

Urban–agricultural water appropriation: the Hyderabad, India case

MATTIA CELIO*, CHRISTOPHER A SCOTT† AND MARK GIORDANO‡

**Water Engineering and Development Centre, Loughborough University, Leicestershire LE11 3TU*
E-mail: mcelio@free.fr

†*Udall Center for Studies in Public Policy, University of Arizona, 803 E. First St., Tucson, AZ 85719 and School of Geography & Development, University of Arizona, 410 Harvill Bldg, Tucson, AZ 85721, USA*
E-mail: cascott@email.arizona.edu

‡*International Water Management Institute, 127, Sunil Mawatha, Pelwatte, Battaramulla, Sri Lanka*

E-mail: mark.giordano@cgiar.org

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With the urbanisation drive comes steady growth in urban water demand. Although in the past this new demand could often be met by tapping unclaimed water sources, this option is increasingly untenable in many regions where little if any unclaimed water remains. The result is that urban water capture, and the appropriation of associated physical and institutional infrastructure, now often implies conflict with other existing uses and users. While the urbanisation process has been studied in great depth, the processes and, critically, impacts of urban water capture and appropriation are not well researched or understood. This paper undertakes a critical examination of the specific case of Hyderabad, one of India's fastest growing cities, to shed light more generally on the process of water capture by cities and the resultant impacts on pre-existing claims, particularly agriculture. It does this by examining the history and institutional response to Hyderabad's urban–rural water contest; how the results of that contest are reflected in surface and groundwater hydrology; and the eventual impacts on agriculture. The findings show that the magnitude, and sometimes even direction, of impact from urban water transfer vary in space and time and depend on location-specific rainfall patterns, the nature of existing water infrastructure and institutions, and farmers' adaptive capacities and options, notably recourse to groundwater. Broader consideration of the specific findings provides insights into policy mechanisms to reduce the possible negative impacts from the global, and seemingly inexorable, flow of water to the world's growing cities.

KEY WORDS: Hyderabad, India, water allocation, water balance, water institutions, urban water supply, adaptive strategies

Introduction

Urban expansion and the thirst for water: the process is global while its manifestations are regional and local. Cities as diverse as Barcelona (Saurí and Del Moral Ituarte 2001), San Diego (Johns 2003) and Beijing (Wei and Gnauck 2007) have extended water services in response to growing populations and their changing demands. Cities have conventionally secured water for their growth from

'natural sources' – rivers or groundwater aquifers – in their immediate proximity in the well described process of subjugating nature for human purposes. However, they must increasingly contend with pre-existing social claims for the water they seek to capture. Partially, as a result, cities have diverted water from more distant sources, and spatial proximity has become a less important determinant of urban water sourcing. Technology and infrastructure have facilitated this extended reach, both in scale and

magnitude, and the resulting capture through the exercise of power has been described as the ‘urbanisation of water’ (Swyngedouw 1997 2004). In many regions, even these more distant sources have now already also been claimed for other uses, sometimes resulting in economic, institutional, and political clashes. The historical trajectory of urban water sourcing, then, has substituted contested social power and equity for the human–nature divide that characterised earlier capture processes and their conceptualisation as the urbanisation of water.

While the growing phenomenon of water transfers to cities is undisputed (see e.g. Molle and Berkoff 2006), theory on the underlying processes, and their meaning, that eventually move water to urban areas, has diverged along disciplinary divides. Water allocation to meet growing urban needs has been researched primarily from an economics perspective (see e.g. National Research Council 1992; Dinar *et al.* 1997; Chong and Sunding 2006; Meinzen-Dick and Ringle 2008). Where users’ water rights are established and enforceable, market reallocation of water has been a mechanism to resolve disputes (Colby 2001), or alternately has been proposed to offset compensation claims (Saleth and Dinar 1999) and address ‘area of origin’ impacts (that is, areas from where water is withdrawn) where source waters have pre-existing claims (National Research Council 1992).

Conversely, geographers’ critiques of urbanisation and its expanding water demand are more concerned with water ‘capture’ and, as highlighted here, ‘appropriation’. *Capture* is a social and political process that effects the physical transfer of water from one geographic location to another. For geographers, capture is akin to reallocation, a concept often defined by economists in inter-sectoral (use and valuation) terms and with notable differences in emphasis on the means employed to effect transfer (power for geographers vs markets for economists). *Appropriation* as applied here is not just the exercise of power to effect water transfer, but more importantly the process by which the appropriator partially or totally subsumes for its own purposes the institutions (meant here as water policy, law, and administration) for its control and secures entitlement to the infrastructure which made possible the pre-existing uses.

In many cases, urban water capture from distant sources – as well as the appropriation of its built infrastructure, engineered systems, management capacity and, increasingly, institutional controls – has come to create and confront the limits of water availability, with human processes and nature in dialectic interaction. Thus successful appropriation by cities requires also the exercise of ‘authority’. As agriculture is globally the largest existing user of water resources, it is often water already claimed for agriculture which urban interests attempt to appropriate by applying

state authority in discursive and political terms. At the same time, farmers, who often form their own potent political lobbies, can contest the urban assertion of authority. In this context, Robbins (1998) assessed state–local power relations in India and the contested use of natural resources – land, pasture, and forest – holding that *authority* is the ‘relationship that assures binding obligations’ (p. 413). He further clarified the distinction between ‘property... [and] *control*’ (original italics), in which ‘authority control[s] social action and access to resources’ (p. 413). Such an evolutionary perspective applied to urban growth permits consideration of cities’ appropriation of agricultural produce and resources – land and, of particular concern here, water – while at the same time accounting for reflexive action, adaptation, and strategic intent in agriculture.

Although prolific in their analysis of urbanisation processes and to a lesser degree contested water demands (see e.g. Zimmerer 2000; Giordano *et al.* 2002; van der Zaag 2007; Watson *et al.* 2007), geographers have only marginally addressed the question of the impact of water capture on pre-existing uses – such as agriculture – which can lead to conflicting claims, appropriation, or the reflexive and adaptive response by farmers described by Robbins (1998). Further, while there are limited empirical enquiries from other fields into the implications for irrigated agriculture, they are focused primarily on sale, rather than appropriation, and even then present contrasting results. For example, research conducted in Tamil Nadu, south India, by Palanisami (1994) demonstrates that transfers can have positive economic impacts with the sale of water by farmers to urban residents alleviating diverse labour problems, improving profits, and disposing of unutilised surplus water. Thobani (1998) reports on new employment possibilities for farmers who sold their water rights in Chile and Mexico; whereas Rosegrant and Gazmuri Schleyer (1994) present evidence suggesting that negative area-of-origin effects in Chile are small and that agricultural regions have benefited substantially from water trading and sale.

Conversely, Hearne (1998) found that the sale of water rights by a few farmers in market-based water allocation systems can have substantial, negative impacts on the farming community. Dixon *et al.* (1993) observe that operating costs rose and crop sales and agribusiness revenues in California dropped because of water sales to the California water bank during the 1991 drought. However, the impact depends on the characteristics of the area of origin. Severe economic and social impacts, if any, are to be mostly expected in specialised, marginal agricultural regions rather than in prosperous basins (Howe and Goemans 2003). Taking California as a case study, Philip (2003) notes that although water transfers are

likely to reduce farm income and employment in some farming areas, they engender relatively small effects, largely because farmers tend to adapt by shifting away from water-intensive crops.

These conflicting outcomes may be in part explained by consideration of adaptation. Adaptation by investing in increased water productivity (Molden 2007), shifting to less water-intensive crops (Scott *et al.* 2007), shift cropping calendars (Molle 2007), or resorting to groundwater are seen as strategies for offsetting or at least reducing the impact of water transfers out of agriculture. This view is supported, for instance, by Loeve *et al.* (2004), who demonstrated that crop production and water productivity increased in the area irrigated by the Zhanghe Reservoir in China after reallocation to other sectors took place. Along the same lines, Nickum (1997) reports that because of a shift to high value crops and increase in water productivity, grain and overall agricultural outputs continued to increase in the suburbs of Beijing even after water was diverted to the urban core and the overall irrigated area had declined. Wei and Gnauck's (2007) game-theory modelling of Beijing's water appropriation was only partially able to characterise the complex processes of urban growth, land expropriation, and bureaucratic compensation in China, such as documented by Lin and Ho (2005). The recourse to groundwater has received particular attention in the case of South Asia, for example by Shah *et al.* (2003a) with reference to resource overexploitation, Shah (1993) and Mukherji (2004) with reference to the political economics of Indian groundwater markets and policy, and Birkenholtz (2008) in terms of conflicting systems of knowledge and use and the changing relationships between state and local users. For China, changes in cropping patterns and the growth of agricultural groundwater use, at least partially as a response to scarcity, has been documented by Wang *et al.* (2007).

