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SPONGE CITY: WATER BALANCE OF MEGA-CITY WATER USE AND WASTEWATER USE IN HYDERABAD, INDIA†

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ABSTRACT

Cities are increasingly competing with agriculture for water resources as urbanization unfolds in water-scarce river basins in Asia. This study documents a partial water balance of Hyderabad city, located in the Krishna basin and currently the fastest growing city in India, and gives estimates of its impact on both traditional and wastewater irrigated area. Though previous projects have had significant local impacts on irrigated areas, additional water supply from a major reservoir on the Krishna river to Hyderabad is likely to be a relatively small component of total reservoir releases to irrigated agriculture (5.3–10.2% by 2030). Urban storm water runoff generates a volume of water of the same order of magnitude as the domestic wastewater volume, though the fate of this water vis-à-vis irrigated agriculture is not known. Wastewater irrigation compensates for more than half of the traditional irrigated area water lost, so the urban–agriculture conflict also generates significant opportunities that also need to be considered. However, the impact of wastewater use on crop yields, cropping changes, human health and the environment need to be fully addressed. Copyright © 2005 John Wiley & Sons, Ltd.

KEY WORDS: cities; wastewater; irrigation; reallocation; Hyderabad

RÉSUMÉ

Dans les bassins versant d'Asie aux ressources hydriques limitées, la compétition entre villes et agriculture pour l'accès à l'eau s'accroît à fur et à mesure que les premières s'étendent. Cet article documente une étude de bilan en eau partiel calculé pour la ville d'Hyderabad, située dans le bassin versant de la rivière Krishna et caractérisée par la plus grande croissance démographique urbaine de l'Inde. Le bilan analyse l'impact de la croissante consommation d'eau par la ville sur l'irrigation traditionnelle, ainsi que sur les zones irriguées avec les eaux urbaines usées. Malgré le fait que les projets mis en œuvre jusqu'à ce jour aient eu un impact local considérable sur les surfaces irriguées, des apports en eaux supplémentaires à la ville provenant d'un grand réservoir sur le Krishna n'amèneraient qu'un faible volume d'eau additionnel par rapport aux apports totaux à l'agriculture traditionnelle (5.3–10.2% en 2030). Les ruissellements de pluie en zone urbaine génèrent un volume d'eau du même ordre de grandeur de celui provenant des eaux domestiques usées, mais on ne sait pas sa contribution à l'irrigation. L'irrigation avec les eaux usées compense au moins par la moitié les pertes observées dans les zones irriguées traditionnelles. Ainsi, le conflit entre urbanisation et agriculture présente aussi des opportunités qui méritent d'être considérées, en tenant néanmoins toujours compte du possible impact négatif des eaux usées sur le rendement et le changement des cultures ainsi que sur la santé et l'environnement à long terme. Copyright © 2005 John Wiley & Sons, Ltd.

MOTS CLÉS: villes; eaux usées; irrigation; réaffectation; Hyderabad

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INTRODUCTION

River basins in many arid and semi-arid zones are ''closing'' due to an intensification and expansion of water use. ''Closure'' occurs when all the ''available'' water in the basin is committed and any further development will have an impact on existing users elsewhere. The largest consumer of water in river basins is usually irrigated agriculture, but rapid urbanization and increased urban water demands in water-scarce or closed basins requires the reallocation of water from agriculture. Molle and Berkoff (forthcoming) argue that cities will always ''win out'' in capturing water from agriculture since the economic imperative of the urban population is an irresistible force in de facto water allocation. They show, through a wide range of case studies, that cities succeed in appropriating water from agriculture through many different formal and informal mechanisms. They point out that, in many cases, the costs of the infrastructure development to bring water to a city and distribute it and then manage it far outweigh the cost and difficulty of acquiring new water resources. Urban areas are likely to be effective competitors for water, which could exacerbate evolving water scarcity problems in irrigated agriculture. This is illustrated by the changes in basin-level water balance now being seen in the North China Plain, where the proportion of abstracted water volume used in agriculture has fallen from more than 85% (1970s) to 60–65% in 2000 (MWR-PRC, 2000). Approximately 35% of diverted water is now used for urban and industrial needs.

While urban areas require water for growth, much of that water becomes wastewater. Irrigation using wastewater could compensate to a certain extent for decreases in existing irrigated area due to transfers to urban use. Wastewater is being used as a viable alternative source of water for irrigation in a range of developing countries including: Pakistan (Van der Hoek *et al*., 2002), India (Strauss and Blumenthal, 1990) and Bolivia (Durán *et al*., 2003). It is becoming more commonly acknowledged that wastewater use in irrigation provides an indispensable source of water in water-scarce areas, to farmers who live adjacent to or downstream of a city. Despite prohibition in much existing legislation and policy, the practice has been shown to be widespread. There is a broad agreement among researchers that it is no longer a question of whether wastewater should be used, but how wastewater irrigation can be made more sustainable and safe (Scott *et al*., 2004). Urban expansion impacts the local water balance not only through domestic water demand, but also by changing runoff generation magnitudes from the urbanized area. Urban surfaces generate significant amounts of storm water runoff compared with the pre-urbanized surface. Assessment of the effect of urban area change on the basin water balance and irrigated agriculture should incorporate the estimates of the additional storm water runoff generated by urbanized surfaces.

