable groundwater rights can be (e.g. volume limited or not) and also by the level of information available to the public on groundwater management and market processes (GHD et al. 2011). According to the National Water Commission Water Market Trends and Drivers (2011a), groundwater trading is limited in most regions in Australia due to:

- The limited hydrogeological connections between aquifers and the limited physical infrastructure linking groundwater areas which restricts trade within individual aquifers;
- Limitations linked to groundwater rights as they are yet to be fully unbundled from land;
- Provisions relating to groundwater licensing and trading are relatively recent and therefore markets have not had the time to develop despite the fact that all states have legislation enabling groundwater trading;
- Some boundaries of aquifer systems are still being defined;
- In many cases, trade is prevented by caps on trade between zones and catchments.

3.2 Water and groundwater trading in the Lower MDB

Water trading was agreed by the National Water Initiative (NWI) to be expanded across state and regional boundaries in the Lower Murray-Darling Basin. The parties to the NWI however raised concerns in 2004 "about the potential economic and social impacts of further expansion of water entitlement trading where that trade results in the rapid movement of water out of local irrigation areas and communities. To address those concerns, the NWI included the provision for a 4% annual 'interim threshold limit' on the net amount of water entitlements that can be traded out of an irrigation area" (National Water Commission 2012: 5). The 4 percent interim threshold limit is therefore a security cap that limits water exports in order to prevent too much export of water outside a defined irrigated area or irrigation license, calculated annually based on the bulk water license amount in an area and applied to net trades (Hyder Consulting 2008). This prerogative began to be phased out in 2009 by the Australian and Victorian governments from July 2011, with the view to remove it entirely by 2014.⁹⁹

The impacts of water trading (mainly surface water trading) in the southern Murray-Darling Basin have been studied by the National Water Commission (2012). In their report they focused on a five-year period from 2006-2007 to 2010-2011, which included four years of drought, a

⁹⁹ After it was established, some irrigation districts served by the Central Irrigation Trust reached the 4 percent limit in 2008-2009 with the potential to limit trade. The 4 percent limit was therefore revised and increased to 12 percent over two years (Frontier Economics 2009).

'buyback' program from the Australian government to buy water entitlements for environmental flows, and a basin-wide water market and charge rules (ibid.).¹⁰⁰ The study's findings remained optimistic, stating that irrigators accepted water trading and were increasingly reliant on it, with 30 percent of announced allocations and 10 percent of entitlements issued, traded [surface water]. As the report suggests, "[l]earning from the recent drought, many successful irrigators better understand the value of their water assets and have highly sophisticated and proactive water trading strategies to optimize their water use, production and financial performance in response to a range of factors. As water availability increased in 2010-11, many irrigators with flexible production systems who previously sold allocations during the drought bought water to increase production" (National Water Commission 2012: xi).

The National Water Commission (2012) also estimated that inter-regional and intra-regional water trading reduced the economic impact of drought on the regional gross domestic product by 4.3 billion USD (from 11.3 billion to 7 billion USD) (Figure 61). Most of the benefits generated by the trade accrued in dry years, when the need to reallocate water to high production values is the greatest (to horticulturalists in the Victorian Murray basin, facilitating the expansion in horticultural industries up to 2008).¹⁰¹ Of all surveyed irrigators by the National Water Commission, 44 percent had sold their rights to the Australian Government (who had bought over 672 Mm3 of various entitlements, mostly in 2009 and 2010) (including groundwater volumes) (ibid.).

The overview provided by the National Water Commission of water trading activities in the South of the MDB indicates that allocation trading (temporary water trading) represents the highest volume of water traded (Figure 62). Additionally, of the announced allocation volumes, allocations effectively traded remain lagging behind (Figure 62). Data indicates that total entitlement traded increased from 2006 to 2008 from 139 Mm3 to 552 Mm3 (with 221 Mm3 sold to the Australian government) (out of a total volume traded for entitlements of 1.3 Bm3 in 2012-2013). As part of the findings of the report, water allocation and water entitlement trading were noted to increasingly be elements of "an overall trading strategy adopted by individual irrigators which need to be considered in combination. Individual water trading decisions tend to form part of an irrigator's broader business strategy" (National Water Commission 2012: 22).

As the National Water Commission (2012: 44) put it, "the most significant development in interregional entitlement trading in the current assessment period was sales from all regions to the Commonwealth under the Restoring the Balance in the Murray-Darling Basin buyback program" (which bought 44 percent of all entitlements in 2009-2010) (National Water Commission 2011a; National Water Commission 2012). As of September, 30 2015, purchases secured under the Restoring the Balance in the Murray-Darling Basin Program amounted to 1.16

¹⁰⁰ In 2007-2008 the Australian government began buying entitlements from willing sellers in order to restore environmental flows in the Murray-Darling as part of a 3.1 billion USD 'Water for the Future Initiative' programme (National Water Commission 2012). This was set up by the Prime Minister at the time, providing "a way to reimburse irrigators for water that they were going to lose without compensation if the National Water Initiative was implemented in its original form" (as the environment would get a permanent share of surface water rights) (Connell 2011: 336).

¹⁰¹ The halt in entitlements bought by horticultural developers came to a halt in 2008 due to the collapse of the irrigated wine grape industry due to less favourable market and financial conditions (including also the almond industry) (National Water Commission 2012).

Bm3¹⁰², most of it surface-water but the program is also now buying groundwater (e.g. currently the Groundwater Purchase Tender in Queensland Upper Condamine Alluvium¹⁰³).

Additionally, from an irrigator's perspective, many saw the Commonwealth buyback program "as an opportunity to reduce debt" (National Water Commission 2012: 32). For groundwater trading specifically however, traded levels were not important drivers of change in groundwater levels (National Water Commission 2012). Interregional trading however remains lower than internal trading in water allocations (83 percent vs. 17 percent in 2010-2011 for instance, with a much closer share in 2008-2009 – 58 percent to 42 percent) (National Water Commission 2011a). South Australia however shows a reverse trend, becoming a net importer of water via traded allocations (from 1 percent in 2007-2008 to 65 percent in 2010-2011) (including surface and groundwater).

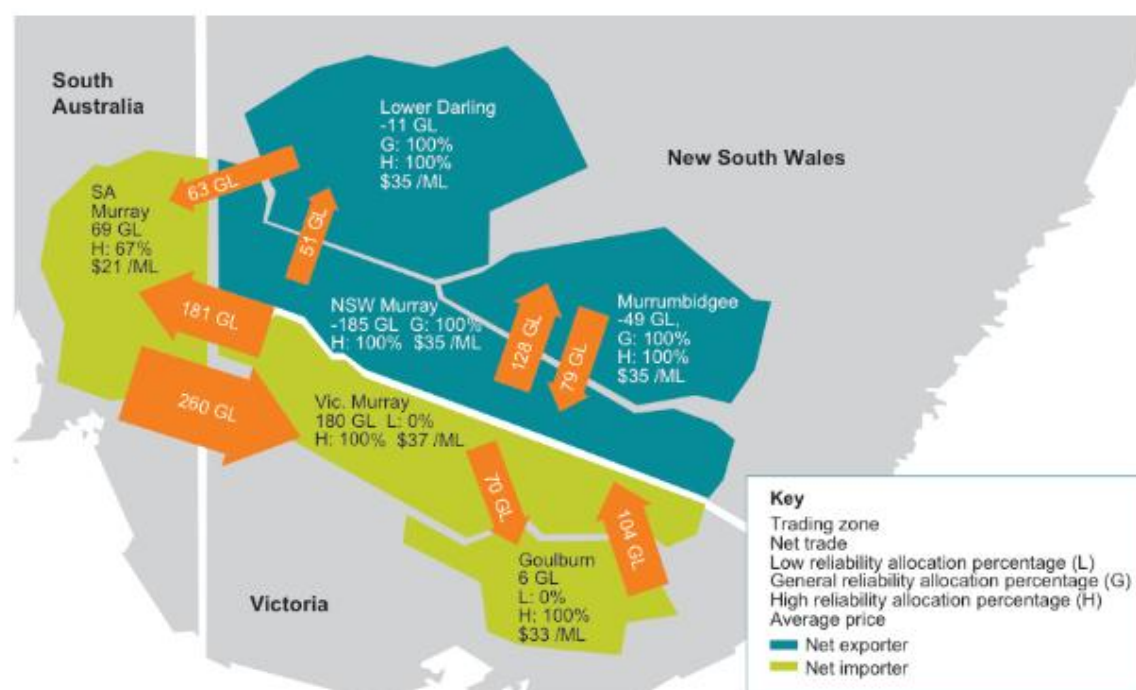
According to Ross (2012: 719), groundwater trading volumes in the MDB "are small compared to the total increase in volumetric groundwater extraction over the past 15 years, and therefore have not been the major driver of changes in the status of groundwater resources". Groundwater trading in the MDB is dominated by "temporary transfers of unused allocation within a season [sleeper rights] and activity reflects the general drought cycle and water resources availability" with permanent trades accounting less than 1 percent of the licensed volume (Turrall and Fullagar 2007: 325). Sleeper rights are defined as license-holders paying for their license but using some or none of their abstraction rights. Typically they will keep part of their entitlement as insurance during a dry year (either for fodder production or livestock watering) (Turrall and Fullagar 2007).

Groundwater trading volumes are generally small compared to surface water but have nevertheless increased equally (from 2-5 percent to 10-20 percent) in 10 years. However, according to the National Water Commission (2010: 96), "[s]urface water trading may have an indirect impact on groundwater extraction through opportunistic sales of surface entitlements or allocations by irrigators who have access to unused groundwater allocations" but this is difficult to assess as they could also "have occurred anyway as a result of drought."

¹⁰² www.environment.gov.au/water/rural-water/restoring-balance-murray-darling-basin/progress-water-recovery

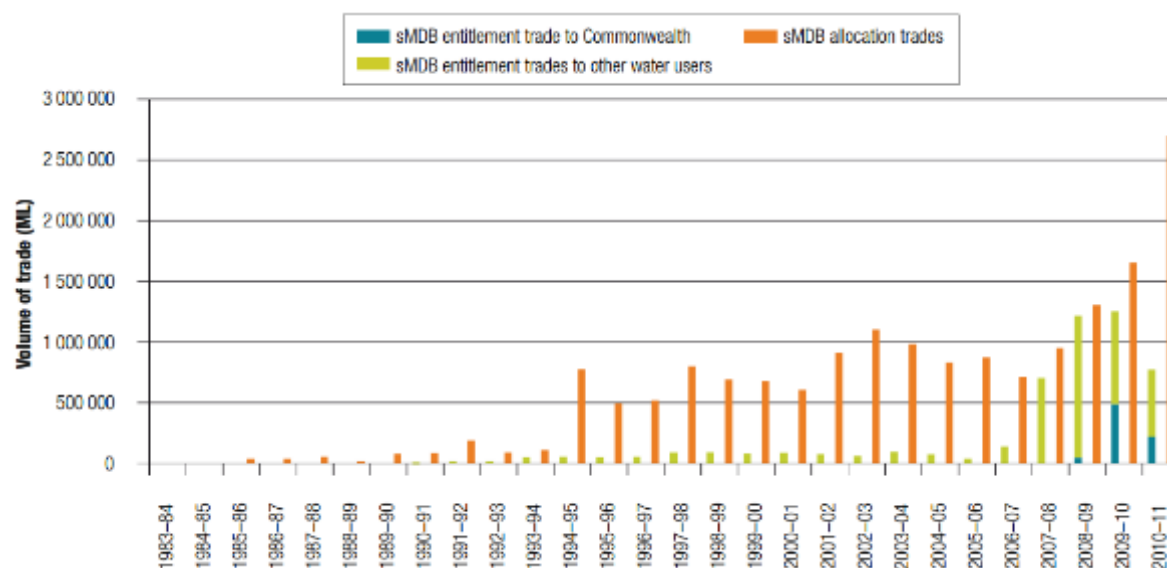
¹⁰³ <https://www.environment.gov.au/water/rural-water/restoring-balance-murray-darling-basin>

Figure 61. Water allocation trading in the Lower MDB (2010-2011)



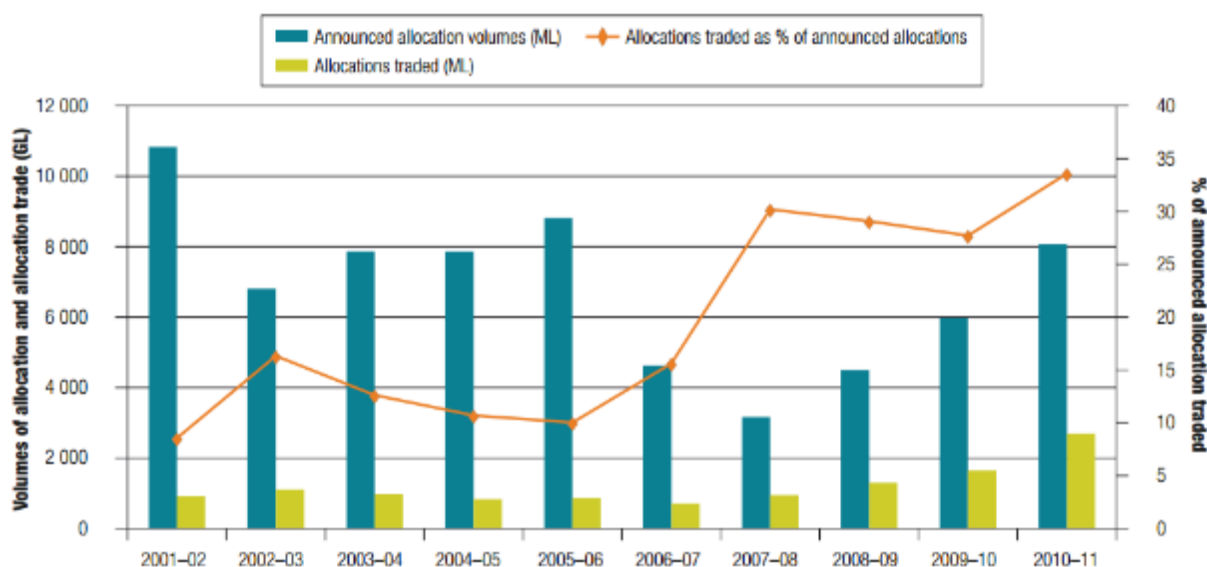
Source: National Water Commission 2011a.