It is with this background that the present paper attempts to provide new insights into the multiple implications of growing urban water demand. With specific reference to Hyderabad, India, the paper reviews the process of urban water appropriation from pre-existing irrigation use, and proceeds to assess the hydrologic impact of water capture, appropriations from the agricultural sector, and farmer adaptation to the resulting outcomes. To do so, it uses theoretical advances in the appropriation hypothesis – that in order to explain urban water capture fully, it is necessary for appropriation to account for both physical transfer of the water resource and institutional capture of infrastructure, operations, and decisionmaking mechanisms – and an empirical assessment of the specific case of water transfer in the south Indian state of Andhra Pradesh from longstanding agricultural uses to the rapidly growing city of Hyderabad to answer

four questions. First, what were the historic and political processes through which Hyderabad's water appropriation occurred? Second, what are the implications of urban water appropriation for state controlled surface water irrigation and its infrastructure? Third, to what extent does consideration of locally controlled groundwater and its infrastructure change our understanding of impacts and agricultural adaptation to surface water appropriation by cities? Finally, what is the actual impact of surface water transfer on agriculture?

Answers are sought by first reviewing the geographic and historic context of the overall Hyderabad water transfer strategy and the politics of administrative control based on existing literature, unpublished reports and newspaper accounts. How the changes actually impact on the delivery of state controlled surface water to agriculture is then examined through the development of a water balance model for Nizamsagar, the main irrigation project affected by Hyderabad's water appropriation. A similar quantitative analysis of groundwater use, an often-ignored piece of the appropriation and adaptation equation, is carried out. The agricultural implications of the surface water reallocation are then quantified in terms of variations in crop production and gross revenue. The counter-intuitive result is that the agricultural impacts of water urbanisation can be much more dependent on political, institutional and hydrologic conditions than may be conventionally assumed. In fact, this study shows that the impacts are not necessarily negative. The paper concludes by placing the study results in context, answering the original research questions, and drawing general lessons for urban appropriation of water from agriculture and potential implications for groundwater use as an adaptive strategy to overcome urban-induced water scarcity in agriculture.

Research context – Hyderabad's water space

The global nature of the urban challenge is manifest in population growth trends and demographic shift. According to the United Nations (2002), the world's urban population rose from 750 million in 1950 to 2.9 billion in 2000, and over the same period the proportion of urban dwellers increased from 30% to 48% and equalled rural populations for the first time in 2007. The growing city populations bring new demands for water, both for direct human consumption as well as for the industrial needs that accompany urban economic change. At the same time, indirect demand by urban residents for agricultural water continues, or more generally increases, as growing incomes induce more water-intensive food consumption (e.g. meat). In a context where available water supplies are already at or near their limit and where existing water use, infrastructure, and the livelihoods

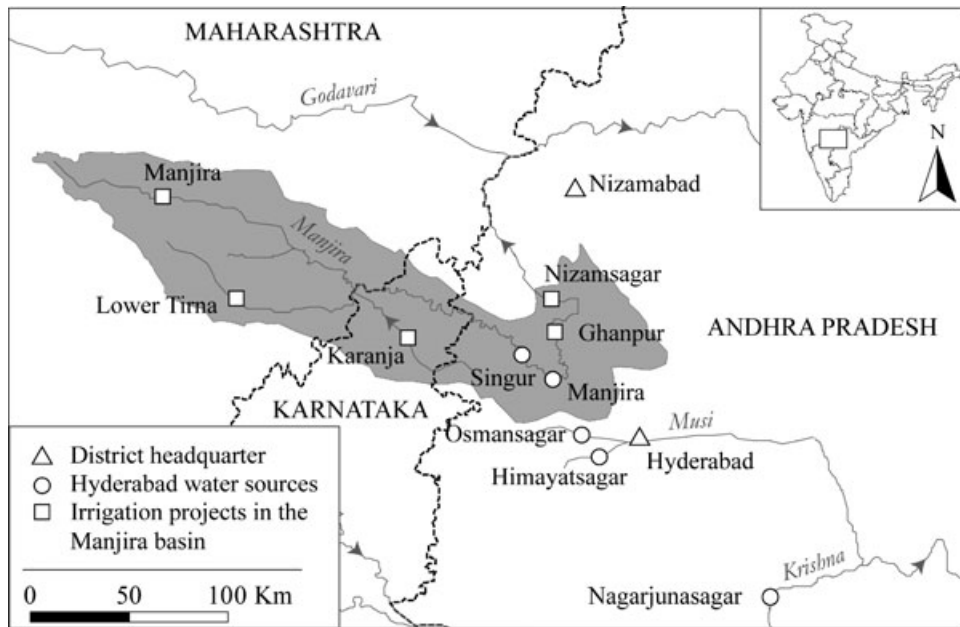


Figure 1 Hyderabad's water sources and the catchment area of the Nizamsagar irrigation project (grey area)

it supports are largely rural based, the result of these changes can be rural–urban competition and conflict. The city of Hyderabad is in numerous ways an exemplar of the resulting water challenge, both within India and globally.

Hyderabad, capital of the state of Andhra Pradesh in south India (Figure 1) is the fastest growing large city in India and now has an estimated 7 million inhabitants (HUDA 2003), up from 4.3 million in 1991. This growth, boosted in particular by economic reforms introduced by the government to promote foreign and national investments (Naidu and Ninan 2000; Kennedy 2007; Shifferes 2007), has increased urban water demand for domestic, commercial and industrial uses. One reason for urban population growth is migration enticed by a vibrant economy which has grown at an average rate of 8.73% per year between 2004–5 and 2007–8 (Government of Andhra Pradesh and Centre for Economic and Social Studies 2008).

As in much of peninsular India, Hyderabad is an area where water was already in short supply. To meet Hyderabad's new demands, the city was left with few options but to appropriate water from the surrounding area where it had already been claimed by agricultural users. Use in agriculture has been supported by significant and continuing investment in irrigation infrastructure over the past 50 years. In 2005–6, for example, the Andhra Pradesh State government had an irrigation budget of approximately US\$1.5 billion,

equivalent to 40% of its total annual expenditures (budget data drawn from Rosaiah 2005). Not surprisingly, massive urban growth in a state where most available water resources have already been allocated, and where there remains high livelihood dependence on agriculture, has engendered conflicts between the rural and urban sectors (Celio and Giordano 2007b). Understanding this conflict requires an analysis of the mechanisms employed to capture water for the city.

Hyderabad's water appropriation

At its founding in 1591 and through its early history, Hyderabad derived its water supplies from 'tanks' (manmade lakes) and groundwater tapped through shallow dug wells. At the beginning of the twentieth century, the seventh Nizam of Hyderabad, H.E.H. Osman Ali Khan, commissioned the construction of two reservoirs approximately 8 km upstream of the city: the Osmansagar on the Musi River and the Himayatsagar on the Esi (Mudiraj 1934), both tributaries to the Krishna, a major river draining parts of the three south Indian states of Karnataka, Andhra Pradesh and Maharashtra.

Between 1965 and 1993, the city's supplies were augmented from 75 to 250 million m³ per year (Mm³/year) through the conveyance of 175 Mm³/year of water from the Manjira and Singur reservoirs along

the Manjira River, a tributary of the Godavari originating in the neighbouring state of Maharashtra. After traversing Karnataka state, the Manjira joins the Godavari River in Andhra Pradesh. Singur was the largest water source for Hyderabad until 2005, when additional water was appropriated from the Nagarjunasagar irrigation reservoir located on the main stem of the Krishna river, over 135 km south of the city (Figure 1), and requiring a pumped lift in excess of 400 m in elevation.

How these water transfers were enabled, the responses they engendered from farmers and their representatives, as well as their hydrologic and agricultural impacts require an understanding of the physical and socio-economic setting of the state and associated developments in the Krishna and Godavari rivers and their tributaries (Venot *et al.* 2007). The geography of agriculture water in itself is complex with upstream and downstream groups in multiple regions of the state claiming water for farming.

Regional and historical determinants

Andhra Pradesh has historically been divided into three geographical regions: Telangana in the north; Rayalseema in the south; and Coastal Andhra in the east. Inter-regional economic disparities and the politicisation of regional identities have long affected State politics and elections (Suri 2002), and it is often within a regional discourse that political forces have contested economic resources and claimed entitlements to, among other things, water. In fact, an outstanding feature characterising the political discourse over water in Andhra Pradesh is its regionalisation, i.e. its subtle blending within general debate over regional disparities, injustices and secessionist claims within the State.