RESEARCH HYPOTHESIS AND OBJECTIVES

The hypothesis of the research is that, while currently modest in terms of total water use, urban growth will lead to considerable changes in irrigated agriculture in the future, in terms of its wastewater irrigated area and water resource availability for existing irrigated systems. We also hypothesize that urban storm water runoff could represent a significant amount of water relative to urban wastewater generation. Thirdly, the extent of the wastewater irrigated area downstream of Hyderabad might compensate to a large extent for the loss in conventionally irrigated area, as a result of increasing urban water demands. The initial objective is to build and test a model of a city water balance that uses future water supply scenarios and the impacts of meeting those demands on existing agricultural water use, and estimates offsetting increases in the area of wastewater agriculture.

Hyderabad city case study in the Krishna river basin

Hyderabad city lies close to the edge of the Krishna–Godavari basin boundary, just north of the Musi river, which is a minor tributary of the Krishna river. The upper catchment of the Musi river has been regulated by two dams, Osman Sagar and Himayat Sagar, which provide water to the city. The Musi has become a wastewater river, from the city downstream, and otherwise has little natural flow. The Musi river sub-basin (11 295 km^2) drains into the lower portion of the Krishna mainstream about 150 km downstream of Hyderabad (Figure 1).

The twin cities of Hyderabad-Secunderabad (herein referred to as ''Hyderabad''), is one of the fastest-growing urban agglomerations in India, with an annual population growth rate of more than 5% (UN, 2002). The city population, currently 6.8 million, is expected to exceed 10 million in 2015. At this rate, Hyderabad will rise from

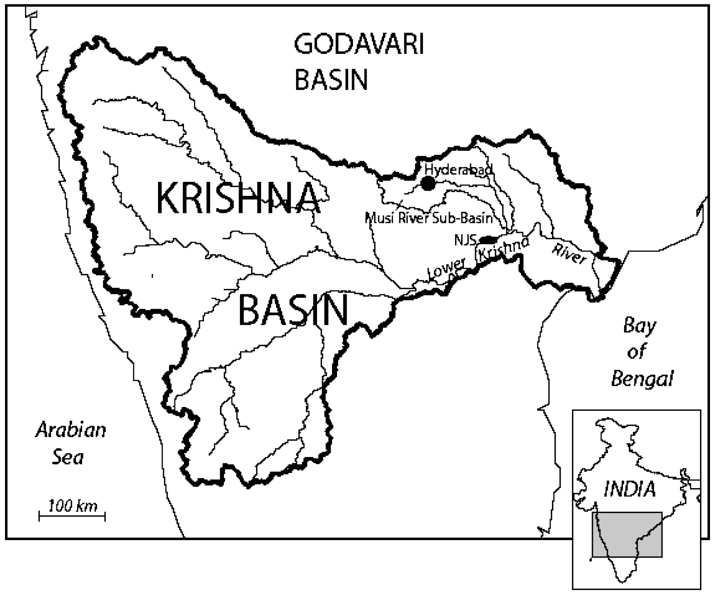

Figure 1. Map of Krishna basin

its current global rank of 31st to 22nd of the biggest urban agglomerations, overtaking Bangkok, Lima and Hong Kong (UN, 2002).

The water supply to Hyderabad grew rapidly over the period 1950–2004 and is projected to increase further with the completion of additional projects by 2030 (Figures 2(a) and (b)). In 1950, when Hyderabad had a population of 1.1 million people, water supply was secured by two nearby reservoirs, providing the city with roughly 3.5 million cubic metres per month (MCM month^{-1}). In the 1960s, water began to be diverted from sources outside the local catchment area, and those sources now dominate the total urban water balance. In 1991, when the Singur reservoir started operating, water supply doubled in volume, rising to about 18 MCM month^{-1} in the late 1990s. In March 2003, Krishna river water from the Nagarjuna Sagar reservoir began to be pumped from a distance of more than 120 km, giving an enormous boost to water supply and already accounting for one-third of water supply in 2004, with 10 MCM month^{-1}. This is the first stage of a multi-stage project which will provide Hyderabad with an additional 10 MCM in 2011 and a similar extra water supply in 2021. For 2020, plans exist to launch an ambitious inter-basin transfer project that will take another 25 MCM from the Godavari river (Figure 3). The extent of