Figure 62. Volumes of water allocations and entitlement trades in the Lower MDB (1983-2011)



Source: National Water Commission 2012.

Figure 63. Announced water allocations and trades (2001-2011)



Source: National Water Commission 2012.

3.3 Groundwater trading in the Lower Murrumbidgee Valley, New South Wales

Of all states in Australia, New South Wales has the highest volume of groundwater traded. The traded volume varies according to surface water availability. During the dry years of 2008-2009 and 2010-11 groundwater trade was higher than during the wet years of 2010-11 and 2011-12 (Deloitte 2013). Additionally, of all sub-basins in the Southern MDB, the Lower Murrumbidgee is the one with the highest number of entitlements issued (28.1 percent of total entitlements on issue in the Southern MDB in 2010) (National Water Commission 2011a). In the Lower Murrumbidgee there are 311 groundwater licenses for the deep aquifer source (representing 267 Mm³, issued for perpetuity), one license for domestic use and livestock (324,000 m³, for perpetuity), three licenses for local water utilities (2 Mm³, for perpetuity) and an additional 128 for supplementary access¹⁰⁴ (41 Mm³, issued for 10 years) (Kumar 2013).

The Lower Murrumbidgee has a high concentration of horticulture (fruits, grapes, vegetables) and rice production. The basin's 'Water Sharing Plan' allocates a portion of the estimated recharge to be reserved for the environment and the rest to be available for abstraction (NSW 2013). Before the plan, a total volume of 514.6 Mm³ of groundwater entitlements from the

¹⁰⁴ As defined by the Office of Water of New South Wales, "Supplementary water, formerly known as off-allocation water, is effectively surplus flow that cannot be conserved. When storm events result in flows that cannot be controlled (regulated) in storage structures such as dams or weirs for future use, and the water is not needed to meet current demands or commitments, then it is considered surplus to requirements. [...]As soon as these conditions are identified, a period of Supplementary Access is announced and details of the subject river reaches and time periods are published. License holders generally can choose to pump water during these periods as usual. However, those people with Supplementary Water Access Licenses can only pump water against these licenses during these announced periods" (Department of Primary Industries, Office of Water, <http://www.water.nsw.gov.au/water-management/water-availability>) (Accessed 28th June 2015). Under the Water Management Plan for the Lower Murrumbidgee, "access to supplementary water commenced at 90% in 2006-07 and will progressively reduce by 10% of share component per year leading to 0% on 1 July 2015, after which the license will be cancelled" (Kumar 2010b: 2).

deeper groundwater source had been allocated but reduced to 270 Mm3 in 2006 with the Water Sharing Plan (the long term annual abstraction limit set to be reached in 2016).¹⁰⁵ Groundwater users are requested to report suspected unauthorized pumping or water theft to the Departments Compliance Unit (via email, phone call, and all reports remain confidential). The water sharing plan is also shared with users and communities through consultative processes. The maximum abstracted volume 381 Mm3, was reached in 2002-2003. The estimated average annual recharge of the deeper aquifer is 335 Mm3 (ibid.). Abstraction limits at the aquifer level for the deep groundwater source vary each year, with basic landholder rights not metered and abstraction limits for the other access licenses are set as the sum of Local Water Utility and aquifer access licenses plus additional allocations made to Supplementary Water Access Licenses (NWC 2013).

Abstraction from the shallow aquifer is limited to 10 Mm3 per year. At the start of every year, an 'Available Water Determination' is established, setting groundwater allocation levels for the different categories of licenses (ibid.). The 2006-2012 Plan (extended until 2017), requires that in cases where "the average of 3 years' extraction exceeds the extraction limit by 5% or greater, then an allocation determination of less than 100% is to be made for the following water year to return the water usage back to the extraction limit" (NSW 2013: 3). The reduction in annual abstraction limits for the deep groundwater source in the Lower Murrumbidgee's Water Management Plan included a reduction of supplementary water licenses and aquifer access licenses (carryovers) and water available for use (total capped to use limit) from 206 Mm3 in 2006-2007 to 112 Mm3 in 2009-2010 and from 451 Mm3 to 357 Mm3 respectively (Kumar 2010b).

The water plan also allows for the carryover of unused allocations, added to the yearly allocation for aquifer licenses up to a maximum of twice the licensed amount (NSW 2013). The Lower Murrumbidgee groundwater source has a 200 percent usage limit for each entitlement share per user, allowing for carryovers to be considered within periods of three successive years.¹⁰⁶

The existence of carryovers and different rules for different jurisdictions has had an influence on allocation trading towards Victoria, particularly in 2010-2011. These carryover provisions are available since 2007-2008 for all three southern MDB states. With water availability levels improving after the drought period, in 2010 carryover arrangements were adjusted differently across the states (Victoria offered to continue its carryover policy, as opposed to New South Wales for instance, which announced the limitation of carryover between 2011 and 2013 with no carryover possible for high-security entitlements from 2011-2012 to 2012-2013).¹⁰⁷ Irrigators appeared to have taken advantage of this situation in order to trade with carry-over allocations

¹⁰⁵ Groundwater in the Lower Murrumbidgee is found in a shallow aquifer at 40 metres below the surface and in a deeper aquifer (sand and clay layers) with a thickness varying between 100 and 300 metres. There are around 340 production wells in the Deep aquifer and 30 in the shallow aquifer. All wells are metered (NSW 2013).

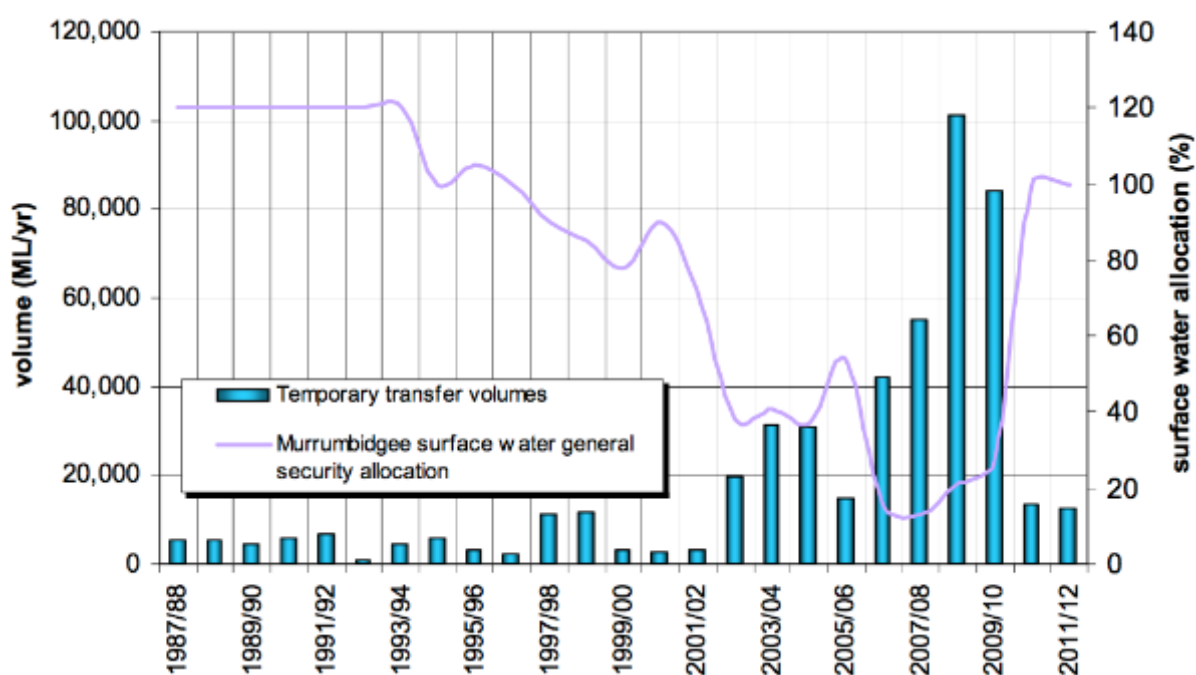
¹⁰⁶ As an example, if a user has 50 entitlement shares, each year its allocation will be 50,000 m3 (100 percent). The usage limit is however 100,000 m3 (200 percent of the original entitlement). So if this user uses only 25,000 m3, there will be another 25,000 m3 remaining at the year-end to be carried over. This means that in year 2, the user will be able to use the entire allocation (50,000 m3) plus the remaining 25,000 m3 left from year 1 (a total of 75,000 m3, which is still less than the 200 percent usage limit) (Valli 2015, pers. com.).

¹⁰⁷ Despite these limitations imposed in New South Wales, irrigators in Victoria traded allocations via South Australia and back into Victoria as a work-around to the trade suspension (National Water Commission 2011a).

with Victoria and buy carry-over volumes from other users from 2010-2011 into 2012 (National Water Commission 2011a). Carryovers during dry spells or droughts are still limited by the 3-year average usage. If the 3-year average usage is exceeded, subsequent year allocations will be reduced in order to balance out and match the cap (Valli 2015, pers. com.).

As elsewhere in Australia, trading in the Lower Murrumbidgee is permitted via two types of dealings: 1) permanent dealings (resulting in a permanent change of a portion of an access license or a change in the location where abstraction occurs within the same water source) and; 2) temporary dealings (trades resulting in a change in volume of water from an access license for a specific water year). Licenses for groundwater abstraction are issued with separate titles to land and are fully tradable. The volume of groundwater traded shows an increase in 2008-2009 (in temporary and also permanent dealings). This is due to diminishing surface water availability (and trading in surface water entitlements) due to the drought, an increase in drilling of new wells with special abstraction conditions,¹⁰⁸ and incentives in the form of rice industry subsidies for groundwater users to grow rice (Kumar 2010b; Kumar 2013; NSW 2013) (Figure 64). Groundwater hydrographs for this period reflect aquifer level drops of up to 20 meters between 1996 and 2010 (including the effects of the drought) and increasing levels after the end of the 'Millennium drought' in 2010 (Kumar 2010b) (Figure 65).