In 1953 the Indian government appointed the States Reorganization Commission to put forth recommendations on the formation of new states after India gained independence from British rule in 1947. The state of Andhra was formed in the same year by combining the economically underdeveloped state of Rayalseema with its wealthier neighbour, Coastal Andhra. To facilitate integration, the formation was conditioned on the implementation of the 1937 Sri Bagh Pact, which in part related to the use of water resources. In particular, the pact was meant to protect the economically weakest Rayalseema region from water capture by Coastal Andhra: 'to ensure the rapid development of the agricultural and economic interests of Rayalaseema . . . to the level of those in the coastal districts, schemes of irrigation should, for a period of ten years or such longer period as conditions may necessitate, be given a preferential claim' (Rao 1972). The Commission further suggested the joining of Andhra with the Telangana region of the Hyderabad

State, specifically positing that 'the advantages of the formation of [Andhra Pradesh] are obvious. The desirability of bringing the Krishna and Godavari river basins under unified control, the trade affiliations between Telangana and Andhra and the suitability of Hyderabad as the capital for the entire region are in brief the arguments in favour of the bigger unit' (Government of India 1955, 106).

The desirability of constituting the new State was contested from the outset by leaders in Telangana, because of regional disparities and fears of economic subjugation by the wealthier Coastal Andhra region. In spite of opposition, Andhra Pradesh was formed on 1 November 1956, when the leaders of Telangana and Andhra State signed the so-called 'Gentlemen's Agreement' (Forrester 1970), another example of conditionality meant for safeguarding the interests of the weakest, in this case Telangana, in resource sharing. Notwithstanding the provisions of the agreement, in the years following the formation of Andhra Pradesh the existing regional disparities were only accentuated (Acharya 1979). This led in 1969 to the outbreak of a major agitation demanding a separate Telangana State and resulting in more than 5000 arrests and nearly 40 deaths by police firing. A second major agitation seeking bifurcation of the State broke out in 1973. Disparity over access to water and irrigation facilities between the three regions was among the factors that contributed to the agitations (Forrester 1970), and it is still among the arguments exploited today by regional political leaders for justifying – or contesting – water resources appropriation. This demonstrates the complexity of contested claims to irrigation supplies, in which the growing city increasingly exerted its influence to capture water.

Hyderabad water supply from the Manjira River

Impelled by the urban growth that followed the formation of Andhra Pradesh and the deepening gap between water demand and supply, work was started in the 1960s to convey water to Hyderabad from the Manjira River, a tributary of the Godavari, at a take-off point located around 60 km northwest of the city. Water from the Manjira Reservoir was first conveyed to Hyderabad in 1965 (Figure 2). Because the water supply was still insufficient to meet demand, in 1972 the Government of Andhra Pradesh appointed the Sreenivasarao expert commission to recommend options for augmenting the Hyderabad water supply. Groundwater was deemed inappropriate, since it was scarce and pollution prone. The Manjira River was already largely committed to agricultural uses, and the Godavari River was eliminated based on costs. The commission therefore suggested in 1973 to conduct further investigations for drawing water from the Krishna River (Government of Andhra Pradesh 1973).

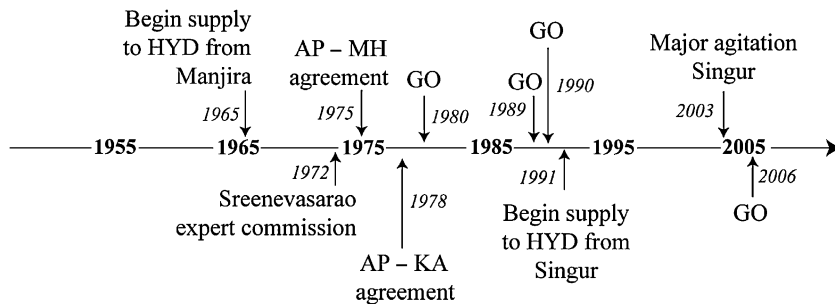


Figure 2 Milestones in water supply to Hyderabad from the Manjira River mentioned in the text. AP: Andhra Pradesh; HYD: Hyderabad; MH: Maharashtra; KA: Karnataka; GO: Government Order

Rejecting these recommendations, and despite the fact that the water was already entirely committed to agriculture, in 1975 and 1978 the government of Andhra Pradesh signed two separate agreements with the states of Maharashtra and Karnataka (upstream riparian on the Manjira) for withdrawing an additional 113 Mm³ of water annually from the Manjira river for the supply of Hyderabad. Consistent with the agreements, the construction of the Singur reservoir across the Manjira, with a storage capacity of 850 Mm³, was started. The system to convey the water to Hyderabad was completed in two phases, one in 1991 and one in 1993 (Government of Andhra Pradesh 2005a).

In the reallocation from the Manjira River, the primary allocation issue was between Hyderabad, the junior water user, and Ghanpur and Nizamsagar irrigation projects, the senior users. The issue was addressed by allocation 'rights' through the iconic tool for administrative authority in India – the Government Order (GO) – issued by the Government of Andhra Pradesh in 1989. The GO stipulates that Hyderabad is entitled to 197 Mm³ of water annually from Manjira and Singur; whereas Ghanpur and Nizamsagar reservoirs are allocated 352 Mm³. In dry years, these amounts might not be available. However, an additional GO was signed in 1990 which gave Hyderabad priority over agricultural uses when storage was insufficient, and which specified operational rules to regulate, and if required bar, water releases for agricultural purposes (Celio and Giordano 2007a). Both the 1989 and 1990 GOs appear to provide evidence that Hyderabad sought to capture water progressively not simply by direct appropriation but also by mobilising the institutional means for its control via specific reservoir operating rules. This follows the appropriation hypothesis advanced above as the proposition that cities produce the physical movement of water through manipulation of the institutions for its management, in this case, the Irrigation Department.

In contrast, the Government of Andhra Pradesh had earlier issued a GO in 1980 to provide 57 Mm³ of water from Singur to farmers located just downstream from the planned reservoir. This 'pro-agricultural' GO, however, was never implemented, and in April 2003, 1 year before the general elections in Andhra Pradesh, a major agitation demanding the implementation of the 1980 GO occurred, led by political leaders affiliated with the opposition Indian National Congress Party (INC). Following their victory in the 2004 elections, the INC Government issued a new GO in 2006 ordering the implementation of the 1980 GO. For the purposes of our analysis, physical resource appropriation was effected through a decades-long institutional process of political capture of political decision-making.

Hyderabad water supply from the Krishna River

While increasing the transfers from the Manjira, in 1986 the Government of Andhra Pradesh appointed the Sri J. Raja Rao expert commission to submit technically and economically sound alternatives for further augmenting the Hyderabad water supply from other sources. The options considered by the commission were the Krishna River as well as the Godavari (Government of Andhra Pradesh 1987). In its final report, the commission recommended drawing the required 467 Mm³ of water annually from Nagarjunasagar reservoir of the Krishna basin. While this would require a reallocation from the agricultural sector, the expert commission pointed out that priority had to be given to drinking water over irrigation, quoting from a landmark report of the India Irrigation Commission that was issued some years earlier (Government of India 1972), as well as from the award of the Krishna River Disputes Tribunal given in 1976 (Government of India 1973/1976)¹. Moreover, the

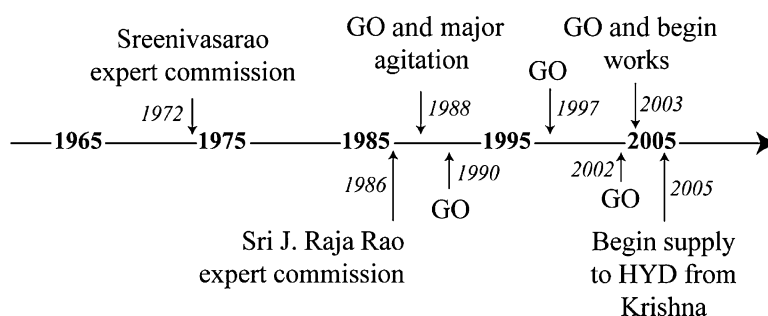


Figure 3 Milestones in water supply to Hyderabad from the Krishna River mentioned in the text. GO: Government Order; HYD: Hyderabad

commission put forth criteria for urban appropriation priority, by asserting that ‘the water supply to Hyderabad city which is the capital of Andhra Pradesh state where people belonging to all the districts of the state are living, is to be treated on par, if not on a higher priority, than the schemes already taken up from Krishna river’ (Government of Andhra Pradesh 1987, 11).

Endorsing the recommendations of the expert commission, the Government of Andhra Pradesh issued a GO in August 1988 sanctioning the supply of water to Hyderabad from the Krishna River (see timeline on Figure 3). This decision, the first ever official sanctioning of the transfer of water from Krishna to Hyderabad, occurred in a climate of particularly tense political relations between the ruling Telugu Desam Party (TDP) and the INC (Bhaktavatsalam 1991). In this sensitive political climate, the decision of the government to take up the Krishna project brought about vehement agitation by legislators of the INC who organised sit-ins in the State Legislative Assembly, accentuated by hunger strikes by some party members from Rayalseema, the southern, dry region of Andhra Pradesh most affected by Hyderabad’s water appropriation from the Krishna (*Deccan Chronicle* 1988). Allegations of regional disparities and discrimination were put forth during the protest. In particular it was argued that before bringing water to Hyderabad, the government had to provide Rayalseema with its due share of water, as allocated by the Krishna Waters Dispute Tribunal and according to the specifications of the Sri Bagh Pact of 1937 (Government of Andhra Pradesh 1988).