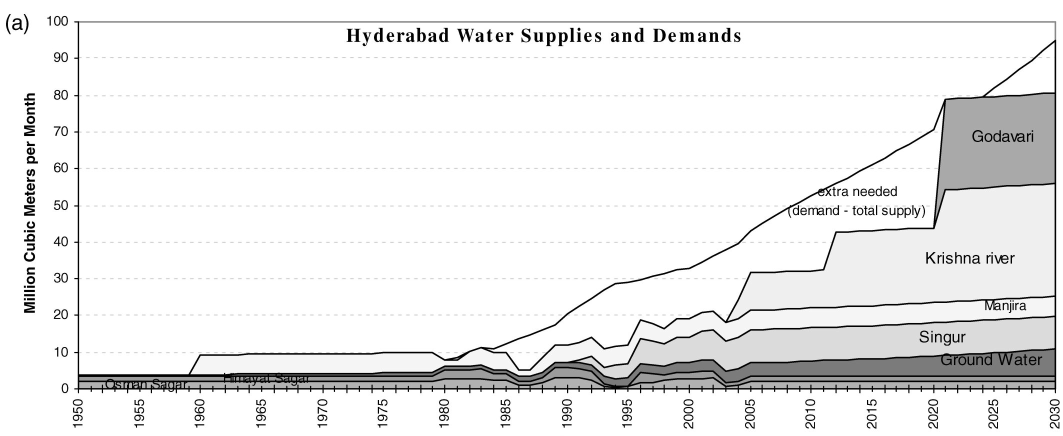

Figure 2(a). Hyderabad urban water supply patterns. Water delivery rates from the different water sources for urban water supply in Hyderabad in the period 1950–2030. For the period 1980–2003 more detailed water delivery data were used

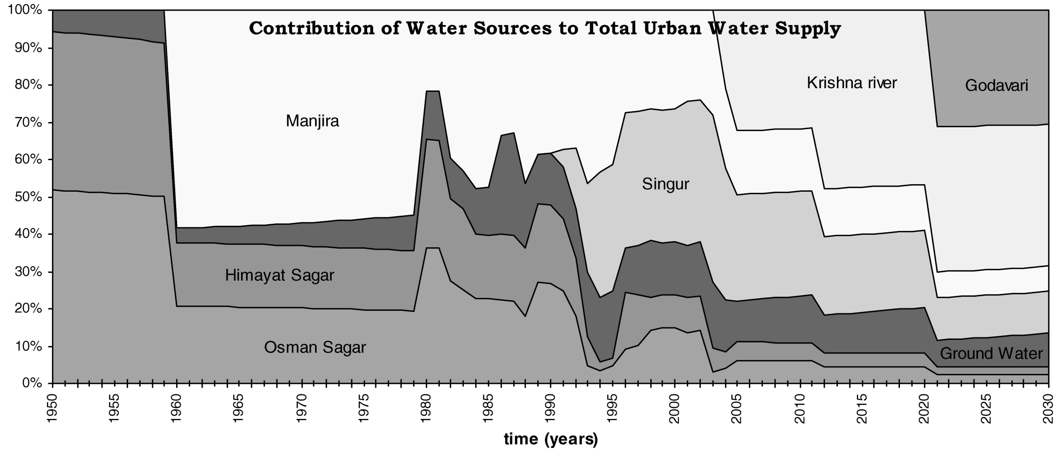

Figure 2(b). Hyderabad urban water supply patterns. Relative contribution of the water sources for urban water supply in Hyderabad in the period 1950–2030. Absolute values were converted to percentages of total water deliveries to Hyderabad city. The percentage of each source is called ''contribution to total supply'', showing its relative importance

groundwater withdrawal for urban use is estimated to be 3.3 MCM month^{-1}, which has clearly caused drops in the groundwater table. Water supply is governed by the Hyderabad Metropolitan Water Supply and Sewerage Board (HMWSSB). Total water losses with treatment and transportation can amount to one-third of net delivery (HMWSSB, 1995).

Wastewater irrigation along the Musi river

The seasonal flow pattern of the Musi river has lost its natural characteristics since most of the water is stored upstream in the Osman Sagar and Himayat Sagar reservoirs. Below Hyderabad, an essentially new ''river'' flows out of the city that consists mostly of urban wastewater that drains into the Musi river. Limited treatment is practised, although two wastewater treatment facilities exist at Amberpet and Hussainsagar lake with capacities of