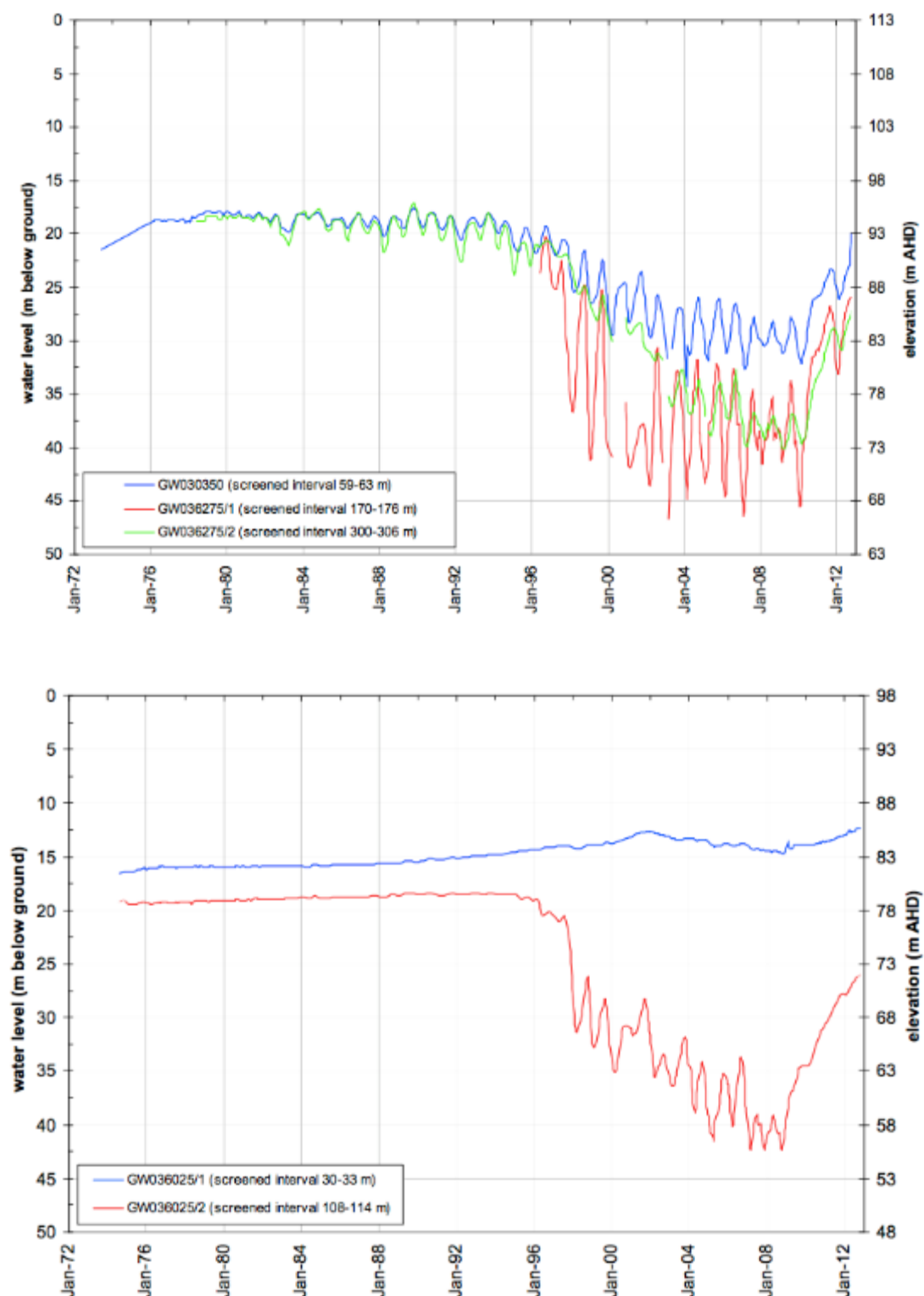
Figure 64. Annual temporary volumes traded within the deep groundwater source in the Lower Murrumbidgee



Source: Kumar 2013.

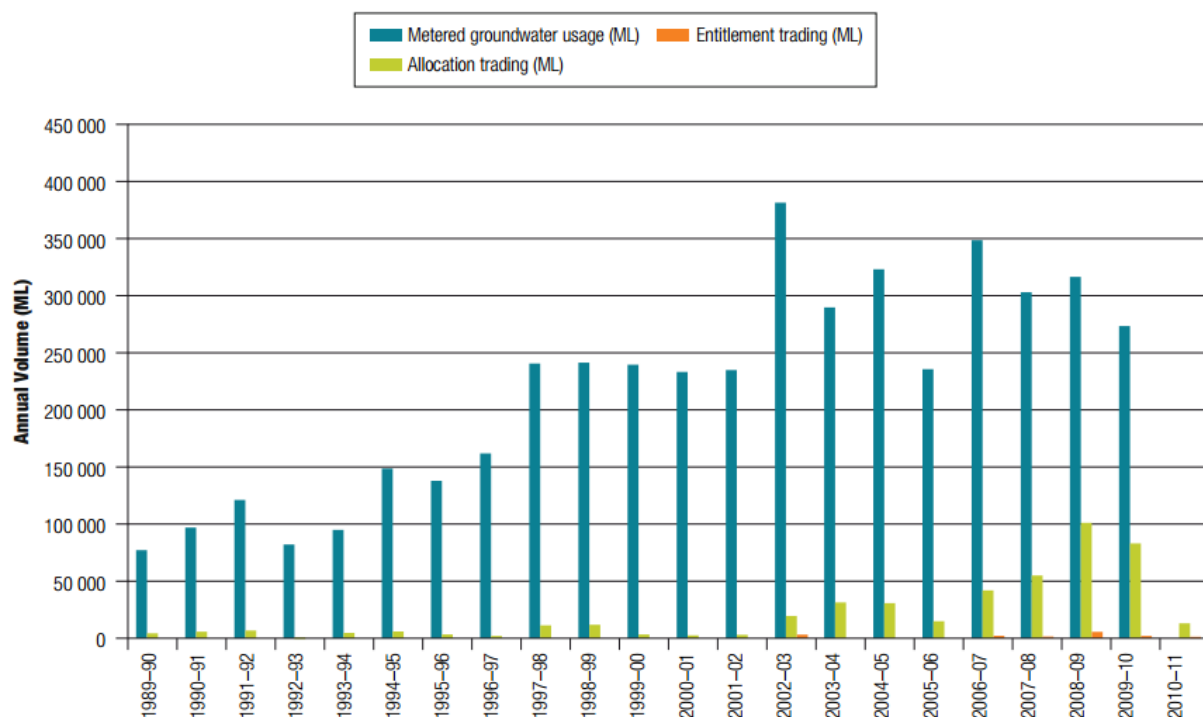
¹⁰⁸ The drilling of these wells is associated with zero share aquifer access licenses. These are licenses where either the entitlement or allocation are purchased from existing access license holders, these boreholes are imposed with an annual bore extraction limit as an additional approval condition and are not allowed to have carry overs from one year to the next (Kumar 2010b; NSW 2013).

Figure 65. Sample hydrographs for two groundwater monitoring sites in the Lower Murrumbidgee (Tonganmeine and Hay sites)



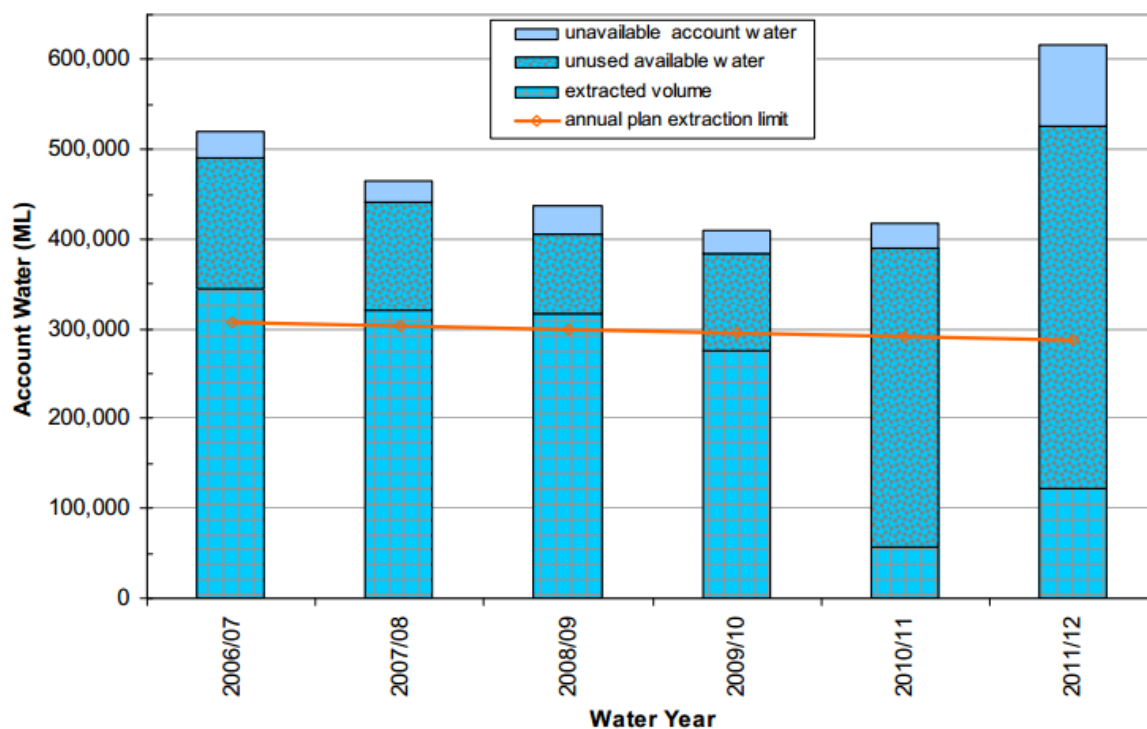
Source: NSW 2013.

Figure 66. Groundwater trading in the Lower Murrumbidgee Deep Aquifer (1989-2011)



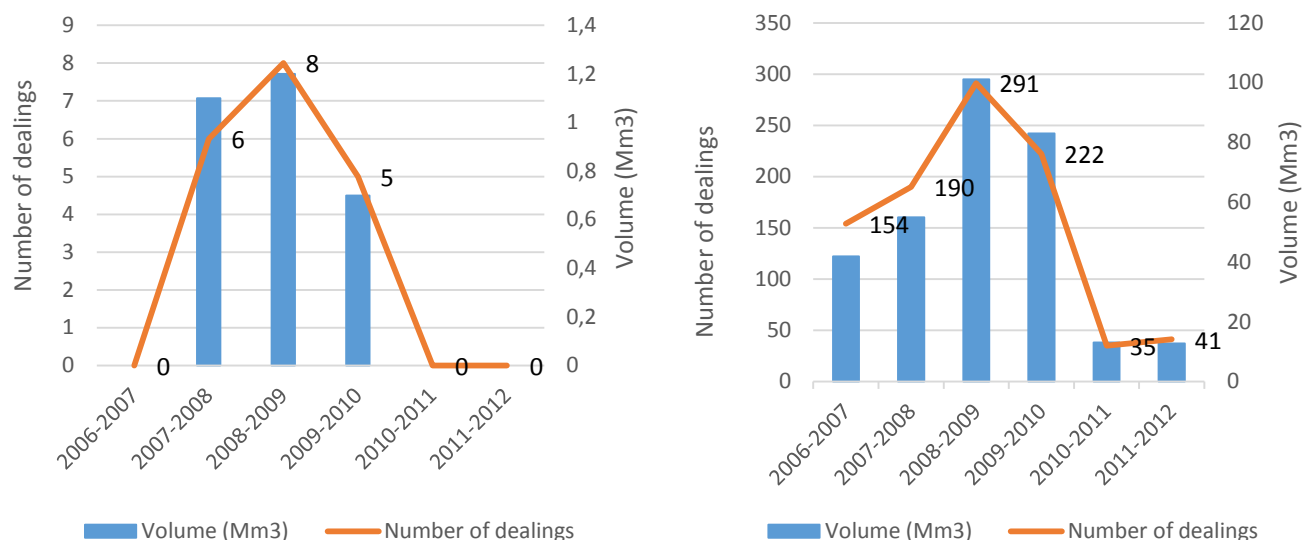
Source: National Water Commission 2012.

Figure 67. Account information for the deep groundwater aquifer in the Lower Murrumbidgee



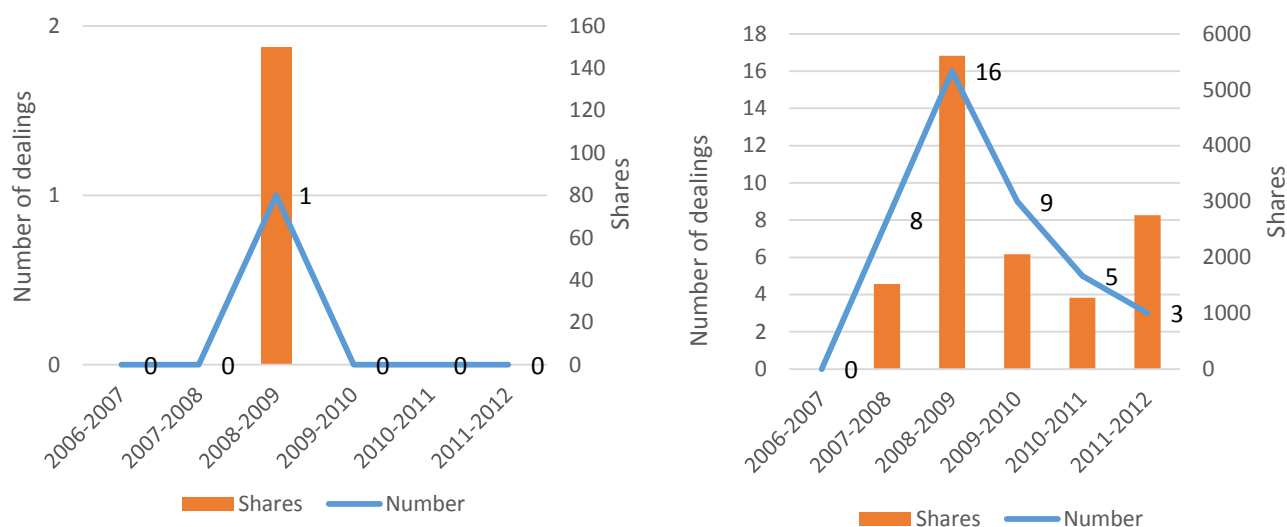
Source: NWS 2013.