The TDP lost the elections in 1989 and in January 1990 the newly elected INC Chief Minister appointed another expert commission, whose recommendations led the government to sanction the withdrawal of 467 Mm³ annually from the Krishna River, at Nagarjunasagar reservoirs (D’Souza 2006). The period of time from 1990 to 1994, during which the INC remained in power, was characterised by high

political instability, strong factionalism within the INC, and Hindu-Muslim communal violence in Hyderabad that shifted the concern of the political class from Hyderabad’s increasing water needs. As a result, the project to supply water from the Krishna River did not go further than the foundation stone. However, the withdrawal from the Krishna was again sanctioned through GOs issued in 1997, 2002 and 2003, outcomes influenced by the exceptionally low rainfall in 2001 and 2002, which put the city under severe water stress (*The Hindu* 2003). This immediate water crisis, together with concern over the dependence on only one major water source and the chronic water deficit in Hyderabad, were important factors that eventually triggered the Government of Andhra Pradesh formally to commence the allocation of water from the Krishna River to the city in 2003. Having demonstrated that Hyderabad captured water physically and institutionally by resorting to ‘scarcity’ and ‘crisis’ discourse, it can be assumed that hydrologic impacts are experienced in the source basins causing, in turn, changes in agriculture.

Water transfer to Hyderabad: hydrologic and agricultural impacts

As discussed above, water transfers to Hyderabad have been stridently opposed on arguments of regional disparities and the assumption that reallocation will have negative impacts on the areas of origin and on agriculture in particular. By quantifying the impact of the water transfer to Hyderabad from the Manjira River, this section examines this assumption. The following subsection addresses the impact of water transfer to Hyderabad on surface canal water deliveries from Nizamsagar, the reservoir which supplies water to the largest irrigation district affected. The second subsection estimates agricultural groundwater use, both to show its role in overall agricultural water use and to examine this as a principal adaptive strategy by farmers. Drawing from these results, the

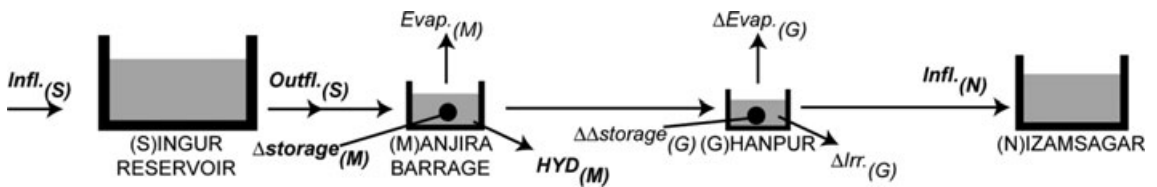


Figure 4 Schematic of the Manjira basin reservoirs and water transfer to Hyderabad. Infl.: inflow; Outfl.: outflow; Evap.: evaporation; Δ storage: variation in storage; HYD: water transfer to Hyderabad. Specifically for Ghanpur: Δ Irr.: difference in water use for irrigation with versus without water reallocation; $\Delta\Delta$ storage: difference in variation in storage with versus without water reallocation; Δ Evap.: difference in evaporation with versus without water reallocation. Parameters that have to be calculated are written in plain text, whereas those for which data are available are in bold

final subsection examines the implications of the surface water transfer to Hyderabad on agricultural productivity and gross agricultural revenue in Nizamsagar irrigation command area.

Canal water use for irrigation under Nizamsagar without water transfer to Hyderabad

The primary goal of this section is to examine the hydrologic impacts of Hyderabad's water capture by determining, season-wise, how much surface water would have been used for irrigation at Nizamsagar had the transfer not taken place. This is done using a simple monthly water balance of the Manjira River in three steps to assess what inflow Nizamsagar irrigation reservoir would have received if water had not been transferred to Hyderabad; to determine how much canal water would have been used for irrigation using the inflow that Nizamsagar would have received without reallocation as calculated in the previous step; and to establish monthly water releases for irrigation from Nizamsagar according to water availability in the reservoir and monthly water requirements of the standing crops.

The monthly inflows that Nizamsagar reservoir would have received without the transfer are first determined through a simple water balance between Singur and Nizamsagar as shown in Figure 4 and calculated in equation (1).

$$Infl'_{(N)} = Infl_{(N)} + \frac{\text{WaterUse}_{\text{Singur}}}{\text{WaterUse}_{\text{ManjiraBarrage}}} + \frac{(\text{Evap}_{(M)} + \text{HYD}_{(M)} + \Delta\text{storage}_{(M)})}{\text{Difference}_{\text{WaterUse}_{\text{Ghanpur}}}} * \alpha - \frac{(\Delta\text{Evap}_{(G)} + \Delta\text{Irr}_{(G)} + \Delta\Delta\text{storage}_{(G)})}{\text{Difference}_{\text{WaterUse}_{\text{Ghanpur}}}} \quad (1)$$

Equation (1) states that the inflow to Nizamsagar ($Infl'_{(N)}$) without transfer to Hyderabad is equal to the actual Nizamsagar inflow ($Infl_{(N)}$) plus the sum of the water that has been used (retained) at Singur and the water used at the Manjira Barrage multiplied by a

factor α to account for conveyance losses. Water use in Singur reservoir is calculated as the difference between inflow ($Infl_{(S)}$) and outflow ($Outfl_{(S)}$). Water use in Manjira Barrage is calculated as the sum of evaporation ($Evap_{(M)}$), transfer to Hyderabad ($HYD_{(M)}$) and change in storage ($\Delta\text{storage}_{(M)}$), since inflow and outflow data at the barrage are not available. Water use in the Ghanpur irrigation project would also have been different without the transfer and is accounted for in the last part of equation (1), which specifies the difference between evaporation ($\Delta\text{Evap}_{(G)}$), water use for irrigation ($\Delta\text{Irr}_{(G)}$), and storage ($\Delta\Delta\text{storage}_{(G)}$) with and without the water transfer to Hyderabad.

Reservoir inflow and outflow data, including transfers to Hyderabad, were collected from the Irrigation and Command Area Development Department of Andhra Pradesh (hereafter referred to as the Irrigation Department). Values of monthly evaporation from the water bodies were calculated by multiplying potential evapotranspiration (PET), obtained from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in nearby Patancheru, by a constant spread area equivalent to half the surface area at maximum elevation². Differences in irrigation use were calculated with data from the Irrigation Department. Finally, a value of 0.6 was used for α . This is the same value used by Andhra Pradesh irrigation managers and is calculated based on the historic record, considering water releases from Singur and inflows to Nizamsagar, but without taking into account Ghanpur withdrawals (Nizamabad District Irrigation Advisory Board 2005).

The difference between evaporation ($\Delta\text{Evap}_{(G)}$) and storage change ($\Delta\Delta\text{storage}_{(G)}$) at Ghanpur with and without water transfer to Hyderabad can be assumed to be nil, since the differences are expected to be low and offsetting when aggregated at an annual time step. Thus, equation (1) can be rewritten as:

$$Infl'_{(N)} = Infl_{(N)} + [(Infl_{(S)} - Outfl_{(S)}) + (\text{Evap}_{(M)} + \text{HYD}_{(M)} + \Delta\text{storage}_{(M)})] * \alpha - \Delta\text{Irr}_{(G)} \quad (2)$$

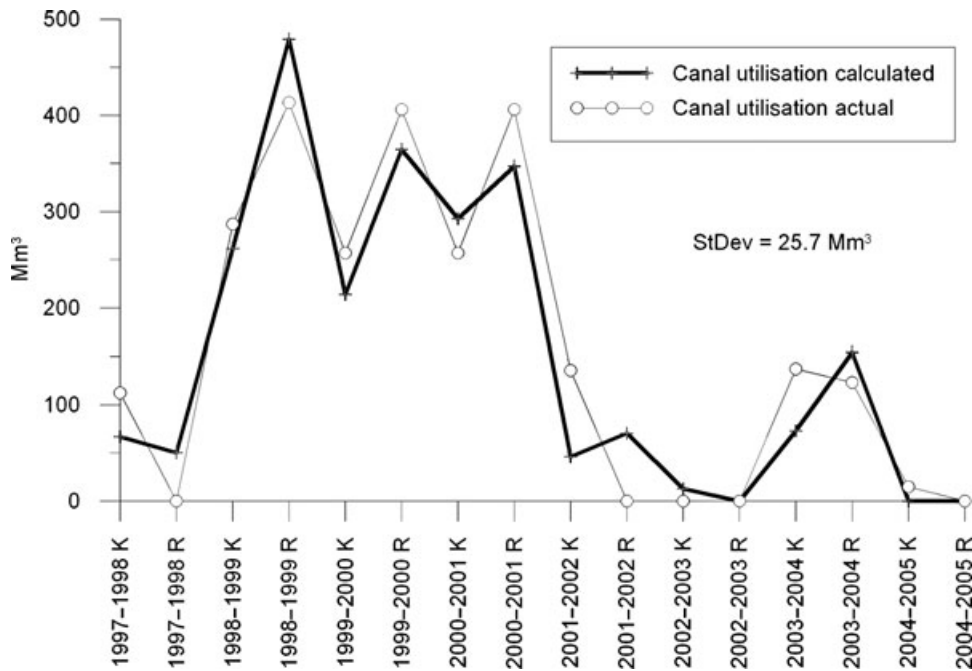


Figure 5 Season-wise canal utilisation at Nizamsagar, actual and calculated. R: Rabi; K: Kharif