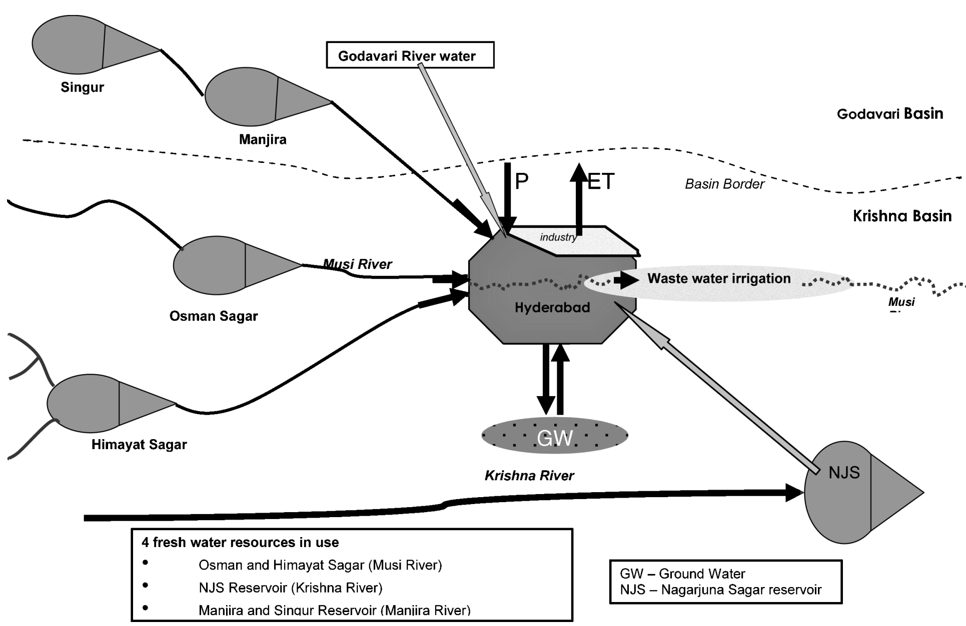

Figure 3. Sketch of the water balance, Hyderabad

3.4 and 0.6 MCM month^{-1}, respectively. A Musi river conservation project report has been prepared and is under consideration by the government of India. It should start in 2005 with target treatment capacity of 18.3 MCM month^{-1}, although it is not clear whether this project will be approved.

Currently, the urban wastewater is used in agriculture mostly to grow paragrass and paddy rice along the river. Water quality improves further downstream, as a result of particle settlement behind weirs (old irrigation anicut structures) in the river and reaeration (Ensink *et al*., 2004). Runoff from water harvesting tanks, small river dams and irrigation return flow containing better quality water also contribute to the improvement of the water quality downstream. Wastewater from a major industrial area in the north-west of Hyderabad (Patancheru) is so far not being deposited in the Musi river, but in local tanks that drain to tributaries of the Godavari basin to the north. However plans exist to drain this water into the Musi river in the near future.

Land in the wastewater irrigated area close to Hyderabad has gradually been converted to fodder grass, predominantly paragrass, for the urban dairy market, though a large fraction of the wastewater irrigated corridor is cultivated in rice. The switch from rice to paragrass cultivation could be caused by low rice yields in the wastewater irrigated area. The major market opportunity of paragrass as fodder for stall-fed livestock that forms the basis of the milk supply industry within and around the city could also contribute to the switch to paragrass. Other wastewater irrigated crops include bananas, coconuts and vegetables. Estimates of the area of wastewater use indicate a net area of more than 200 km^2. This number is based upon satellite image analysis and field visits (Yuanije and Zomer, 2004), though coming field surveys should give a better estimate.

METHODS

The Hyderabad city water balance

A simple model of a partial urban water balance and its effects on irrigated agriculture (Figure 4) has been developed using the VENSIM dynamic modeling shell (VENSIM, 1998). Water enters the city from various