Figure 68. Temporary dealings with shallow and deep groundwater



Source: Based on data from NSW 2013.

Figure 69. Permanent dealings with shallow and deep groundwater



Source: Based on data from NSW 2013.

3.4 Groundwater trading and control in South West Australia

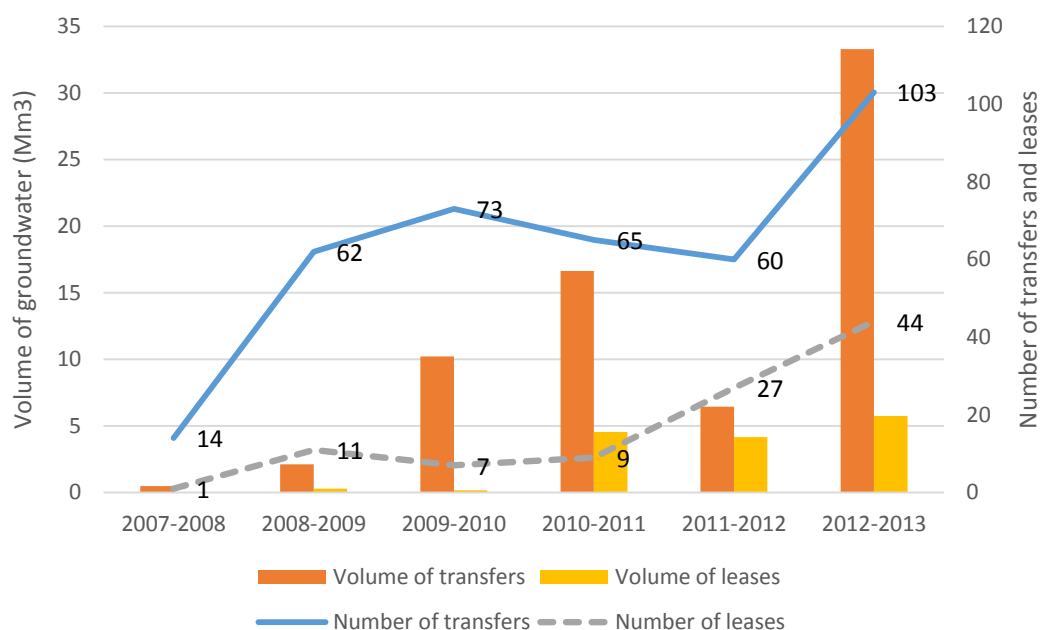
Market-based mechanisms for water allocation in South West Australia "are not used in the initial allocation of groundwater entitlements. Groundwater is normally allocated for free under a 'first-in, first-served' approach, in which the applicant who is first in time has priority over later applicants" (Bennett and Gardner 2014: xiv). The reason according to these authors for the lack of market mechanisms to allocate water is that "current legislation does not provide a clear

basis to do so" (ibid.). Water entitlement trading has however been possible in South West Australia since 2001 when amendments to the Rights in Water and Irrigation Act from 1914 were made. Users purchasing water entitlements need to be the owners or occupiers of the land from where the water is taken or have an agreement with that person. Under these amendments, there are three possibilities under which trade water can be done:

- 1) A license can be permanently transferred to another person. Water is however to be taken from the same location (in the case for instance when there has been a change in land ownership).
- 2) A licensee can enter into an agreement with a third party regarding the transfer or water for a limited amount of time (i.e. a 'water lease'). This lease needs to be formalized by the Minister and the license will state for how long the lease will take place.
- 3) A water entitlement can be transferred to another user holding a license in the same area. This can be done by reducing the water to be abstracted in one license and transferring it to another license.

Groundwater trade has happened on a number of occasions since 2001. Between 2007 and 2013 there have been a total of 377 transfers representing 69 Mm³. There have also been a number of groundwater leases (99), which represented 14 Mm³ of water. Both numbers of transfers and leases have increased on a yearly basis (from 14 transfers in 2007-2008 to 103 in 2012-2013). Skurray et al. (2013 in Bennett and Gardner 2014) have stated however that the following barriers exist in the Gnangara system preventing groundwater trading: 1) the weakness of property rights to groundwater use (including time-limited nature and the Minister's power to amend a license); 2) the license eligibility under the Law, which requires that the purchaser must own or occupy the land on which the water is to be used; 3) transaction costs associated with the detail assessment by the Department of each transaction; 4) lack of published information on market prices and sellers.

Figure 70. Number and volume of water of transfers and leases of groundwater



Source: Based on data from Bennett and Gardner 2014.

References

China, Pakistan, Nepal, Bangladesh, Japan

- Aarnoudse, E. 2010 *Farmers' responses to groundwater depletion. Changing institutions and farming strategies in Minqin County, Gansu Province, China*, MSc Thesis, Wageningen University.
- Aarnoudse, E., Bluemling, B., Wester, P., and W. Qu 2012 The role of collective groundwater institutions in the implementation of direct groundwater regulation measures in Minqin County, China, *Hydrogeology Journal*, 20, 1213-1221.
- Adhikary, S.K., Das, S.K., Saha, G.C., and T. Chaki 2013 "Groundwater drought assessment for Barind Irrigation Project in Northwestern Bangladesh", 20th International Congress on Modelling and Simulation, Adelaide, Australia, 1-6 December 2013.
- Aziz, M.A., Majumber, M.A.K., Kabir, M.S., Hossain, M.I., Rahman, N.M.F., Rahman, F., and S. Hosen 2015 Groundwater depletion with expansion of irrigation in Barind Tract: a case study of Rajshahi District of Bangladesh, *International Journal of Geology, Agriculture and Environmental Sciences*, 3(1), 32-38.
- Bluemling, B., Pahl-Wostl, C., Yang, H., and H.J. Mosler 2010 Implications of stakeholder constellations for the implementation of irrigation rules at jointly used wells – cases from the North China Plain, China, *Society & Natural Resources*, 23(6), 557-572.
- Cao, G., Zheng, C., Scanlon, B.R., Liu, J., and W. Li 2013 Use of flow modeling to assess sustainability of groundwater resource in North China Plain, *Water Resources Research*, 49, 159-175.
- China 2006 *Regulation on the Administration of the License for Water Drawing and the Levy of Water Resource Fees*.
- China 2002 Water Law of the People's Republic of China.
- COWI 2013a *Groundwater in China. Part 1 – Occurrence and Use*, Nature Agency, Ministry of the Environment.
- COWI 2013b *Groundwater in China. Part 2 – Market analysis*, Nature Agency, Ministry of the Environment.
- Crow-Miller, B. 2015 Discourses of deflection: the politics of framing China's South-North water transfer project, *Water Alternatives*, 8(2), 173-192.
- Endo, T. 2014 "The Kabu-ido system: implications for current groundwater management policy", in Taniguchi, M. and T. Hiyama (eds.) *Groundwater as a key for adaptation to changing climate and society*, Verlag: Springer, 129-141.
- Endo, T. 2015a Groundwater management: a search for better policy combinations, *Water Policy*, 17, 332-348.
- Endo, T. 2015b Personal communication.
- Foster, S., and H. Garduño 2004 *China: towards sustainable groundwater resource use for irrigated agriculture on the North China Plain*. Sustainable Groundwater Management Lessons from Practice Case Profile Collection; No. 8. Washington, DC: World Bank.
- GBK and VSO 2012 *Study report on water scarcity in Northern Bangladesh*, Gram Bikash Kendra and VSO International Volunteers, <https://static.weadapt.org/placemarks/files/895/516392dfaec9avsob-sniijder-2012-report-on-water-scarcity-in-northern-bangladesh.pdf> (Accessed 7th June 2015).
- Guisheng, F., van Steenberg, F., and Z. Wenzhong 2013 *Climate Change Adaptation through Groundwater Management of Shanxi Province, People's Republic of China*. Report to ADB.
- Iftikhar, S., Kazmi, H.S., and M. Ertsen 2011 Changes in tubewells count in two decades in area under conjunctive irrigation in Pakistan, Paper IV-17, repository.tudelft.nl/assets/uuid...4ceb.../Paper_IV-17_Ertsen_et_al.pdf, (Accessed 24th November 2015).

- Jacoby, H., Murgai, R., and S.U. Rehman 2001 *Monopoly power and distribution in fragmented markets: the case of groundwater*, Policy Research Working Paper, No. 2628, The World Bank, Washington DC: The World Bank Group.
- Jinno, K. and K. Sato 2010 "Groundwater resources management in Japan", in Findikakis, A.N. and K. Sato (eds.) *Groundwater Management Practices*, USA: CRC Press/Balkema, 17-32.
- Kazmi, S.I., Ertsen, M.W., and M.R. Asi 2012 The impact of conjunctive use of canal and tube well water in Lagar irrigated area, Pakistan, *Physics and Chemistry of the Earth*, 47-48, 86-98.
- Kansakar, D.R. 2011 *Regulating common pool groundwater under fugitive surface water law: limitations in laws and regulations in Nepal*. Report submitted to Global Water Partnership Nepal.
- Kansakar, D.R., Pant, D.R., and J.P. Chaudhary 2009 "Reaching the poor: effectiveness of the current shallow tubewell policy in Nepal", in Mukherji, A., Villholth, K.G., Sharma, B.R., and J. Wang (eds.) *Groundwater governance in the Indo-Gangetic and Yellow River Basins*, CRC Press/Balkema, 163-181.
- Kendy, E., Molden, D. J., Steenhuis, T. S., Liu, C.M., and J. Wang 2003 *Policies drain the North China Plain: Agricultural policy and groundwater depletion in Luancheng County, 1949-2000*, Research Report 71. Colombo, Sri Lanka: International Water Management Institute.
- Khair, S.M., Mushtaq, S., Culas, R.J., and M. Hafeez 2012 Groundwater markets under the water scarcity and declining watertable conditions: the upland Balochistan Region of Pakistan, *Agricultural Systems*, 107, 21-32.
- Khair, S.M. Mushtaq, S., and K. Reardon-Smith 2015 Groundwater governance in a water-starved country: public policy, farmers' perceptions, and drivers of tubewell adoption in Balochistan, Pakistan, *Groundwater*, 53(4), 626-637.
- Li He, Y. 2011 *Case study on typical irrigation districts*. Submitted as part of the FAO "Study on Analysis of Sustainable Water Resource Use" project, funded by the Government of Japan.
- Liu, J., Cao, G. and C. Zheng 2011 Sustainability of Groundwater Resources in the North China Plain . in J.A.A. Jones (ed.), *Sustaining Groundwater Resources*, International Year of Planet Earth. Springer.
- Margat, J., and J. van der Gun 2013 *Groundwater around the World*, CRC Press/Balkema.
- Mbugua, A. 2011 *Research report on water scarcity in Northern Bangladesh*, VSO and GBK, Dinajpur, Bangladesh.
- Meinzen-Dick, R. 1996 Groundwater markets in Pakistan: participation and productivity, Research Report 105, International Food Policy Research Institute, Washington DC, USA: IFPRI.
- Nepal 1992 Water resources act, 2049.
- Pandey, V.P. and F. Kazama 2014. From an open-access to a state-controlled resource: the case of groundwater in the Kathmandu Valley, Nepal, *Water International*, 39(1), 97-112.
- Qin, H., Cao, G., Kristensen, M., Refsgaard, J.C., Ramussen, M.O., He, X., Liu, J., Shu, Y., and C. Zheng 2013 Integrated hydrological modeling of the North China Plain and implications for sustainable water management, *Hydrology and Earth System Sciences*, 17, 3759-3778.
- Qureshi, A.S. 2015 Improving food security and livelihood resilience through groundwater management in Pakistan, *Global Advanced Research Journal of Agricultural Science*, 4(10), 687-710.
- Qureshi, A.S., Shah, T., and M. Akhtar 2003 *The groundwater economy of Pakistan*, Working Paper 64, Lahore, Pakistan: International Water Management Institute (IWMI).
- Qureshi, A.S., McCornick, P.G., Sarwar, A., and B.S. Sharma 2010 Challenges and prospects of sustainable groundwater management in the Indus Basin, Pakistan, *Water Resources Management*, 24, 1551-1569.
- UNEP 2012 A glass half empty: regions at risk due to groundwater depletion – reproduced from United Nations Environment Program (UNEP) Global Environmental Alert Service (GEAS), *Environmental Development*, 2, 117-127.