The last parameter that needs to be discussed here is the difference between actual water withdrawals at Ghanpur for irrigation and theoretical withdrawals if the water transfer to Hyderabad had not taken place ($\Delta Irr_{(G)}$). Ghanpur has a storage capacity of just 5.7 Mm³, and partially acts as a weir diverting the Manjira waters to left and right-bank lateral canals. Because daily irrigation diversion data are not available, values were simulated based on the assumption that if more water were to be received in Ghanpur without transfer, then $\Delta Irr_{(G)}$ is equal to half this extra volume³, subject to the condition that actual water use for irrigation plus $\Delta Irr_{(G)}$ does not exceed the maximum monthly withdrawal capacity for irrigation. Conversely, if less water is received from upstream without transfer, $\Delta Irr_{(G)}$ equals the monthly deficit, provided that actual water use for irrigation less the deficit is not less than zero.

Monthly canal water use for irrigation under Nizamsagar in the without transfer scenario is calculated by applying a separate simple monthly water budget at Nizamsagar. Monthly inflows without transfer are calculated using equation (2). Outflows consist of evaporation losses, surplus discharge, and water use for irrigation. Since these three parameters depend upon the available storage at a given time in Nizamsagar reservoir, the water balance is:

$$Storage_{(t)} = Storage_{(t-1)} - Evap_{(t-1)} - Irr_{(t-1)} + Infl'_{(t)} \quad (3)$$

That is, monthly storage ($Storage_{(t)}$) is equal to storage in the previous month ($Storage_{(t-1)}$) less evaporation ($Evap_{(t-1)}$) and irrigation diversion ($Irr_{(t-1)}$), plus inflow ($Infl'_{(t)}$) for the previous month. Monthly storage is limited to the storage capacity of Nizamsagar reservoir of 504 Mm³ with any excess discharging as surplus. Evaporation is calculated as described for equation (1) above. Water use for irrigation ($Irr_{(t)}$) under Nizamsagar is modelled according to a set of operational rules which specify how much water is to be released each month. These releases in turn depend on the availability of water in the reservoir and the specific time of the year. Before calculating canal water use for irrigation without transfer, the model is tested by applying equation (3) with the actual inflow in Nizamsagar (instead of $Infl'_{(t)}$), and the calculated versus actual values of canal water use for irrigation (with transfer) are compared⁴. The results follow the trends in actual canal use and the standard deviation between actual and calculated values – in the order of one-tenth of the mean values – shown in Figure 5 indicate that the model is robust⁵.

Annual water use at Nizamsagar with and without water transfer is shown in Figure 6, which also reports

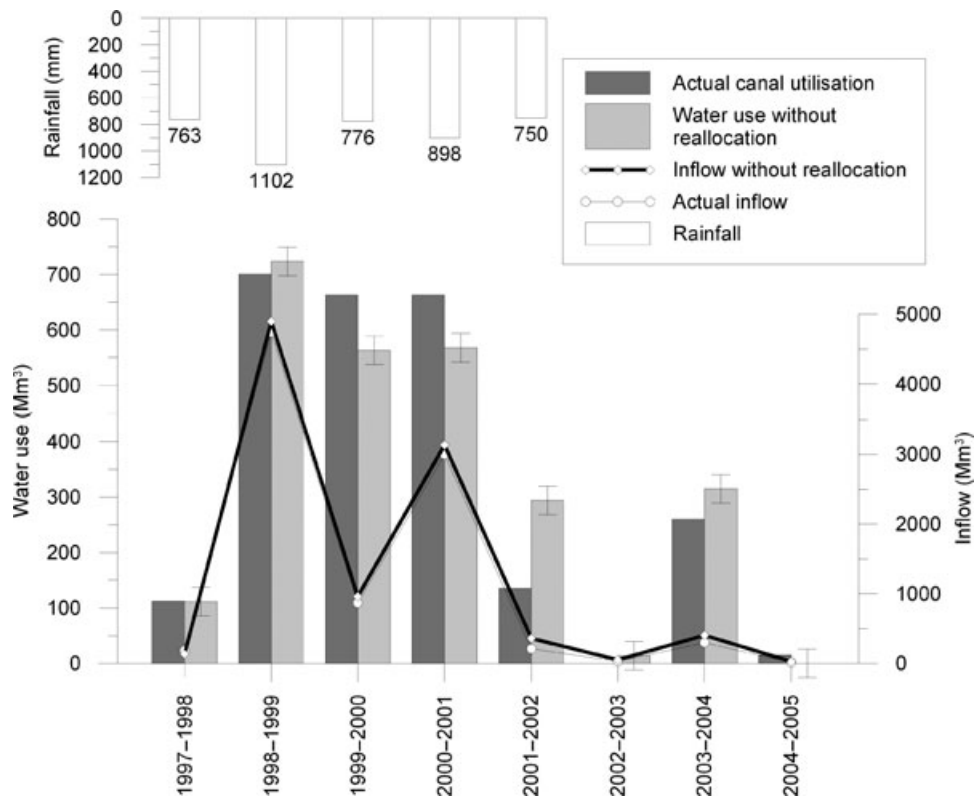


Figure 6 Inflow and canal utilisation at Nizamsagar, actual and calculated, and rainfall in the catchment area of Nizamsagar. The vertical error bars on water use at Nizamsagar without reallocation represent the calculated standard deviation

Source: rainfall data are drawn from Mitchell and Jones (2005) and are available up to 2002

the actual inflow and the Nizamsagar inflow without transfer. During years with above average rainfall, e.g. 1998–9, 1999–2000, and 2000–1, Nizamsagar inflow is sufficient to fill the 504 Mm³ reservoir, and canal water use exceeds the maximum reservoir capacity. In these cases, the water reallocation to Hyderabad has no impact on agriculture and differences between water use with and without transfer are due to the distribution and intensity of the precipitation during the rainy season. This explains why in 1999–2000 and 2000–1 more canal water was used under Nizamsagar with transfer than without. Conversely, with low annual rainfall over the Manjira basin, transfer to Hyderabad induces canal water scarcity and reduces use for irrigation. This can be seen in Figure 6, in particular for 2001–2 (158 Mm³ of additional water used for irrigation), and 2003–4 (54 Mm³). For the very dry years of 1997–8, 2002–3 and 2004–5, the difference between water use with and without reallocation to Hyderabad is very low, largely because

water is so scarce that little would have gone to irrigation anyway. This finding may be considered to be counter-intuitive, and demonstrates how essential it is to assess impacts through rigorous, quantitative analysis. What follows is a continued effort to understand hydrologic and agricultural implications of farmers' adaptive response – pumping groundwater – in the face of continued urban appropriation of river water.