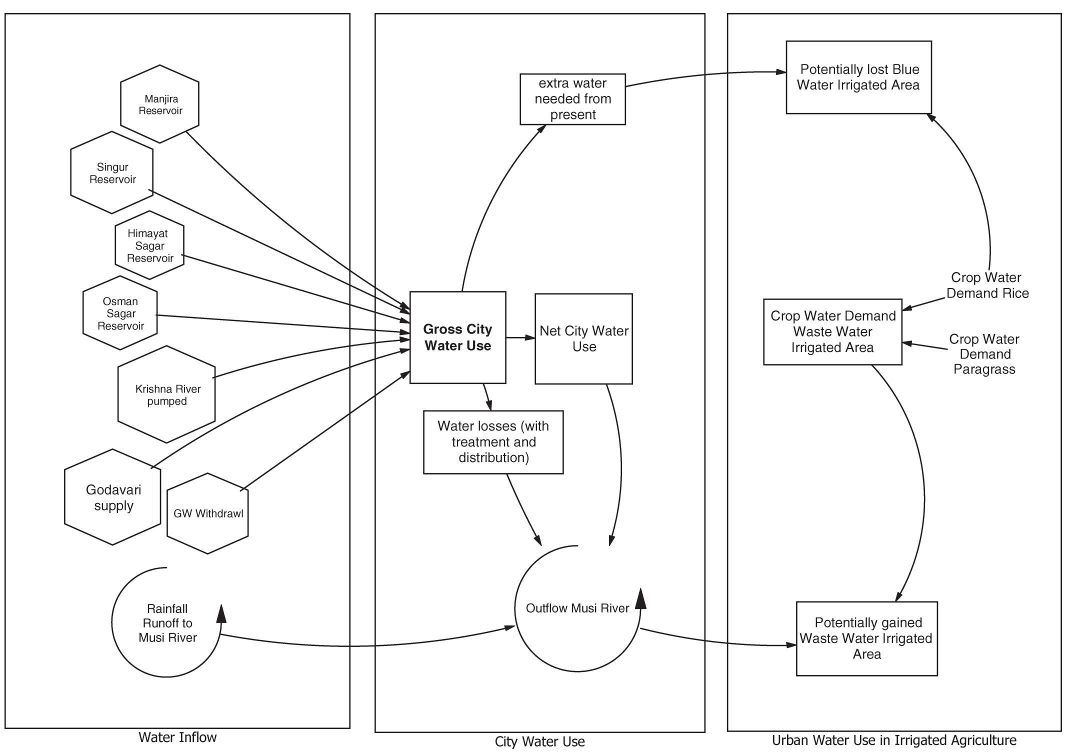

Figure 4. Hyderabad city water balance as used for dynamic modelling

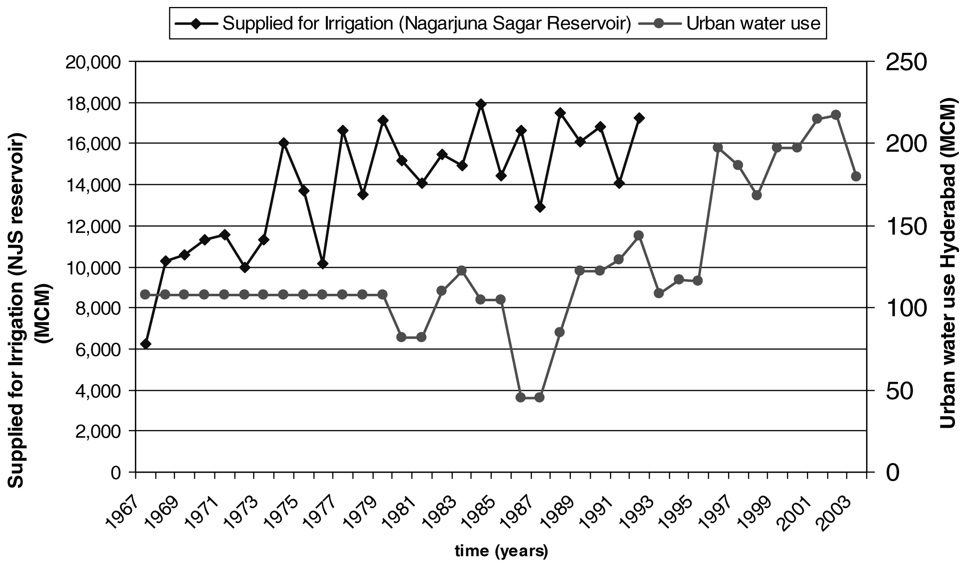

Figure 5. Relative volumes of water used for irrigation in Nagarjuna Sagar, versus that diverted to the city

surface water sources, as measured (1950–2004) or projected (2004–30) by the HMWSSB board. Groundwater withdrawal is assumed to increase at 3% per year over the whole period analysed, with a current estimate of 3.3 MCM yr^{-1} (Venkateswara Rao, 2000). Approximately 30% of water supplied to the city is lost during delivery, and a constant fraction of that lost water is assumed to drain to the Musi river and becomes available for irrigation. The model includes a coefficient for losses that occur during urban water use (80%), which was estimated as 80–90% (Tchobanoglous and Schroeder, 1985).

The runoff coefficient from unurbanized surfaces, represented by the inflow time series at Osman Sagar, averaged 13% and ranged between 4 and 29% from 1974 to 1984, before the expansion of groundwater irrigation in the catchment (HMWSSB, unpublished data). The urban runoff coefficient is assumed to be 65% (Maidment, 1993), an increase of 50% over the unurbanized surface. This runoff increase illustrates the effect of urbanization on runoff relative to wastewater generation.

The fraction of water that Hyderabad is taking to supply their urban water needs has never been more than 2% of irrigation canal flows at Nagarjuna Sagar (see Figure 5). Therefore, based upon this information, a partial shift of water from irrigation to urban use occurred in 1967–92, but the total urban water use is small compared with irrigation. However, these values have been measured for a large project where urban extractions are relatively recent; withdrawals from smaller projects such as Singur have had more significant influence (Lakshimipathi, 2001).

The water supply to Hyderabad is based entirely on observed values for 1950–2004, and on projections from the HMWSSB for 2004–50. The urban population size and growth rate is used to compare urban water demands with urban water supply, but the water supply to Hyderabad depends only on the HMWSSB data and projections.