- Rahman, M.M., and A.Q.M. Mahbub 2012 Groundwater depletion with expansion of irrigation in Barind district: a case study of Tanore Upazila, *Journal of Water Resource and Protection*, 4, 567-575.
- Sakura, Y., Tang, C., Yoshioka, R., and H. Ishibashi 2003 "Intensive use of groundwater in some areas of China and Japan", in Llamas, R., and E. Custodio (eds.) *Intensive use of groundwater: challenges and opportunities*, Lisse: A.A. Balkema Publishers, 337-354.
- Sato, K. and N. van Hoang 1995 *Recent countermeasures for land subsidence and groundwater resources in Japan*, Proceedings of the Fifth International Symposium on Land Subsidence, The Hague, October 1995, IAHS Publ. no. 234.
- Sato, K., Shichinohe, K., and T. Ueno 2011 "Groundwater-related laws in Japan", in Findikakis, A.N. and K. Sato (eds.) *Groundwater Management Practices*, USA: CRC Press/Balkema, 282-294.
- Shah, T., Giordano, M., and J. Wang 2004 Irrigation institutions in a dynamic economy: what is china doing differently from India?, *Economic and Political Weekly*, July 31, 3452-3461.
- Shamsudduha, M., Taylor, R.G., Ahmed, K.M., and A. Zahid 2011 The impact of intensive groundwater abstraction on recharge to a shallow regional aquifer system: evidence from Bangladesh, *Hydrogeology Journal*, 19, 901-916.
- Van Steenberg, F., and W. Oliemans 2002 A review of policies in groundwater management in Pakistan 1950-2000, *Water Policy*, 4, 323-344.
- Tanaka, T. n.d. *Groundwater resources, development and management in the Kanto Plain*, Japan. University of Tsukuba, Japan.
- The Water Channel 2012 The Qinxu Groundwater Management System, <http://www.thewaterchannel.tv/media-gallery/3216-the-qinxu-groundwater-management-system> (Accessed 29th October 2015).
- Ui Hassan, M., Shah, T., Ur Rehman, S., Khattak, M.Z., Tanwir, F., A. Saboor, and B.K. Lashari 2008 Diesel price hike and the energy squeeze on Pakistan's smallholder irrigators, *Zeitschrift fur Bewässerungswirtschaft*, 43, 19-40.
- Van Steenberg, F., Basharat, M., and B.K. Lashari 2015 Key challenges and opportunities for conjunctive management of surface and groundwater in mega-irrigation systems: Lower Indus, Pakistan, *Resources*, 4, 831-856.
- Wang, J.; Huang, J. and Rozelle, S. 2005. Evolution of tubewell ownership and production in the North China Plain. *The Australian Journal of Agricultural and Resource Economics*, 49, 177-195.
- Wang, J., Huang, J., Huang, Q., and S. Rozelle 2006 Privatization of tubewells in North China: determinants and impacts on irrigated area, productivity and the water table, *Hydrogeology Journal*, 14, 275-285.
- Wang, X., Otto, I.M., and L. Yu 2013 How physical and social factors affect village-level irrigation: an institutional analysis of water governance in northern China, *Agricultural Water Management*, 119, 10-18.
- Wang, J., Zhang, J., Huang, Q., Huang, J., and S. Rozelle 2014 "Assessment of the development of groundwater market in rural China", in Easter, K.W., and Q. Huang (eds.) *Water markets for the 21st Century: what have we learned?*, Dordrecht: Springer, 263-282.
- Xu, Y., Mo, X., Cai, Y., and X. Li 2005 Analysis on groundwater table drawdown by land use and the quest for sustainable water use in the Hebei Plain in China, *Agricultural Water Management*, 75, 38-53.
- Ye, A., Duan, Q., Chu, W., Xu, J., and Y. Mao 2014 The impact of the South – North Water Transfer Project (CTP)'s central route on groundwater table in the Hai River basin, North China, *Hydrological Processes*, 28(23), 5755- 5768.
- Zaman, A. 2015 "The Barind Multipurpose Development Authority – a model for financial sustainability", PPT Presentation, 7th World Water Forum, April 12-17, Doegu and Gyeongbuk, Republic of Korea.
- Zaman, A. 2015a, personal communication, 25th April 2015.

Zaman, A. 2015b, personal communication, 28th November 2015.

Zaman, M.A.U. and K.R. Rushton 2006 Improved yield from aquifers of limited saturated thickness using inverted wells, *Journal of Hydrology*, 326, 311-324.

Zhang, L., Wang, J., and J. Huang 2008 Development of groundwater markets in China: a glimpse into progress to date, *World Development*, 36(4), 706-726.

Zhang, L., Wang, J., Huang, J., Huang, Q., and S. Rozelle 2010 Access to groundwater and agricultural production in China, *Agricultural Water Management*, 97, 1609-1616.

Zhen, L., and J.K. Routray 2002 Groundwater resource use practices and implications for sustainable agricultural development in the North China Plain: a case study in Ningjin County of Shandong Province, PR China, *Water Resources Development*, 18(4), 581-593.

Zhou, Y., Wang, L., Liu, J., Li, W., and Y. Zheng 2012 Options of sustainable groundwater development in Beijing Plain, China, *Physics and Chemistry of the Earth*, 47-48, 99-113.

Zhu, X., Li, Y., Li, M., Pan, Y., and P. Shi 2013 Agricultural irrigation in China, *Journal of Soil and Water Conservation*, 68(8), 147-154.

India

AFPRO 2006 *A systematic assessment of community based groundwater management experiences in Andhra Pradesh*, Irrigation and Command Area Development Department, Government of Andhra Pradesh.

Aggarwal, R.M. 2000 Possibilities and limitations to cooperation in small groups: the case of group-owned wells in Southern India, *World Development*, 28(8), 1481-1497.

Aguilar, D. 2011 Groundwater reform in India: an equity and sustainability dilemma, *Texas International Law Journal*, 46, 623-653.

AgWater Solutions 2010 *West Bengal Situation Analysis*, January 2010, IWMI Briefing Note, http://awm-solutions.iwmi.org/Data/Sites/3/Documents/PDF/Country_Docs/West_Bengal/Situation%20Analysis%20Brief%20West%20Bengal.pdf (Accessed 17th November 2014).

AgWater Solutions 2012 *Groundwater Irrigation in West Bengal*, April 2012, IWMI Briefing Note, <http://awm-solutions.iwmi.org/Data/Sites/3/Documents/PDF/groundwater-irrigation-in-west-bengal.pdf> (Accessed 29th April 2014).

Alberts, J.H. 1998 *Public tubewell irrigation in Uttar Pradesh, India: a case study of the Indo-Dutch Tubewell Project*, International Institute for Land Reclamation and Improvement IILRI.

Anantha, K.H., Sena, D.R., and A. Mukherji 2009 "Groundwater resource conditions and groundwater sharing institutions: evidence from eastern Indo-Gangetic basin, India", in Mukherji, A., Villholth, K.G., Sharma, B.R., and J. Wang (eds.) *Groundwater governance in the Indo-Gangetic and Yellow River Basins*, Leiden, The Netherlands: CRC Press, 119-140.

Aubriot, O. 2006 «Quel partage des responsabilités dans la gestion de l'eau souterraine en Inde du Sud? (Cas du Tamil Nadu et Pondichery)», Colloque International GEVOREV – UVSQ, 26-28th June 2006.

Aubriot, O. 2013. "No pumping limit?", in Aubriot, O. (ed.) *Tank and well irrigation crisis: spatial, environmental and social issues. Cases in Puducherry and Villupura, Districts (South India)*, New Delhi, India: Concept Publishing Company, 149-173.

Aubriot, O., and P.I. Prabhakar 2011. Water institutions and the 'revival' of tanks in South India: What is at stake locally?, *Water Alternatives*, 4(3), 325-346.

Banerjee, P.S. 2010. *Agricultural water management solutions: the situation analysis in West Bengal*, AgWater Solutions Project Case Report, Colombo, Sri Lanka: International Water Management Institute.

Bassi, N. 2014 Assessing potential of water rights and energy pricing in making groundwater use for irrigation sustainable in India, *Water Policy*, 16, 442-453.

Bassi, N., Vijayshankar, P.S., and M. Dinesh 2008 "Wells and ill-fare: impacts of well failures on cultivators in hard-rock areas of Madhya Pradesh", in Kumar, M.D. (ed.). *Managing water in the face of growing scarcity*,

inequity and declining returns: exploring fresh approaches, Proceedings of the 7th Annual Partners Meet, IWMI TATA Water Policy Research Program, ICRISAT, Patancheru, Hyderabad, India, 2-4 April 2008. Vol.1. Hyderabad, India: International Water Management Institute (IWMI), 318-330.

Bhatia, b. 1992. *Lush fields and parched throats: the political economy of groundwater in Gujarat*, Working Papers No.100, WIDER, The United Nations University.

Birkenholtz, T. 2009 Irrigated landscapes, produced scarcity, and adaptive social institutions in Rajasthan, India, *Annals of the Association of American Geographers*, 99(1), 118-137.

Birner, R., Gupta, S., Sharma, N., and N. Palaniswamy 2007. The political economy of agricultural policy reform in India: the case of fertilizer supply and electricity supply for groundwater irrigation, International Food Policy Research Institute.

Buisson, M.C. 2015. "What does pump sets electrification change? Impacts on cropping patterns, productivity and incomes in West Bengal", 26th European Regional Conference, International Commission on Irrigation and Drainage ICID, 12-15 October 2015, Montpellier, France.

CGWB 2013a. *Ground Water Year Book – India 2012-2013*, Central Ground Water Board, Ministry of Water Resources, Government of India.

CGWB 2013b. Master Plan for artificial recharge to ground water in India, Central Ground Water Board, Ministry of Water Resources, Government of India.

Chandrakanth, M.G. 2009. *Karnataka State water sector reform: current status, emerging issues and needed strategies*, ITP Research Series 3, IWMI-TATA Water Policy Program, International Water Management Institute (IWMI).

Chandrakanth, M.G., and J. Romm 1990 Groundwater depletion in India – Institutional management regimes, *Natural Resources Journal*, 30, 485-501.

COMMAN 2005 Managing groundwater resources in rural India: the community and beyond, British Geological Survey, Report CR/05/36N.

Cullet, P. 2010 *Groundwater regulation – need for further reforms*, IELRC Working Paper 2010-01, Geneva, Switzerland: International Environmental Law Research Centre.

Cullet, P. 2012a "Groundwater – towards a new legal and institutional framework", in Cullet, P., Paranjape, S., Thakkar, H., Vani, M.S., Joy, K.J., and M.K. Ramesh (eds.) *Water conflicts in India – towards a new legal and institutional framework*, Pune: Forum for Policy Dialogue on Water Conflicts in India, 58-71.

Cullet, P. 2012b *Groundwater regulation in Uttar Pradesh: beyond the 2010 Bill*, IELRC Policy Paper 2012-02, International Environmental Law Research Centre.

Cullet, P. 2012c The groundwater model bill. Rethinking regulation for the primary source of water, *Economic and Political Weekly*, 47(45), 40-47.

Cullet, P. 2014 Groundwater law in India, towards a framework ensuring equitable access and aquifer protection, *Journal of Environmental Law*, 26, 55-81.

Cullet, P. 2014 Personal Communication.

Das, D., Samanta, G., Mandal, B.K., Chowdhury, T.R., Chanda, C.R., Chowdhury, P.P., Basu, G.K., and D. Chakraborti 1996 Arsenic in groundwater in six districts of West Bengal, India, *Environmental Geochemistry and Health*, 18, 5-15.

Das, S.V.G., and J. Burke 2013 *Smallholders and sustainable wells. A retrospect: participatory groundwater management in Andhra Pradesh (India)*, Food and Agriculture Organization (FAO), Rome: FAO.

Davis, J. 2004 Corruption in public service delivery: experience from South Asia's water and sanitation sector, *World Development*, 32(1), 53-71.

Deb, U., Bantilan, C., and G.V. Anupama 2014 *Drivers of Change, Dynamics of Rural Livelihoods and Poverty in SAT India*. Research Bulletin No. 26. Patancheru 502 324, Telangana, India: International Crops Research Institute for the Semi-Arid Tropics.