Groundwater use

Because of data limitations, the goal of this section is not to estimate how agricultural groundwater use responded to changes in surface water availability. Rather, it is to examine the magnitude of groundwater use in the overall agricultural system and thus provide perspective on the impact of surface water transfer. In addition, it is to highlight the possibility of agricultural groundwater use as an adaptive mechanism to urban

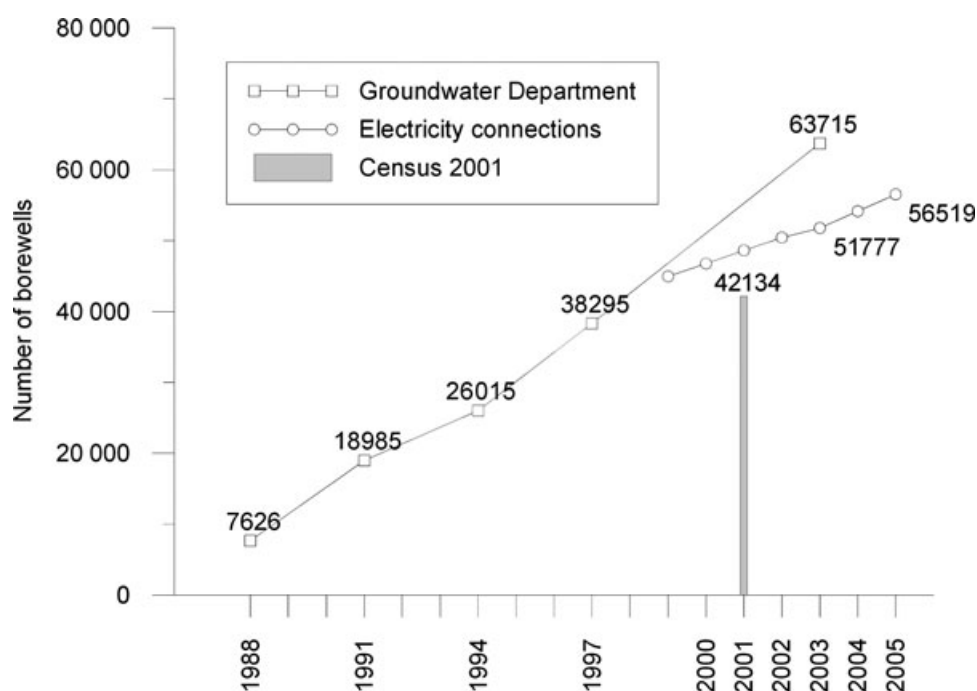


Figure 7 Number of borewells in Nizamsagar command area by source

Source: Government of Andhra Pradesh (2005b); India Census (2001); and Northern Power Distribution Company of A.P. Ltd, Nizamabad Operation Circle

water appropriation, an issue revisited in the discussion section.

Determining groundwater use in agriculture is difficult, and different estimation methods will produce different results. To address this issue, two methods are applied here to estimate plausible upper and lower bounds of agricultural groundwater use in the Nizamsagar command area. The upper bound is calculated by multiplying the active number of borewells in the command area by their average discharge scaled by an estimated daily pumping duration. Figure 7 shows the number of borewells in the Nizamsagar command area, based on a report of the Groundwater Department of Andhra Pradesh (Government of Andhra Pradesh 2005b), the 2001 Census of India and the number of electricity connections registered as 'agricultural services' by the Andhra Pradesh State Electricity Board. As diesel pumps are rarely used in peninsular India, these electricity connections correspond to the number of active borewells. For the calculations presented here, the electrical connection estimates, lying between the other two, are applied.

Average pumping capacity is estimated at 150 litres per minute based on February 2005 field data collected in Nalgonda and Rangareddy Districts, Andhra Pradesh in the Musi river catchment (Massuel *et al.*

2007). Pumping duration is estimated based on the assumption, substantiated through fieldwork (Shah *et al.* 2003b), that with free agricultural power supply, farmers permanently leave their pumps on during the growing season. However, as electricity supply is intermittent, pumping duration is assumed equal to the hours of actual supply in the cropping season. According to primary data collected among 219 farmers' households, this is 7 h/day in the crop growing periods. The weakness of this assumption is that aquifers do not always hold water, and so pumping duration may actually be lower than the time of electricity supply. While such conditions are generally less common in canal-irrigated command areas (where aquifers receive irrigation return flows), such as Nizamsagar as compared with areas without surface irrigation, this assumption may still result in an overestimation of use. The final variable, total crop duration, was estimated at 270 days/year (132 days in *Rabi* – the dry cropping season, December–May, and 139 days in *Kharif* – the wet cropping season, June–November), based on information collected in the same survey. Based on these data and assumptions, maximum annual groundwater withdrawals are estimated to have varied between 764 and 921 Mm³ from 1999–2000 to 2004–5 as shown in Table 1.

Minimum agricultural groundwater use estimates were made by inferring groundwater use from land-use data and empirical relations derived from field observations by Dewandel *et al.* (2007) in the Gajwel area, located approximately 100 km southeast of our study area and characterised by similar aquifer geology and soils, socio-economic conditions and crop types. These relations for *Kharif* and *Rabi* rice and the other crops, for which the relations were calculated (tomato, chilli, maize, sunflower, and curry leaves), are shown in equation (4):

$$\text{GroundwaterUse (m}^3\text{)} = \text{AreaCultivated (m}^2\text{)} * \text{GrowthDuration (days)} * \beta \quad (4)$$

where β is the empirically derived daily crop water demand equal to 0.0144 for *Rabi* and 0.0103 for *Kharif* for rice; and 0.0115 for *Rabi* for tomato, chilli, maize, sunflower and curry leaves.

Using these formulae and data on the area cultivated by crop from the State Directorate for

Economics and Statistics of Andhra Pradesh, groundwater use in Nizamsagar command area was calculated for 2002–3 and 2004–5 when groundwater was the only source of irrigation⁶. The results are presented in Table 2. However, since empirical correlations between groundwater use and the production of some other minor crops (maize and pulses in *Kharif*) were not available, the groundwater extraction figures appearing in column [E] may be somewhat of an underestimate. The overall results of the two methods result in a difference in estimated 2002–3 and 2004–5 groundwater withdrawals of some 20%. The implications of these groundwater use figures are explored further below.

Urban water appropriation and implications for agriculture

To calculate the impact of the surface water transfer on agriculture, we use two basic assumptions. The first is that the impact of reduced canal flows induced by the Hyderabad transfer is solely reflected in variations in rice area. This simplifying assumption has been corroborated by field survey and interviews. The second assumption is that groundwater use is not contingent upon surface water availability; that is, farmers withdraw the same volume of groundwater with or without the water transfer to Hyderabad⁷. This assumption is partially validated through field observations of farmers' pumping behaviour being limited by hours of electrical power supply, given that power is not metered (see discussion below).

Applying these two assumptions, the change in rice area caused by reduced canal flows can be calculated using equation (5) and the same crop water use coefficient applied for groundwater⁸ in equation (4), i.e.

$$\Delta \text{AreaCultivated} = (\text{Irr}'_{(N)} - \text{Irr}_{(N)}) / \beta / \text{GrowthDuration (days)} \quad (5)$$

Table 1 Maximum groundwater withdrawals in Nizamsagar command area from 1999–2000 to 2004–5

Year	Number of working borewells	Annual withdrawals (Mm ³ /year)
1999–2000	44 943	764
2000–1	46 739	795
2001–2	48 607	827
2002–3	50 402	857
2003–4	51 777	881
2004–5	54 137	921

Note: number of borewells for 1999–2000 and 2000–1 has been inferred from linear extrapolation of existing data from 2001–2 to 2004–5. Annual withdrawals estimated by the authors

Table 2 Area cultivated (ha) and groundwater use (Mm³) in Nizamsagar command area for 2002–3 and 2004–5

Year	Season	Rice		Sunflower		Maize		Total pulses		GW use [E] = [A] + [B] + [C] + [D]
		Area cult.	GW use [A]	Area cult.	GW use [B]	Area cult.	GW use [C]	Area cult.	GW use [D]	
2002–3	<i>Kharif</i>	38 979	558	0	0	2138		4608		558
	<i>Rabi</i>	7444	140	2346	25	1240	14	3200	33	213
	Total	46 423	698	2346	25	3378	14	7808	33	771
2004–5	<i>Kharif</i>	21 486	308	0	0	2727		5674		308
	<i>Rabi</i>	4909	93	18 083	195	980	11	3878	40	339
	Total	26 395	400	18 083	195	3707	11	9552	40	647

Source: area statistics from Andhra Pradesh Directorate for Economics and Statistics, use estimated by the authors

Note: excludes groundwater use for non-rice crops in *Kharif*

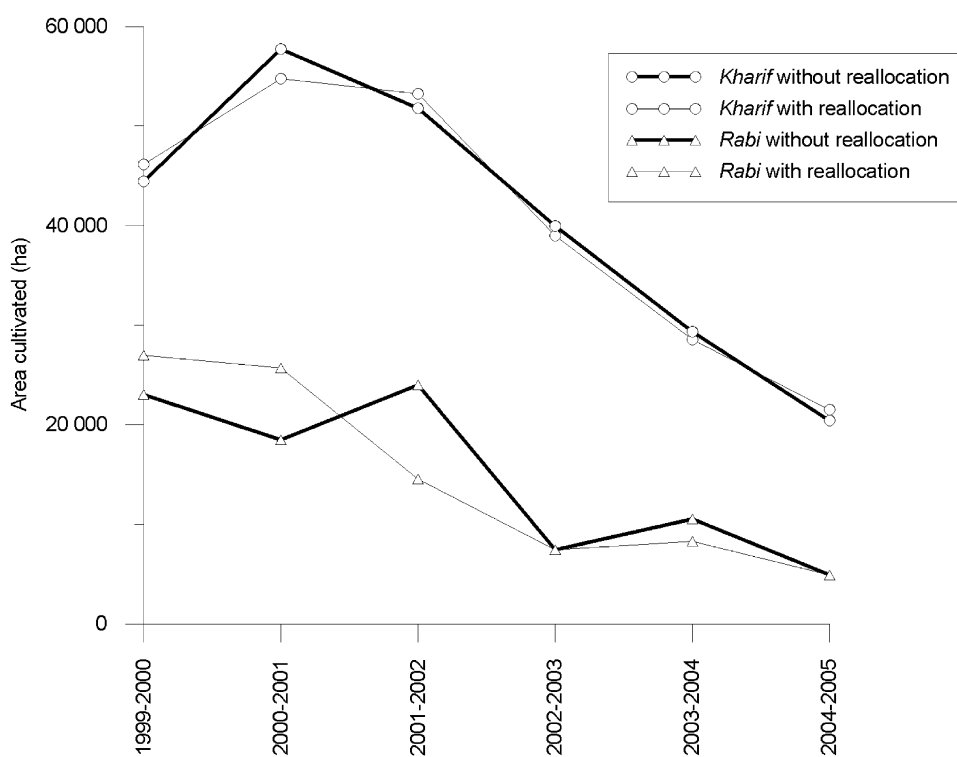


Figure 8 Seasonal area cultivated under paddy in Nizamsagar command area, actual (with water transfer to Hyderabad) and calculated (for the scenario without water transfer)