Crop water demands and urban storm water runoff

A list of parameter values and model equations can be found in Table I. The blue-water irrigated area lost and wastewater irrigated area gained are computed from crop water demands and the cropping pattern measured from remote sensing imagery and field observations. Crop water demands are determined from the Penman–Monteith and crop coefficient method (Allen *et al.*, 1996). The Penman–Monteith potential ET is computed with meteorological station data from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) near Hyderabad. Rainfall at ICRISAT was used to estimate runoff from the urban surface. The mean rainfall and potential ET were used for simulation of future urban storm runoff and crop water demands. The integration of expected increases of extreme weather events, changes in rainfall and periods of drought have so far not been

Table I. Model parameters and input and output data of the water balance model

Symbol	Model parameters	Value	Unit	Source
A_c	City area (at present)	313	km^2	Yuanije and Zomer (2004)
RRC	Rainfall runoff coefficient	0.67	—	Maidment (1993)
WL	Water losses	0.3	—	HWSSB (1995)
WRF	Overall water return fraction	0.8	—	Tchobanoglous and Schroeder (1985)
K_c	K_c rice/paragrass	0.91/0.99	—	Allen *et al.* (1996)
CI	Crop intensity rice/paragrass	0.8/0.95	—	IWMI unpublished data, 2003
Symbol	**Input from data series**	**Type of data**	**Unit**	**Source**
I_i	Manjira, Singur, Himayat, Osman Sagar reservoirs, Krishna- and Godavari supply	Measured/project plan	m^3 $month^{-1}$	HWSSB (1995)
GWW	Ground water withdrawal	Estimated	m^3 $month^{-1}$	Venkateswara Rao (2000)
ET_o	Reference crop evapotranspiration	Measured/stochastic series	mm $month^{-1}$	ICRISAT Patancheru
P	Rainfall (precipitation)	Measured/stochastic series	mm $month^{-1}$	Weather station
N_{pop}	Population number	Recorded/predicted	no.	UN (2002)
Symbol	**Output data calculated**	**Formula**	**Unit**	
WU_{gc}	Gross city water use	$\Sigma I_i + GWW$	m^3 $month^{-1}$	
WU_{nc}	Net city water use	$WU^*_{gc}(1 - WL)$	m^3 $month^{-1}$	
WU_{pcd}	Per capita domestic water use	$WU_{dom}/N_{pop}/30.42$	$l\,cap^{-1}\,day^{-1}$	
WD_{dom}	Domestic water demand	$N^*_{pop}PCWD^*30.42/1000$	m^3 $month^{-1}$	
CWD	Crop water demand	$CI^*(ET^*_o K_c) - (P^*0.7)$	mm $month^{-1}$	
Q_{musi}	Outflow Musi river	$W^*_{unc}WRF + Q_{runoff}$	m^3 $month^{-1}$	
Q_{runoff}	Runoff to surface water (Musi)	$A^*_c 1e + 006^*(P/1000)^*RRC$	m^3 $month^{-1}$	
A_{irr}	Irrigated area	Water volume/(CDW/1000)	km^2	
CWD_{ww}	Crop water demand waste- or blue water cropping area	807	mm yr^{-1}	
CWD_{blu}		728	mm yr^{-1}	

included in the stochastic series. The urbanized area is approximately 310 km^2, as estimated from Landsat TM imagery (Yuanije and Zomer, 2004).

The runoff coefficient for the natural, pre-disturbance surface is estimated from the historical precipitation and inflow data at the Himayat and Osman Sagar catchments (15%). The runoff coefficient for the urbanized area is estimated as 0.65 (Maidment, 1993). The difference between these runoff coefficients represents the additional water generated from the urbanized surface, which has been used in the model. The growth in urban area is calculated by assuming a constant urban population density and an urban population growth rate of 4%.

RESULTS

Population growth rates and per capita water availability

Projections of population growth rates can be compared with the planned increases in urban water supply. The population growth rates do not enter the calculations of urban water supply or irrigated area gains or losses, which are based on actual planned water supply values from the HMWSSB. The current population growth rate of Hyderabad exceeds 5%. We investigated the consequences of different population growth rate scenarios on per capita availability water, considering the water resources currently available for future development. Figure 6 shows the population of Hyderabad over time, with 4–6–8% population growth. It also shows the estimated per