- Deloitte and the World Bank 2014 *Solar irrigation with electric vehicle. Public-private approach to energy, water and food nexus*, September 2014, Washington DC: The World Bank.
- Desai, A. 2012 Application of Solar PV based pumping for irrigation: a survey report, Centre for Technology Alternatives for Rural Areas, Indian Institute of Technology Bombay, Powai, Mumbai, <http://www.ctara.iitb.ac.in/tdsl/pastreports/autumn2012/solarpvpumpingsurvey.pdf> (Accessed 20th October 2014).
- Diwakara, H. 2006 Determinants of trust and cooperation: case study of self-managed tubewell organizations in North Gujarat, India, *International Journal of Rural Management*, 2(2), 163-189.
- Dubash, N.K. 2002 *Tubewell capitalism: groundwater development and agrarian change in Gujarat*, New Delhi, India: Oxford University Press.
- Dubash, N. 2007 The electricity-groundwater conundrum: case for a political solution to a political problem, *Economic and Political Weekly*, 42(52), 45-55.
- Eastern Zonal Water Partnership 2013 *Activity Report 2013, Groundwater Legislation in Eastern Indian States of Odisha, West Bengal, Bihar, and Jharkand*, National Institute for Development, <http://cwp-india.org/Reports/Annual2013/pdf/Report%20on%20Groundwater%20Legislations%20in%20Easter%20India%20and%20Status%20of%20Participatory%20Irrigation%20Management.pdf> (Accessed 18th August 2014).
- Everard, M. 2015 Community-based groundwater and ecosystem restoration in semi-arid north Rajasthan (1): socio-economic progress and lessons for groundwater-dependent areas, *Ecosystem Services*, 16, 125-135.
- Fishman, R.M., Siegfried, T., Raj, P., Modi, V., and U. Lall 2011 Over-extraction from shallow bedrock versus deep alluvial aquifers: reliability versus sustainability considerations for India's groundwater irrigation, *Water Resources Research*, 47(6), 1-15. s
- Fishman, R., Jain, M., and A. Kishore 2013 *Patterns of migration, water scarcity and caste in rural northern Gujarat*, Working Paper February 2013, International Growth Centre, London School of Economics and Political Science, <http://www.theigc.org/wp-content/uploads/2014/09/Fishman-Et-Al-2013-Working-Paper.pdf> (Accessed 12th November 2014).
- Fosli, J.K. 2014 *Effects of the free electricity policy in Andhra Pradesh 2004-2013*, MSc Thesis, Faculty of Humanities, University of Oslo.
- Foster, S., Tuinhoff, A., Kemper, K., Garduño, H., and M. Nanni 2006 *Characterization of groundwater systems – key concepts and frequent misconceptions*, Sustainable Groundwater Management – Concepts and Tools, GW-MATE, Washington DC: The World Bank.
- Foster, S., Garduño, H., and A. Tuinhoff 2007 *Confronting the groundwater management challenge in the Deccan Traps country of Maharashtra – India*, Case Profile Collection No.18, GW-MATE, Washington DC: The World Bank.
- Fraenkel, P.L. 1986 *Water lifting devices*, FAO Irrigation and Drainage Paper 43, Rome: Food and Agriculture Organisation.
- Gale, I.N., MacDonald, D.M.J., Calow, R.C., Neumann, I., Moench, M., Kulkarni, H., Mudrakartha, S. and K. Palanisami 2006 Managed Aquifer Recharge: an assessment of its role and effectiveness in watershed management, British Geological Survey Commissioned Report, CR/06/107N.
- Gale, I., Neumann, I., Calow, R.C., and M. Moench 2002 *The effectiveness of artificial recharge of groundwater: a review*, British Geological Survey Report CR/02/108N, Keyworth: British Geological Survey.
- Gandhi, V.P., and V. Bhamoriya 2011 "Groundwater irrigation in India: growth, challenges, and risks" in IDFC *India Infrastructure Report 2011 – Water: policy and performance for sustainable development*, Infrastructure Development Finance Company, Oxford: Oxford University Press.
- Garduño, H., Foster, S., Raj, P., and F. van Steenbergen 2009 *Addressing groundwater depletion through community-based management actions in the weathered granitic basement aquifer of drought-prone Andhra Pradesh – India*, GW-MATE, Case profile collection No.19, The World Bank.

- Garduño, H., Romani, S., Sengupta, B., Tuinhof, A., and R. Davis 2011 *India Groundwater Governance: Case Study*, Water Papers, The World Bank.
- Government of Karnataka and Central Ground Water Board 2010 *Dynamic groundwater resources of Karnataka, March 2009*, Department of Mines and Geology, Government of Karnataka, Central Ground Water Board South Western Region, http://www.indiawaterportal.org/sites/indiawaterportal.org/files/Dynamic_groundwater_resources_of_Karnataka_as_of_March_2009_DMG_GoK_CGWBSWR_2010_0.pdf (Accessed 19th August 2014).
- Grönwall, J.T. 2008 *Access to water – rights, obligations and the Bangalore situation*, PhD Thesis, Department of Water and Environmental Studies, Linköping University.
- Grönwall, J. 2014 *Power to segregate: improving electricity access and reducing demand in rural India*, SIWI Paper 23, Stockholm: SIWI.
- Gupta, S. 2009 "Ground water management in alluvial areas", in 5th Asian Regional Conference of INCID, December 9-11, New Delhi, India.
- Gupte, P.R. 2009 "Issues of groundwater governance and policy instruments in the Gujarat State, India", in, *Proceedings of the Joint International Convention of 8th IAHS Scientific Assembly and 37th IAH Congress*, Hyderabad, India, September 6-12, 2009.
- Hossain, S. 2013 Is commercialization of microfinance responsible for over-indebtedness? The case of Andhra Pradesh crisis, *Journal of Economics and Sustainable Development*, 4(17), 142-153.
- Humphreys, E., Kukal, S.S., Christen, E.W., Hira, G.S., Singh, B., Yadav, S., and R.K. Sharma 2010 Halting the groundwater decline in north-west India – which crop technologies will be winners?, *Advances in Agronomy*, 109, 155-217.
- Islam, A., and R.S. Gautam 2009 "Groundwater resource conditions, socio-economic impacts and policy-institutional options: a case study of Vaishali District of Bihar, India", in in Mukherji, A., Villholth, K.G., Sharma, B.R., and J. Wang (eds.) *Groundwater governance in the Indo-Gangetic and Yellow River Basins*, Leiden, The Netherlands: CRC Press, 105-118.
- Jegadeesan, M., and K. Fujita 2009 *Aspects of tank irrigated agrarian economy in Tamil Nadu, India: a study of three villages*, Kyoto Working Papers on Area Studies No. 77 (G-COE Series 79), Center for Southeast Asian Studies, Kyoto University, file:///C:/Users/ict/Downloads/77_muniandi.pdf (Accessed 12th November 2014).
- Kajisa, K. 2012 "An assessment of the replacement of traditional irrigation systems by private wells in Tamil Nadu, India", in Grafton, Q., Wyrwoll, P., White, C., and D. Allendes (eds.) *Global Water: Issues and Insights*, Canberra: ANU Press, 33-36.
- Kishore, A. 2014 *When wells fail: farmers' response to groundwater depletion in India*, Agriculture and Ecosystems Blog, CGIAR Research Program on Water, Land, and Ecosystems, June 10, 2014, <http://wle.cgiar.org/blogs/2014/06/10/wells-fail-farmers-response-groundwater-depletion-india/> (Accessed 11th June 2014).
- Kulkarni, H., Badarayani, U., Phadnis, V. and Robb R., 2005 *Detailed case study of Kolwan valley, Mulshi taluka, Pune district, Maharashtra*, AGRAR Project, Final Case Study Report, Advanced Center for Water Resources Development and Management.
- Kulkarni, H., Shah, M., and P.S. Vijay Shankar 2015 Shaping the contours of groundwater governance in India, *Journal of Hydrology: Regional Studies*, in press.
- Kumar, M.D., and O.P. Singh 2008 "How serious are groundwater over-exploitation problems in India?: a fresh investigation into an old issue", in Kumar, M.D., and M. Dinesh (eds.) *Managing water in the face of growing scarcity, inequity and declining returns: exploring fresh approaches*, Proceedings of the 7th Annual Partners Meet, IWMI TATA Water Policy Research Program, ICRISAT, Patancheru, Hyderabad, India, 2-4 April 2008. Vol.1. Hyderabad, India: International Water Management Institute (IWMI).
- Kumar, M.D., Sivamohan, M.V.K., Niranjana, V., and N. Bassi 2011 *Groundwater management in Andhra Pradesh: time to address real issues*, Occasional Paper No.4-0211, Institute for Resource Analysis and Policy, Hyderabad, India.

- Limaye, S.D. 2010 Sustainable Ground Water development in hard rock aquifers in low-income countries and the role of UNESCO – IUGS – IGCP project "Grownet", *Iranian Journal of Earth Sciences*, 2, 1-9.
- Mnjunatha, A.V., Speelman, S., Chandrakanth, M.G., and G. Van Huylenbroeck 2011 Impact of groundwater markets in India on water use efficiency: a data envelopment analysis approach, *Journal of Environmental Management*, 92, 2924-2929.
- Ministry of Water Resources 2010 Minor Irrigation Schemes Census, 4th Edition, <http://micensus.gov.in/index.html> (accessed 9th of November 2014).
- Mitra, A., and M.C. Buisson 2014 "From land reform to pump energisation: a shift in agricultural drivers in West Bengal", Stockholm World Water Week, 2 September 2014, http://program.worldwaterweek.org/sites/default/files/archisman_mitra_www14ppt.pdf (Accessed 17th November 2014).
- Molle, F. 2013 "Foreword", in Aubriot, O. (ed.) *Tank and well irrigation crisis: spatial, environmental and social issues. Cases in Puducherry and Villupura, Districts (South India)*, New Delhi, India: Concept Publishing Company, v-vii.
- Mollinga, P.P. 2010 The material conditions of a polarized discourse: clamours and silences in critical analysis of agricultural water use in India, *Journal of Agrarian Change*, 10(3), 414-436.
- Mosse, D. 2006 Collective action, common property, and social capital in South India: an anthropological commentary, *Economic Development and Cultural Change*, 54(3), 695-724.
- Muddu, S., Javeed, Y., Bandyopadhyay, S., Mangiarotti, S., and P. Mazzega 2011 "Groundwater management practices and emerging challenges: lessons from a case study in the Karnataka State of South India", in Findikakis, A.N., and K. Sato (eds.) *Groundwater management practices*, Boca Raton: CRC Press, 57-81.
- Mukherjee, S. 2007 *Groundwater for agricultural use in India: an institutional perspective*, Working Paper 187, Institute for Social and Economic Change, Bangalore: India.
- Mukherjee, S. 2009 Examining farmer suicides in India: a study of literature, MPRA Paper No.35675, Centre for Development Studies, Thiruvananthapuram, http://mpra.ub.uni-muenchen.de/35675/1/MPRA_paper_35675.pdf (Accessed 12th november 2014).
- Mukherji, A. 2006 Political ecology of groundwater: the contrasting case of water-abundant West Bengal and water-scarce Gujarat, India, *Hydrogeology Journal*, 14(3), 392-406.
- Mukherji, A. 2007a "Against the dominant discourse: making a case for groundwater irrigation for poverty alleviation in West Bengal, India", paper presented at the International Conference on Comparative Development, New Delhi, India, 18-20 December 2007.
- Mukherji, A. 2007b Implications of alternative institutional arrangements in groundwater sharing: evidence from West Bengal, *Economic and Political Weekly*, June 30, 2543-2551.
- Mukherji, A. 2008 Spatio-temporal analysis of markets for groundwater irrigation services in India: 1976-1977 to 1997-1998, *Hydrogeology Journal*, 16, 1077-1087.
- Mukherji, A., and A. Das 2014 The political economy of metering agricultural tube wells in West Bengal, India, *Water International*, 39(5), 671-685.
- Mukherji, A. and A. Kishore 2003 *Tubewell transfer in Gujarat: A study of the GWRDC approach*, Research Report 69, Colombo, Sri Lanka: International Water Management Institute (IWMI).
- Mukherji, A., and T. Shah 2005a Groundwater socio-ecology and governance: a review of institutions and policies in selected countries, *Hydrogeology Journal*, 13, 328-345.
- Mukherji, A., and T. Shah 2005b "Socio-ecology of groundwater irrigation in South Asia: an overview of issues and evidence", in *Selected papers of the Symposium on Intensive Use of Groundwater*, Valencia, Spain, 10-14 December 2002, IAH Hydrogeology Selected Papers, Oxford, UK: Taylor and Francis, 67-91.
- Mukherji, A., Das, B., Majumdar, N., Nayak, N.C., Sethi, R.R., Sharma, B.R., and P.S. Banerjee 2009 Metering of agricultural power supply in West Bengal, India: who gains and who loses? *Energy Policy*, 37(12), 5530-5539.