where $Irr'_{(N)}$ is canal utilisation without transfer, $Irr_{(N)}$ is actual utilisation with transfer, and β is the same coefficient as for equation (4). The seasonal results with and without transfer are shown in Figure 8. Of particular interest are the results for the 1999–2000 and 2000–1 *Rabi* areas, which are higher with transfer than without. This could be explained by releases from Singur to Nizamsagar in the *Rabi* season required by the GOs of 1989 and 1990 on Manjira water sharing between agriculture and Hyderabad (Celio and Giordano 2007a). Without transfer, in the *Rabi* season, there would normally not have been inflow to Nizamsagar. Thus the result is that appropriation, when coupled with new operating rules and a particular precipitation regime, resulted in a net advantage to agriculture in Nizamsagar, at least during some seasons.

Also shown in Figure 8 is a clear downward trend in rice production in both the *Rabi* and *Kharif* seasons. However, there is virtually no difference between the area cultivated with paddy with and without reallocation to Hyderabad in *Kharif*. This strongly suggests that the water transfer to the city cannot be linked to the overall decline in rice observed over the period.

Summarising these findings, Table 3 shows calculated production of rice and related gross revenue with and without reallocation to Hyderabad. It shows that gross revenues from agriculture in Nizamsagar command area have fluctuated as a result of the transfer – but not necessarily detrimental – from a gain of US\$2.3 million in 1999–2000 to a loss of US\$3.2 million in 2001–2. Rice yields (tonnes/ha) and sale prices (US\$/tonne) used for calculating production and gross revenue are inferred from primary data collected from 80 survey respondents located within the Nizamsagar command area⁹.

Discussion

This section synthesises the paper's principal analyses (mechanisms of water capture, appropriations from agriculture, hydrological impacts, farmers' responses, and agricultural outcomes). With rampant urbanisation and increasing water resources variability, the pressure to reallocate water from agricultural to urban uses through outright capture, appropriation of irrigation infrastructure, modified infrastructure operations, and high-level institutional manipulation will

Table 3 Production of rice and gross revenue with and without transfer to Hyderabad (production is in tonnes; gross revenue in million US\$)

Year	Production with reallocation [A]	Production without reallocation [B]	Difference in production [C] = [B] – [A]	Gross revenue with reallocation [D]	Gross revenue without reallocation [E]	Difference in gross revenue [F] = [E] – [D]
1999–2000	143 359	132 124	–11 235	30.1	27.8	–2.3
2000–1	157 569	148 924	–8645	33.2	31.5	–1.7
2001–2	132 386	148 337	15 950	28.1	31.3	3.2
2002–3	90 530	92 436	1906	19.3	19.7	0.4
2003–4	71 944	77 987	6043	15.2	16.5	1.2
2004–5	51 508	49 445	–2063	10.9	10.5	–0.4

Note: calculations by authors

increase. The intent of this paper is to examine urban water appropriation in its multifaceted complexity, combining analysis of water politics and institutions on the one hand, and hydrological and agricultural production assessment impact and farmers' possible adaptive responses on the other.

Institutional mediation of urban appropriation and agricultural impact

Hyderabad is the case exemplar of administrative water appropriation: the transfer is sanctioned through government administrative orders; agricultural infrastructure, notably water reservoirs, is partially reallocated to the new use; and, as in the case of the Manjira River water institutions, are remodeled so as to mediate the reallocation. Water transfers to Hyderabad have been negotiated upon assumptions of agricultural impact, and vehemently contested, as in the case of the allocation from the Krishna River where the transfer has occurred without compensation and across regions, notably from the backward and water scarce rural Rayalseema region to comparatively wealthy urban Hyderabad in Telangana.

Contestation was comparatively lower for the earlier reallocation from the Manjira River, where water sharing between farmers and the city was mediated by an institutional arrangement that attenuated, and sometimes more than offset, the impact on agriculture. According to the intersectoral water sharing arrangement, Ghanpur and Nizamsagar irrigation projects are entitled to a defined annual volume of water from Singur reservoir, provided that enough water is left in the latter for securing Hyderabad's water supply. Although the arrangement suffered from a number of weaknesses and was not strictly applied, it proved beneficial for farmers in 1999–2000 and 2000–1, when 118 and 153 Mm³, respectively, of water were released from Singur reservoir during the

Rabi season for irrigation purposes (see also Figure 8, where the area cultivated in the *Rabi* season with reallocation to Hyderabad is greater than without reallocation). If the Hyderabad transfer mechanism had not been in place, instead of having been stored in Singur and used in *Rabi* at Nizamsagar, the 271 Mm³ of water would have been 'lost' during the rainy season as flood discharge. The result in these years was an increase in gross revenue from agriculture over what would have occurred had the appropriation process not occurred.

This highlights the potentially mixed consequences of appropriation for farmers and is distinct from conventional wisdom and much existing literature, which generally suggests either that farmers are worse off after reallocation, or benefit only from outright sale (see e.g. Dixon *et al.* 1993; Loeve *et al.* 2004). At the same time, it is important to note that the result presented here is a consequence of the particular hydrologic conditions which prevailed during the study period, the physical infrastructure in place, and the nature of the new operating rules which came into effect at least partially as a response to the contest over appropriation, particularly where politicians successfully negotiating on behalf of farmers derive positive electoral payoffs. The lesson is therefore not that appropriation is uniformly positive for the appropriated, but that the magnitude and even direction of impact will depend on the specific conditions of the place and that impact might be mitigated by well-crafted institutional arrangements.

Can groundwater compensate for urban appropriation?

In addition to pursuing institutional avenues, farmers threatened with surface water appropriation will, in many circumstances, have recourse to locally available groundwater. Surface and groundwater can be

Table 4 Annual groundwater withdrawals and canal utilisation at Nizamsagar (Mm³/year), and groundwater share of total agricultural water use (%)

Year	Groundwater withdrawals	Canal water use (<i>Irr._(N)</i>)	Groundwater share of total water use (%)
1999–2000	764 (612)	663	54
2000–1	795 (636)	663	55
2001–2	827 (661)	136	86
2002–3	857 (686)	0	100
2003–4	881 (705)	261	77
2004–5	921 (737)	0	100

Note: groundwater figures are estimates for maximum and, in brackets, minimum withdrawals

either substitutes or complements ('conjunctive use') in irrigation. Farmers with access to canal irrigation in fact often develop their own groundwater supplies to augment regular surface supplies or to mitigate the risk of surface supplies not being delivered in a timely fashion (Chapman 1983). In the particular case of South Asia, consideration of groundwater is especially important as research has consistently shown that it has become a major source – in some instances the primary source – of irrigation supply, even within the command area of surface irrigation schemes (Deb Roy and Shah 2002; Shah *et al.* 2003a). In addition, the nature of surface and groundwater control provides different opportunities for users to respond to changing water conditions. Surface water irrigation water is often state financed and controlled, as in the case of Andhra Pradesh. In contrast, groundwater access is decentralised, with finance and control largely in the hands of individual farmers (Dubash 2002; Birkenholtz 2008). Thus, groundwater provides a mechanism through which the effects of state-sponsored appropriation may be mitigated by farmers, although with possible implications for long-term water system sustainability.

While discussions of the water transfer to Hyderabad and the implications on agriculture revolved around surface waters, the analysis presented here demonstrates that groundwater is in fact the dominant source of agricultural water in the Nizamsagar area (Table 4). At a minimum, this highlights the need to look at the overall hydrologic system when considering the nature of particular water transfers. It also raises additional questions. The first is whether groundwater use is a direct response to surface water transfer. While groundwater pumping has clearly grown since the transfer began, and we would expect at least some of the growth to be in response to loss of surface water, we are not able to conclude from the

information available whether the changes are causal or merely correlative. Groundwater use is in fact expanding throughout much of India. Sustainability considerations aside for the moment, then, surface water appropriation for urban supply results in a reduction of water for agriculture.