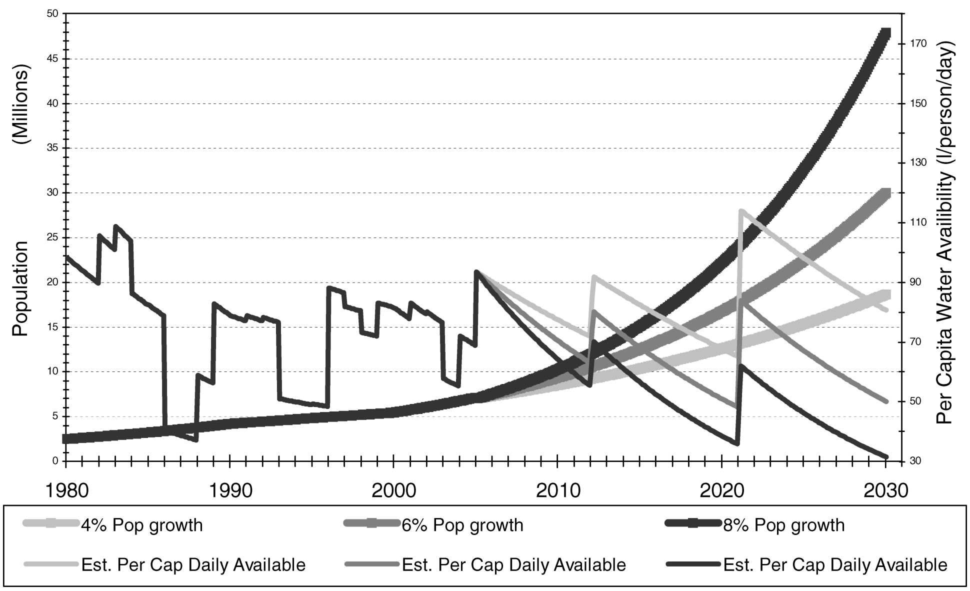

Figure 6. Population growth rates and per capita water availability scenarios for Hyderabad city for the period 1980–2030

capita water use that is calculated from available domestic water (with the water availability base scenario) divided by population number.

Yearly growth rates of 4, 6 and 8% will lead to a Hyderabad population of 18, 30 and 48 million by 2030. In 2030 an estimated per capita water availability of 81 (4% population growth rate), 50 (6%) and 31 (8%) l person^{-1} day^{-1} can be expected. The peaks are a reflection of the incremental availability of new water quantities that originate from Krishna and Godavari water. The drop after each peak is caused by further increases in population over time. The three drops between 1984 and 2004 in per capita water availability, as can also be seen in Figure 2(a), are the result of low reservoir inflows and related water supply and future drops may occur in similar drought conditions.

Impact of urban water use on blue and wastewater irrigated areas

The loss of blue water irrigated area and gain in wastewater irrigated area depend on the amount of water lost during urban water use, and the change in cropping pattern, which can impact on crop water demands. The area that is irrigated with water from the Nagarjuna Sagar Project is 8100 km^2 (Irrigation Department of Andhra Pradesh, 2001), where mostly double-cropped rice is being cultivated. The wastewater irrigated corridor, by contrast, contains ~20% paragrass and ~80% rice, as estimated from Landsat TM imagery of 2000. Paragrass cultivation occurs year round due to constant wastewater flow, while rice is typically double cropped. The annual evaporation from the blue and wastewater cropping systems is marginally different, 728 mm for blue water vs 807 mm for wastewater (Table I).

Based on the crop water demands and cropping patterns described above, Table II shows estimates of the "blue water" irrigated area that could potentially be lost due to water supply to Hyderabad, and the corresponding gain of wastewater irrigated area. The stepwise increase in diversion of Krishna and Godavari water results in a reduction of "blue water" irrigated area of about 550 km^2 by 2010, 750 km^2 by 2020 and 1400 km^2 by 2030. The corresponding increase in wastewater irrigated area is 340, 470 and 870 km^2 by 2010, 2020 and 2030 respectively. Rice production that could otherwise have been obtained from reallocated water volumes are roughly 80 000 and 200 000 t in the years 2020 and 2030, assuming a water productivity of 0.30 kg m^{-3}. Rice yields in the Musi wastewater irrigated corridor are approximately 60–80% of the yields observed in blue water systems, so the total rice production is reduced further from the decrease in rice irrigated area (Table II).

The net water supply to Hyderabad, and the corresponding irrigated area lost, is relatively small compared with the annual water supply to the Nagarjuna Sagar command area (Table II), including historical canal flows during

Table II. Water supply to Hyderabad and irrigated agriculture from the Nagarjuna Sagar Project and irrigated area gain/loss estimates

	Urban-Hyderabad (% of NJS)	Irrigated agriculture (NJS)
Water supply from NJS (MCM yr^{-1})		
2005	380 (3.6–2.1%)	10 000–18 000
2020	550 (5.2–3.0%)	10 000–18 000
2030	1024 (10.2–5.3%)	10 000–18 000
Irrigated area lost/gained (km^2)		
2005	+340	−520
2030	+640	−1000
Irrigated area in 2000 (km^2)	200	8100
Annual evaporation (mm yr^{-1})	807	728
% gain or loss of irrigated area (*from 2000*)		
2005	+170%	−6.4%
2030	+320%	−12.4%
Rice production ('000 t yr^{-1})	*60–80% of 0.3 kg* m^{-3}	
2020	99–132	3000–6000
2030	184–246	3000–6000

drought years (Figure 5). However, the inflows to the Nagarjuna Sagar Project have decreased in recent years, possibly due to upstream irrigation development. If water supplies decrease further, or if a drought occurs, then the relative importance of Hyderabad to the total water balance of the irrigated system could increase.