- Mukherji, A., Shah, T., and S. Verma 2010 "Electricity Reforms and its Impact on Groundwater Use: Evidence from India", in Martinez-Cortina L., Garrido, A., and E. Lopez-Gunn (eds.) *Re-thinking Water and Food Security*, Fourth Botin Foundation Water Workshop, Leiden, Netherlands: CRC Press, 299-306.
- Nageswara Rao, G.D., Anand Babu, P., and M.C.S. Bantilan 2009 *Dynamics and development pathways in the Semi-Arid Tropics: Dokur village profile*, Research Bulletin no.23, Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.
- Narendranath, G., Shankari, U., and K.R. Reddy 2005 To free or not to free power – understanding the context of free power to agriculture, *Economic and Political Weekly*, 40, 5561-5570.
- Nayak, S. 2009 Distributional inequality and groundwater depletion: an analysis across major states in India, *Indian Journal of Agriculture Economics*, 64(1), 89-107.
- Nelson, H., Roe, T., Smith, R., Ponce de Leon Barido, D., and E. Foufoula-Georgiou 2013 The shadow value of groundwater in Punjab, India: an analysis in an economy-wide context, White Paper 2, October 2013, Discovery Grant DG0014-11, Institute on the Environment, University of Minnesota.
- Palanisami, K., Vidhyavathi, A., and C.R. Ranganathan 2008 Wells for welfare or "illfare"? Cost of groundwater depletion in Coimbatore, Tamil Nadu, India, *Water Policy*, 10, 391-407.
- Pandey, R. 2014 *Groundwater irrigation in Punjab: some issues and way forward*, Working Paper No.2014-140, National Institute of Public Finance and Policy, New Delhi: India.
- Perveen, S., Krishnamurthy, C.K., Sidhu, R.S., Vatta, K., Kaur, B., Modi, V., Fishman, R., Polycarpou, L., and U. Lall 2012 *Restoring groundwater in Punjab, India's breadbasket: finding agricultural solutions for water sustainability*, Columbia Water Center White Paper, Earth Institute, Columbia University.
- Phansalkar, S. 2003 "Understanding underdevelopment: characterizing regional development in Vidarbha with special focus on water use", in Phansalkar, S. (ed.) *Issues in water use in agriculture in Vidarbha*, India: Amol Management Consultants, 10-31.
- Phansalkar, S., and V. Kher 2006 A decade of the Maharashtra groundwater legislation: analysis of the implementation process, *Law, Environment and Development Journal*, 2(1), 67-83.
- Planning Commission 2007 *Ground water management and ownership – Report from the expert group*, Government of India.
- Planning Commission 2011 *Annual Report 2011-12 on the working of State Power Utilities and Electricity Departments*, Power and Energy Division, Planning Commission, Government of India.
- Planning Commission 2013 *Report of the High Level Expert Group on Water Logging in Punjab*, Government of India.
- Purohit, P., and A. Michaelowa 2005 *CDM potential of SPV pumps in India*, HWWI Research Paper, No.4-4, Hamburgisches WeltWirtschafts Institut (Hamburg Institute of International Economics).
- Ratnakar, R. and S.G. Das 2006 Participatory irrigation management in the APWELL project: Indo-Dutch teamwork, 22nd Annual Conference Proceedings, Association for International Agricultural and Extension Education (AIAEE), Clearwater Beach, Florida, <https://www.aiaee.org/attachments/article/850/555.pdf>, (Accessed 7th January 2014).
- Rawat, S., and A. Mukherji 2012 *Poor state of irrigation statistics in India: the case of wells and tube wells*, Water Policy Research Highlight 5, IWMI-TATA Water Policy Program.
- Reddy, V.R. 2003 *Costs of Resource Degradation Externalities: A Study of Groundwater Depletion in Andhra Pradesh*, Working paper No. 49, Centre for Economic and Social Studies, Hyderabad.
- Reddy, M.S., and V.R. Reddy 2010 *Groundwater: development, degradation and management (a study of Andhra Pradesh)*, Working Paper no.92, RULNR Working Paper no.7, Research Unit for Livelihoods and Natural Resources, Centre for Economic and Social Studies, Begumpet, Hyderabad, India.
- Reddy, V.R., Reddy, M.S., and S.K. Rout 2014 Groundwater governance: a tale of three participatory models in Andhra Pradesh, India, *Water Alternatives*, 7(2), 275-297.
- Rosin, R.T. 1993 The tradition of groundwater irrigation in northwestern India, *Human Ecology*, 21(1), 51-86.

- Sakthivadivel, R. 2007 "The groundwater recharge movement in India", in Giordano, M., and K. Villholth (eds.) *The agricultural groundwater revolution: opportunities and threats to development*, Wallingford, Cambridge, Massachusetts: CABI, 195-210.
- Sarkar, A. 2011 Socio-economic implications of depleting groundwater resource in Punjab: a comparative analysis of different irrigation systems, *Economic & Political Weekly*, XLVI(7), 59-66.
- Sarkar, A. 2012 "Equity in Access to Irrigation Water: A Comparative Analysis of Tube-Well Irrigation System and Conjunctive Irrigation System", in Kumar, M. (ed.) *Problems, Perspectives and Challenges of Agricultural Water Management*, Rijeka, Croatia: InTech Europe, 3-18.
- Scott, C.A., and T. Shah 2004 Groundwater overdraft reduction through agricultural energy policy: insights from India and Mexico, *Water Resources Development*, 20(2), 149-164.
- Scott, C.A. and B. Sharma 2009 Energy supply and the expansion of groundwater irrigation in the Indus-Ganges Basin, *International Journal of River Basin Management*, 7(2), 119-124.
- Sekhri, S. 2012 Sustaining groundwater: role of policy reforms in promoting conservation in India, India International Centre, New Delhi, India Policy Forum 2012, http://www.ncaer.org/popuppages/EventDetails/IPF_2012/SheetalSekhri.pdf (Accessed 29th April 2014).
- Sekhri, S. 2014 Wells, water, and welfare: the impact of access to groundwater on rural poverty and conflict, *American Economic Journal: Applied Economics*, 6(3), 76-102.
- Selvi, V., Machiwal, D., Shaheen, F., and B.R. Sharma 2009 "Groundwater resources and the impact of groundwater sharing institutions: insights from Indian Punjab", in Mukherji, A., Villholth, K.G., Sharma, B.R., and J. Wang (eds.) *Groundwater governance in the Indo-Gangetic and Yellow River Basins*, Leiden, The Netherlands: CRC Press, 87-104.
- Sengupta, P. 2011 An analysis of West Bengal Ground Water Resources (Management, Control and Regulation) Act 2005, India Water Portal, May 11th 2011, <http://www.indiawaterportal.org/articles/analysis-west-bengal-ground-water-resources-management-control-and-regulation-act-2005> (Accessed 18th August 2014).
- Shah, T., 1993 *Groundwater Markets and Irrigation Development: Political Economy and Practical Policy*, Bombay, India: Oxford University Press.
- Shah, T. 2001 Wells and welfare in the Ganga basin: Public policy and private initiative in eastern Uttar Pradesh, India. Research Report 54. Colombo, Sri Lanka: International Water Management Institute.
- Shah, T. 2006 *Conjunctive use of groundwater and surface water*, Agricultural and Development Notes, Issue 6, February 2006, Washington DC: The World Bank.
- Shah, T. 2007a "The groundwater economy of South Asia: an assessment of size, significance and socio-ecological impacts", in Giordano, M., and K. Villholth (eds.) *The agricultural groundwater revolution: opportunities and threats to development*, Wallingford, Cambridge, Massachusetts: CABI, 7-36.
- Shah, T. 2007b Crop per drop of diesel? Energy squeeze on India's smallholder irrigation, *Economic and Political Weekly*, 42(39), 4002-4009.
- Shah, T. 2009 *Taming the anarchy: groundwater governance in South Asia*, Washington DC: RFF Press.
- Shah, E. 2012a Seeing like a subaltern – historical ethnography of pre-modern and modern tank irrigation technology in Karnataka, India, *Water Alternatives*, 5(2), 507-538.
- Shah, T. 2012b Community response to aquifer development: distinct patterns in India's alluvial and hard rock aquifer areas, *Irrigation and Drainage*, 61(Suppl.1), 14-25.
- Shah, T. 2014 Personal Communication.
- Shah, T. 2014 Towards a Managed Aquifer Recharge strategy for Gujarat, India: an economist's dialogue with hydro-geologists, *Journal of Hydrology*, in press.
- Shah, T., and A. Kishore 2012 *Solar-powered pump irrigation and India's groundwater economy: a preliminary discussion of opportunities and threats*, Water Policy Research Highlight, No. 26, IWMI-TATA Water Policy Program, Mangalpur, Anand, India: IWMI.

Shah, T., Scott, C., Kishore, A., and A. Sharma 2004 Energy-irrigation nexus in South Asia: Improving groundwater conservation and power sector viability, Research Report 70. Colombo, Sri Lanka: International Water Management Institute.

Shah, T., Mehta, M., Sankar, G., and S. Mondal 2012 *Organizational Reform in Gujarat's Electricity Utility: Lessons for Revitalizing a Bureaucratic Service Delivery Agency*, IWMI-TATA Vol. 6.

Shah, T., Verma, S., and N. Durga 2014 Karnataka's smart, new solar pump policy for irrigation, *Economic and Political Weekly*, 49(48), 10-14.

Sharif, M., and K.R. Ashok 2011 Impact of groundwater over-draft on farm income and efficiency in crop production, *Agricultural Economics Research Review*, 24, 291-300.

Sidhu, R.S. 2013 Political economy of groundwater in Punjab, Punjab Agricultural University, http://ihr.ucsc.edu/wp-content/uploads/2013/04/UCSC_29March2013_Final_Rev.pdf (Accessed 27th August 2014).

Sikka, A.K., and P.R. Bhatnagar 2005 "Realizing the potential: using pumps to enhance productivity in the Eastern Indo-Gangetic Plains", in Sharma, B.R., Villholth, K., and K.D. Sharma (eds.) *Groundwater research and management: integrating science into management*, Groundwater Governance in Asia Series – 1, Proceedings of IWMI-ITP-NIH International Workshop on "Creating synergy between groundwater research and management in South and Southeast Asia", 8-9 February 2005, Roorkee, India, 200-212.

Singh, K. 2009 Act to save groundwater in Punjab: its impact on water table, electricity subsidy and environment, *Agricultural Economic Research Review*, 22, 365-386.

Singh, B., Singh, S., and J.S. Brar 2004 *Border risk and unemployment dynamics*. Patiala, India: Publication Bureau, Punjabi University.

Sundarajan, K., Patel, A., Raychoudhury, T. and C. Purohit 2009 "Groundwater Exploitation in India, Environmental Impacts and Limits to Further Exploitation for Irrigation", in, Upali A. Amarasinghe and R.P.S. Malik (eds.) *India's water future: Scenarios and issues. Strategic Analysis of National River Linking Project of India*, Series 2, Colombo, Sri Lanka: International Water Management Institute, 197-216.

Tamuli, J., and M.K. Dutta 2015 *What determines farmers' decision to buy irrigation water in water abundant regions? A study of groundwater markets in Assam in Eastern India*, Working Paper 2015.03, International Network for Economic Research, Germany.

Taylor, M. 2013 Liquid debts: credit, groundwater and the social ecology of agrarian distress in Andhra Pradesh, India, *Third World Quarterly*, 34(4), 691-709.

Tewari, N.P. 2012 *Solar irrigation pumps, the Rajasthan experience*, Water Policy Research Highlight, No. 35, IWMI-TATA Water Policy Program, Mangalpura, Anand, India: IWMI.

Tiwary, R., and J.L. Sabatier 2009 "Anthropological perspectives on groundwater irrigation: ethnographic evidence from a village in Bist Doab, Punjab", in Mukherji, A., Villholth, K.G., Sharma, B.R., and J. Wang (eds.) *Groundwater governance in the Indo-Gangetic and Yellow River Basins*, Leiden, The Netherlands: CRC Press, 221-229.

UNEP and GEAS 2012 A glass half empty: regions at risk due to groundwater depletion – reproduced from United Nations Environment Program (UNEP) Global Environmental Alert Service (GEAS), *Environmental Development*, 2, 117-127.

Veeman, T.S. 1978 Water policy and water institutions in Northern India: the case of groundwater rights, *Natural Resources Journal*, 18, 569-587.

Verma, S., Krishnan, S., Reddy, A., and K.R. Reddy 2012 *Andhra Pradesh Farmer Managed Groundwater Systems (APFAMGS) – a reality check*, Water Policy Research Highlight 37, IWMI –TATA Water Policy Program, Anand, India.

Villholth, K.G., Mukherji, A., Sharma, B.R., and J. Wang 2009 "The role of groundwater in agriculture, livelihoods, and rural poverty alleviation in the Indo-Gangetic and Yellow River basins: a review", in Mukherji,

A., Villholth, K.G., Sharma, B.R., and J. Wang (eds.) *Groundwater governance in the Indo-Gangetic and Yellow River Basins*, Leiden, The Netherlands: CRC Press, 3-22.

Water Governance Facility 2013 *Groundwater Governance in India: Stumbling Blocks for Law and Compliance*. WGF Report No. 3, Stockholm: SIWI.

World Bank 2010 *Deep wells and prudence: towards pragmatic action for addressing groundwater overexploitation in India*, Washington DC: The World Bank.

World Bank 2013 *Lighting rural India: experience of rural load segregation schemes in States*, Energy Sector Unit, South Asia Sustainable Development, Energy Sector Management Assistance Program, Asia Sustainable and Alternative Energy Program.

Australia

ACIL Tasman 2005 *Great Artesian Basin: economic and social assessment*, Final Report, Prepared for the Department of Natural Resources and Mines, State of Queensland.

Anderson, T., Cauchi, T., Hamstead, M., Merrick, N.P., Mozina, M., and K. Phillipson 2014 *Approaches to Achieve Sustainable Use and Management of Groundwater Resources in the Murray–Darling Basin Using Rules and Resource Condition Limits*, Melbourne:GHD Pty Ltd.

Baldwin, C.L. 2008 *Integrating values and interests in water planning using a consensus-building approach*, PhD Thesis, School of Natural and Rural System Management, University of Queensland.