The second question is whether the potential role of groundwater could equitably offset the impacts of surface water transfer. In fact, those farmers affected by induced surface water scarcity are not necessarily those with access to groundwater. Groundwater access requires funds for well drilling and pump purchase and access to energy or the availability of local groundwater markets. The study area is typified by hard-rock aquifers which increase the risk of well-drilling failure and increase expected investment costs. For example, primary data collected from our survey of 219 farm households showed that of 282 borewells drilled, only 118 functioned. High costs limit the possibilities for poor households to drill and maintain their own wells. This problem might be offset to some degree by the presence of groundwater markets, as are found in many parts of India and which can provide groundwater access for those unable to afford drilling and equipment (see e.g. Mukherji 2004). However, our surveys in Ghanpur and Nizamsagar irrigation projects showed that groundwater markets were virtually non-existent, with the area irrigated with purchased groundwater accounting for only 3.8% of the total area irrigated in 2004–5, and 3.2% in 2005–6¹⁰. Thus while groundwater has been called 'democratic' (Shah *et al.* 2007) because of its generally easy and low-cost access, it is not clear in this case at least that the result is one farmer, one vote¹¹.

Even if equity issues could be addressed, the final question is whether increased groundwater use could in fact be seen as a long-term tool to mitigate the contest for and actual impact of water urbanisation. The answer will again be location dependent. In many areas of the world, groundwater is already a limited and overexploited resource (see e.g. Giordano and Villholth 2007). South Asia in general, and south India in particular, are often highlighted as case studies of overuse (see e.g. Liu Changming *et al.* 2001; Reddy 2005). This at least suggests that increased groundwater use is not a solution but rather a postponement of potentially more serious problems in the future.

In fact, the political economy of India's agricultural water sector may make it difficult for groundwater to become part of a long-term solution to the problems surrounding water transfer to agriculture. Electricity is supplied to agriculture free of charge – or on a highly subsidised flat-rate tariff – in many Indian states (Shah *et al.* 2003b; Dubash 2006), encouraging farmers to overuse by not switching off their electric pumping devices and thereby seriously contributing to

groundwater overdraft, or at least suboptimal resource use. Resistance to metering is not simply a financial question but must be viewed as collective muscle flexing on the part of farmers. Given our observations above on the central role Hyderabad city has played in Andhra Pradesh's regional politics and the opposition stance taken by rural interests, it is difficult to imagine the state legislature holding out for metering farm power, as opposed to a flat-rate tariff.

Conclusion

The appropriation of water by Hyderabad from agriculture has entailed capturing not simply the resource, but also in large measure appropriating the infrastructure and institutions for its management. However, farmers have not idly accepted the transfer of 'their' irrigation water to the city. While in the case of the Krishna they stridently contested the transfer, in the Manjira they pursued institutional options including the establishment of two formal water-sharing agreements. Power and struggle may be at the core of urban water appropriation (Meinzen-Dick and Ringler 2008), but the Hyderabad experience shows that mediation is possible and that cities may consider water sharing arrangements as a compromise through which opposition against, and negative impacts of, increases in urban water supply can be softened. These counter examples of outright capture and transfer of water demonstrate the institutional complexities of urban-rural inter-linkages over water.

As evidenced in this case study, however, any institutional solution must be able to address both the spatial and temporal dimensions of rural-urban water transfers. The at times counter-intuitive impacts of water reallocation on agriculture presented here further highlight the complexity in determining costs to the farm sector, possible compensation (Levine *et al.* 2007), and indeed the appropriate institutional responses. The fact that farmers only hold usufruct rights over surface waters, for the State is generally the one vested with ownership rights (Singh 1992), further complicates formal steps to address equity and compensation. Also complicating matters is the role of groundwater as a possible adaptive mechanism and long-term strategy to mitigate the adverse impacts of urban water appropriation. While the causal link in our case study cannot be proven, decreased surface supplies were associated with an increase in groundwater use, and there is no question that surface and groundwater are generally substitutes in agricultural production. Thus, reallocation of surface water can induce additional use of groundwater with the net effect that transfer may be less a reallocation of water than an increase in overall water use. If, or for how long, such an outcome can be sustained, will depend on hydrologic and demand conditions in the area of

interest. In many cases it may be that the problems and true costs of reallocation – economic, social and political – will only make themselves known once groundwater use is no longer an option.

The spatial and temporal variation in outcomes as well as the possible recourse to groundwater suggests that the impacts of surface transfer should not be thought of in terms of a monolithic agricultural sector, but at more disaggregated levels which consider specific winners and losers, for example those upstream or downstream in a system and those with and without access to capital to facilitate adaptation. Equity considerations come therefore to the fore, perhaps particularly in contexts such as India's, where resource access is highly biased towards the better off (Mehta and Shah 2003).

While our analysis has focused on a specific case, the appropriation hypothesis we have presented has broader applicability. In contextual terms, the hypothesis offers explanatory value for urban growth and water capture, as well as a policy opening to offset some of the impacts for pre-existing claims. This is heightened as urban growth and water supply become global challenges. In theoretical terms, our analysis provides additional insights into resource capture as well as rural-urban and human-nature dualities of water itself. Thus, the geography of urban water appropriation encompasses the physical resource, institutional change, evolving power relations and adaptive responses.

Notes

- 1 D'Souza (2002) provides a critical review of India's tribunal system for adjudicating interstate waters, such as the Krishna River.
- 2 The surface at full reservoir level of the Manjira barrage is 600 000 m², whereas Ghanpur is 190 400 m². Because both are stabilisation reservoirs, i.e. intended to 'head-up' water instead of store it, the resulting ET loss estimates are negligible compared with inflow or to irrigation utilisation. $Evap_{(M)}^*$ so calculated ranges around 0.03 Mm³/month, with a maximum of 0.14 Mm³/month. As a comparison, the monthly inflow in Nizamsagar between 1997–8 and 2004–5 has varied between 0 and 2888 Mm³, with an average of 98.9 Mm³. Moreover, taking half the spread area at full elevation is expected to compensate low elevation spread with high when aggregating monthly data to the annual level.
- 3 The daily maximum discharge capacity of all Ghanpur irrigation canals is 1.00224 Mm³, and the volumes of water diverted monthly for irrigation depends upon daily water availability in the Manjira River. Because the water balance in the Manjira River is done on a monthly basis, it is not possible to calculate how much water is withdrawn for irrigation at Ghanpur each month. Assuming that all the additional water available in the Manjira River if water had not been allocated to Hyderabad would be used for irrigation at

Ghanpur might lead to an overestimate. The irrigation canals would not be able to convey all the additional flow in the Manjira River, particularly if concentrated over a few days. To avoid overestimating diversions, we have assumed that only 50% of the additional water available in the Manjira River at Ghanpur can be diverted for irrigation.

- 4 The model is first calibrated with actual Nizamsagar inflows and canal utilisation data, and then used to calculate canal utilisation with Nizamsagar inflows that would have been received without transfer. This assumes that the rules governing Nizamsagar releases are the same with and without water transfer, which is plausible given the prevailing cultivation of paddy rice under canal irrigation.
- 5 The standard deviation is calculated over the differences between actual and calculated canal utilisation in the *Rabi* and *Kharif* seasons (16 points altogether).
- 6 Canal irrigation in 2004–5 can be considered as nil, since only 15 Mm³ of water has actually been released in the irrigation canal from Nizamsagar.
- 7 Since water scarcity and drought are recurrent, the water stored in Nizamsagar reservoir is generally not sufficient to cover all the water needs of farmers in the command area, even if water had not been transferred to Hyderabad. Under these conditions, we may conclude that recourse to groundwater was not primarily driven by the water transfer; therefore, borewell numbers and groundwater withdrawals with and without transfer to Hyderabad would have been similar.
- 8 Although some studies seem to indicate that in India crop yield on groundwater irrigated farms tend to be 1.2–3 times higher than on surface water irrigated farms (Dhawan 1989), there is no evidence showing that surface water and groundwater use for a given crop differ by area.
- 9 Primary data show that between 2004–5 and 2005–6, the average yield in tonnes/ha of rice cultivation is 1.94 for *Kharif* and 1.99 in *Rabi*; whereas the average sale price of rice was US\$214.6 per tonne in *Kharif* and US\$202.7 per tonne in *Rabi* (exchange rate lnR to US\$ = 0.024449).
- 10 The annual percentages are calculated as the average of the *Rabi* and *Kharif* seasons.
- 11 It is worth noting that inequalities in access to surface canal water are also observed in Indian irrigation systems. Notably, farmers located in the tail ends of canals often experience severe water shortages (see e.g. Chapman 1983).

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