DISCUSSION

The simple development of scenarios of water demand and analysis of their probable sources of satisfaction have allowed two simple aspects of urban–agriculture water interactions to emerge. The first is that, as Hyderabad grows, even with maximum reuse of wastewater, the average net loss of irrigated agriculture is 40 000 ha (400 km^2) by 2030. This value is still small relative to the irrigated area of the project that supplies water to Hyderabad, but could become more important if inflows to the reservoir decrease. Another impact is that an additional 200 km^2 of wastewater agriculture could potentially be developed downstream of Hyderabad by 2030, which implies a significant shift in the location and nature of agriculture in the lower Krishna basin. This has considerable implications for infrastructure development and management, and for public health. It is therefore important to know the full public health and health management dimensions of the extensive use of wastewater in order to responsibly adapt to the challenge of growing cities with increasing discharges of wastewater. The study has not yet considered the reliability of water supply, which will be much better in wastewater systems than in blue-water irrigation systems, due to the constant water supply required by urban populations throughout the year. The value of wastewater agriculture may therefore considerably exceed that of blue-water irrigated cropping, and further compensate for the net loss in land area, though water quality reduces yields and selling prices.

Assessments of the impact of urban water supply on traditional irrigated agriculture depend on the scale of analysis and size of the projects experiencing the impact. A small reservoir with a small irrigated command area could experience large changes due to urban water supply. In the Singur Project, water allocation to Hyderabad was 13% of the water allocated to irrigation. This percentage increases during drought years, causing signficant conflict between the urban and irrigation sector (Lakshimipathi, 2001). Additional water supplies to Hyderabad are coming from larger irrigation projects such as Nagarjuna Sagar, which is one of the largest masonry dams in the world with a large irrigated command. The relative impacts of Hyderabad's water supply on the project are correspondingly less significant, particularly compared with allocations to other irrigated systems upstream. At the basin scale, the irrigated area lost due to water use in Hyderabad (400 km^2) is small relative to the basin total irrigated area of 44 533 km^2. Of course, other urban areas and industries in the basin also draw water, so a full accounting of the urban–agriculture water competition and the basin impact of increasing urban water use will have to take into account all water demands in the basin.

The model highlights that urban growth generates wastewater streams not only though increased water supply to the city, but also by enhancing storm water runoff from the urbanized surface. The difference in runoff coefficients assumed here (0.5), generates 163 MCM yr^{-1} of additional runoff, which is 44% of the total water outflow from the city, including urban wastewater generation and storm runoff. The runoff coefficient from the urban area is not well constrained, so this value may change with additional and more refined estimates. Also, the impact of this seasonal storm water runoff on irrigation downstream is likely to differ from the continuous flow from urban wastewater. The ultimate fate of this storm water vis-à-vis irrigated agriculture is not known. The additional storm water may not be used in the wastewater irrigated area, since most anicuts and diversions are normally at full capacity throughout the year. Significant water storage capacity exists downstream in other irrigation projects, and inflows to these projects may be increased by the enhanced urban storm runoff. Despite the uncertainty of the ultimate fate of the urban storm runoff, these intial calculations flag the potential importance of urban storm water runoff in the water balance of the urban area.

The model and analysis also illustrate that urban water supply, while it removes water from traditional irrigated areas, also provides a big increase in the wastewater irrigated area (up to 320%). This return fraction is based on literature values, and estimates of wastewater loss and gain from the distribution system. Values of this return fraction may be different from that assumed and may be refined in the future. The key point is that urban–agriculture relations in water use are not always antagonistic; urban areas can have significant positive impacts on the local wastewater irrigated sector. For example, other wastewater irrigated areas in the Krishna basin (the Hubli-Dharwad urban area) support high-value vegetable production (Bradford *et al*., 2003). However, water quality may depress both short- and long-term yields of rice; in the Musi wastewater corridor, farmers report yield reductions of up to 30%, and complain of low selling prices due to poor rice quality. Other concerns include health and environmental impacts (Ensink *et al*., 2004), and possible long-term accumulations of salts (Jiang *et al*., 2004). A full accounting of the urban–agriculture intersectoral relations needs to account for gains in the wastewater irrigation which includes more information on the ultimate environmental, food production and health impacts.

CONCLUSION

Up to now, the irrigation and urban water supply sectors have coexisted independently, with limited interest and impact of the activities of one sector on the other. As urbanization proceeds, the two sectors will become more and more linked. Decisions on the development, management and reuse of water resources for cities will have increasing impacts on agriculture. The Hyderabad case suggests that the impact of urban supply on irrigated agriculture depends crucially on the size of the source reservoir. Large cities like Hyderabad may still have a relatively small impact on large irrigated systems. Urbanization also entails other processes, like enhancement of impervious surfaces, that can alter the local water balance and increase water delivery downstream. The consequences of urban water supply are not always detrimental to irrigated agriculture, since a large portion of the urban water is potentially reused in wastewater irrigation, though the quality of the wastewater could have important impacts on crop choice, yield, environment and human health. The water balance of the city of Hyderabad gives insight into long-term trends in the impacts of urban growth on agricultural water use. In water-short basins, reuse of wastewater will become increasingly important and complex as cities grow.

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