Bennett, M., and A. Gardner 2014 *Groundwater regulation in a Drying South West*, National Centre for Groundwater Research and Training, Adelaide: Australia.

Bennett, M., and A. Gardner 2015 *Regulating groundwater in a drying climate: lessons from South West Australia*. *Journal of Energy and Natural Resources Law*.

Bhp Biliton 2015 *Monitoring program – Great Artesian Basin (GAB)*, Olympic Dam Document No.2789 V17.

Bjornlund, H., Wheeler, S., and J. Cheesman 2011 "Irrigators, water trading, the environment and debt: buying water entitlements for the environment", in in Connell, D., and R. Quentin Grafton (eds.) *Basin futures. Water reform in the Murray-Darling Basin*, Canberra, Australia: The Australian National University Press, 291-301.

Burrell, M., Moss, P., Ali, A., Petrovic, J., and K. Nguyen 2012 *General purpose water accounting report 2010-2011: Murrumbidgee Catchment*, NSW Department of Primary Studies, Sydney.

Chartres, C., and J. Williams 2006 Can Australia overcome its water scarcity problems?, *Journal of Developments in Sustainable Agriculture*, 1, 17-24.

Connell, D. 2011 "The role of the Commonwealth environmental water holder", in Connell, D., and R. Quentin Grafton (eds.) *Basin futures. Water reform in the Murray-Darling Basin*, Canberra, Australia: The Australian National University Press, 327-337.

Cox, R., and A. Barron (eds.) 1998 *Great Artesian Basin – Resource Study*, Great Artesian Basin Consultative Council, <http://www.gabcc.gov.au/system/files/resources/69eff9d9-18c9-49e4-bb9a-dc1a15fe6ca0/files/resource-study-1998.pdf> (Accessed 24th February 2016).

de Rijke, K., Munro, P., and M. de Lourdes Melo Zurita 2016 The Great Artesian Basin : a contested resource environment of subterranean water and coal seam gas in Australia, *Society & Natural Resources*, 29(6), 696-710.

Deloitte 2013 *Economic value of groundwater in Australia*, National Centre for Groundwater Research and Training, Deloitte Access Economics.

Fensham, R.J., Silcock, J.L., Powell, O., and M.A. Habermehl 2015 In search of lost springs: a protocol for locating active and inactive springs, *Groundwater*, DOI: 10.1111/gwat.12375

Frontier Economics 2009 Volumetric restrictions on water entitlement trade, a report prepared for the ACCC, August 2009, <https://www.accc.gov.au/system/files/Frontier%20Economics%20-%20Volumetric%20restrictions%20on%20entitlement%20trade.pdf> (Accessed 19th November 2015).

GABCC 2010 Great Artesian Basin Resource Study – Update, Great Artesian Basin Consultative Council, <http://www.gabcc.gov.au/system/files/resources/66540f98-c828-4268-8b8b-b37f8193cde7/files/resource-study-2010-update.pdf> (Accessed 24th February 2016).

GHD, Hamstead Consulting, and V.O'Keefe 2011 *A framework for managing and developing groundwater trading*: Canberra: National Water Commission.

Government of South Australia 2014 *Groundwater level and salinity report, GAB Aquifer, FAR North PWA*, Department of Environment, Water and Natural Resources, Adelaide.

Habermehl, M.A. 2006 "The Great Artesian Basin, Australia", in Foster, S., and D.P. Loucks (eds.) *Non-renewable groundwater resources: a guidebook on socially-sustainable management for water-policy makers*, IHP-VI Series on Groundwater No.10, UNESCO, 82-88.

Harrington, N., and P. Cook 2014 *Groundwater in Australia*, Adelaide: National Centre for Groundwater Research and Training.

Herczeg, A.L. 2008 *Background report on the Great Artesian Basin. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project*. CSIRO, Australia.

Hyder Consulting 2008 Review of the interim threshold limit on permanent water trade, Report No.1, <http://www.crikey.com.au/wp-content/uploads/Media/docs/080902-080819-Final-Report-Updated-fde70c66-ed96-406f-a512-c2808035a6cb.pdf> (Accessed 19th November 2015).

Kuehne, G., Bjornlund, H., and A. Loch 2010 *Why do farmers make non-profit decisions? Investigating decisions made during drought*, No. 10/075, Canberra: Rural Industries Research and Development Corporation (RIRDC).

Kumar, P.B. 2010a *Lower Murrumbidgee Groundwater Sources: Groundwater Management Area 002 Groundwater Status Report – 2009*, Sydney: NSW Office of Water.

Kumar, P.B. 2010b *Lower Murrumbidgee Groundwater Sources – Resource condition assessment report – 2010*, Sydney: NSW Office of Water.

Kumar, P.B. 2013 *Groundwater trading and management of local impacts – Lower Murrumbidgee deep groundwater source*, Sydney: NSW Office of Water.

Leblanc, M., Tweed, S., Van Dijk, A., and B. Timbal 2012 A review of historic and future hydrological changes in the Murray-Darling Basin, *Global and Planetary Change*, 80-81, 226-246.

Maddocks, A. 2013 "Australia's Water Markets Succeeding, Yet Severe Challenges Loom", *Circle Of Blue*, 20th of February 2013, <http://www.circleofblue.org/waternews/2013/world/australias-water-markets-succeeding-yet-severe-challenges-loom/> (Accessed 12th February 2015).

Malone, D., Torrible, L., and J. Hayes 2009 *NSW strategic water information and monitoring plan: water inventory and observation networks in New South Wales*, Sydney: NSW Office of Water.

Marshall, G.R., Connell, D., and B.M. Taylor 2013 Australia's Murray-Darling Basin: a century of polycentric experiments in cross-border integration of water resources management, *International Journal of Water Governance*, 1, 231-251.

Morgan, R. 2015 "'Drought-proofing' Perth: the long view of Western Australian water", *The Conversation AU*, 16th of February 2015 (<http://theconversation.com/drought-proofing-perth-the-long-view-of-western-australian-water-36349>, accessed 17th of February 2015).

McKay, J. 2001 "Legal issues in water resources planning regimes – lessons from Australia", in Brennan, D. (ed.) *Water policy reform: lessons from Asia and Australia*, Proceedings of an International Workshop, Bangkok, Thailand, 8-9 June 2001, 48-61.

McKay, J. 2002 Water law in the Australian Federation – the move towards centralism, Paper presented at 'Water Management in Federal and Federal-type systems' Conference, Zaragoza, Spain, 7-8 July 2008.

McKay, J. 2007 'Groundwater as the Cinderella of Water Laws, Policies, and Institutions in Australia', in Bergkamp, G., and J. McKay (eds.) *The Global Importance of Groundwater in the 21st Century: Proceedings of the International Symposium on Groundwater Sustainability*, National Groundwater Association NGWA and IUCN-UNESCO, 317-331.

McKay, J. 2011 "Evidentiary issues with the implementation of the sustainability duty of care the Basin Plan", in Connell, D., and R. Quentin Grafton (eds.) *Basin futures. Water reform in the Murray-Darling Basin*, Canberra, Australia: The Australian National University Press, 233-243.

National Water Commission 2010 The impacts of water trading in the southern Murray-Darling Basin. An economic, social and environmental assessment, Canberra: National Water Commission.

National Water Commission 2011a *Australian water markets: trends and drivers 2007-08 to 2009-2010*, Canberra: National Water Commission.

National Water Commission 2011b *Australian water markets: trends and drivers 2007-08 to 2011-12*, Canberra: National Water Commission.

National Water Commission 2011c *Australian water markets report 2010-11*, Canberra: National Water Commission.

National Water Commission 2012 *Impacts of water trading in the southern Murray-Darling Basin between 2006-07 and 2010-11*, Canberra: National water Commission.

National Water Commission 2013 *Murray-Darling Basin Plan implementation: initial report*, Report No.1, Canberra: National water Commission.

Neville, C.J. 2009 Managing cumulative impacts: groundwater reform in the Murray-Darling Basin, Australia, *Water Resources Management*, 23, 2605-2631.

NSW 2013 Lower Murrumbidgee groundwater sources summary report 2006-2012, New South Wales Government, Department of Primary Industries, Office of Water.

NSW 2015 Lower Murrumbidgee groundwater sources summary report 2006-2014, New South Wales Government, Department of Primary Industries, Office of Water.

Ponder, W.F. 2002 "Desert springs of the Australian Great Artesian Basin", Conference Proceedings *Spring-fed Wetlands: important scientific and cultural resources of the Intermountain Region*, May 7-9, Las Vegas, USA.

Powell, O. Silcock, J., and R. Fensham 2015 Oases to oblivion: the rapid demise of springs in the south-eastern Great Artesian Basin, Australia, *Groundwater*, 53(1), 171-178.

Queensland Department of Natural Resources and Mines 2005 *Hydrogeological framework report for the Great Artesian Basin Water Resource Plan Area*, Version 1.0.

Quiggin, J., and P.L. Tan 2004 *Sustainable management of the Great Artesian Basin: an analysis based on environmental economics and law*, Murray Darling Program Working Paper 3/M04, Risk and Sustainable Management Group, Schools of Economics and Political Science, University of Queensland, Australia.

Ross, A. 2012 Easy to say, hard to do: integrated surface water and groundwater management in the Murray-Darling Basin, *Water Policy*, 14, 709-724.

Sarker, A., Baldwin, C., and H. Ross 2009 Managing groundwater as a pool-resource: an Australian case study, *Water Policy*, 11, 598-614.

SEQWater 2013 Submission by Central Lockyer & Morton Vale Schemes – SEQWater Irrigation Price Review 2013-17 – Draft Report, <http://www.qca.org.au/getattachment/9b95fb57-6485-44aa-bdb4-52b8f01a7401/Central-Lockyer-and-Morton-Vale-Scheme-Representat.aspx> (Accessed 23rd June 2015).

Sinclair Knight Merz 2003 *Projections of groundwater extraction rates and implications for future demand and competition for surface water*, Canberra: Murray Darling Basin Commission.

Sinclair Knight Merz 2012 *Assessment of groundwater licensing, metering and extraction estimation arrangements and techniques in Australia*, Waterlines Report No.83, Canberra: National Water Commission.

Sinclair Knight Merz 2014 Western Porous Rock Groundwater Sustainable Diversion Limit Review – Synthesis Report, Canberra: Murray Darling Basin Authority.

Skurray, J.H., Pandit, R., and D.J. Pannell 2013 Institutional impediments to groundwater trading: the case of the Gnangara groundwater system of Western Australia, *Journal of Environmental Planning and Management*, 56(7), 1046-1072.

Smerdon, B.D., Ransley, T.R., Radke, B.M., and J.R. Kellet 2012 *Water resource assessment for the Great Artesian Basin. A report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment*, CSIRO Water for a Healthy Country Flagship.

State of New South Wales 2009 *Water Sharing Plan: NSW Great Artesian Basin Groundwater Sources – Background document*, Department of Water and Energy, Sydney.

State of Queensland 2007 *Great Artesian Basin Resource Operations Plan*, Department of Natural Resources and Water, State of Queensland.

State of Queensland 2012 *Great Artesian Basin Water Resource Plan – Five Year Review*, Department of Natural Resources and Mines, State of Queensland.

Turrall, H. 2015 Personal communication, Water Resources Management Expert, Melbourne, Australia.

Turrall, H., and I. Fullagar 2007 "Institutional directions in groundwater management in Australia", in Giordano, M., and K. Villholth (eds.) *The agricultural groundwater revolution: opportunities and threats to development*, Wallingford, UK: CABI, 320-361.

Valli, M. 2015 Personal communication, PhD Student, School of Geosciences, University of Sydney (14th February 2015).

Wahlquist, A. 2011 "Rethinking community the face of natural resources management challenges", in Connell, D., and R. Quentin Grafton (eds.) *Basin futures. Water reform in the Murray-Darling Basin*, Canberra, Australia: The Australian National University Press, 115-133.

Water Corporation 2013 *Groundwater replenishment scheme – communications strategy 2013-2016 as at August 2013*, Perth: Water Corporation.

Water Corporation 2014 *Southern seawater desalination project – ministerial statement 792, condition 4.6, Performance and compliance report, reporting period 14 April 2013 to 13 April 2014*, Perth: Water Corporation.

Weir, J.K. 2011 "Water planning and dispossession", in Connell, D., and R. Quentin Grafton (eds.) *Basin futures. Water reform in the Murray-Darling Basin*, Canberra, Australia: The Australian National University Press, 179-191.

Wheeler, S.; Loch, A.; Zuo, A. and Bjorlund, H. 2014. Reviewing the adoption and impact of water markets in the Murray-Darling basin, Australia. *Journal of hydrology* 518, 28-41.

Williams, J. 2011 "Understanding the basin and its dynamics", in Connell, D., and R. Quentin Grafton (eds.) *Basin futures. Water reform in the Murray-Darling Basin*, Canberra, Australia: The Australian National University Press, 1-37.