MITIGATING THE POTENTIAL UNINTENDED IMPACTS OF WATER HARVESTING[1]

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ABSTRACT

Different forms of water harvesting have been used successfully in semi-arid areas of India for millennia as a means of protecting domestic water supplies and increasing or stabilising agricultural production. In recent years, water harvesting both in field (e.g. contour bunding) and along drainage lines (e.g. check dams) has been promoted and funded on a massive scale as part of different government and non-government programmes. Accepted wisdom is that rainfall should as far as possible be harvested where it falls and that these technologies are totally benign. However, evidence is emerging that water harvesting in semi-arid areas, if used inappropriately, can lead to inequitable access to water resources and, in the extreme, to unreliable drinking water supplies. Water balance studies in Andhra Pradesh and Karnataka have shown that water harvesting programmes impact significantly on patterns of water use and that this can result in distinct winners and losers. Winners include people who have improved access to water for productive purposes (e.g. irrigated agriculture) and losers include people whose access to water for domestic, productive and other purposes is reduced. It is also clear that livelihood gains experienced by some "winners" can dissipate as competition for water resources increases and traditional drought coping strategies become less viable and/or increasingly expensive. The recommendation from the analysis presented here is that water harvesting should be encouraged but within an integrated or adaptive water resources management framework using procedures that weigh up the benefits and tradeoffs associated with altered patterns of water use. The aim being identify potential unintended impacts so that, if at all possible they are avoided altogether, but if these do occur, they are recognised at an early stage and steps are taken to mitigate their affects.

1 INTRODUCTION

Water harvesting and soil conservation have been promoted actively by Government of India under programmes such as the Drought-Prone Areas and Desert Development Programmes. Water harvesting, as a means of conserving and protecting sources drinking water supplies, is also recommended as part of the Rajiv Gandhi National Drinking Water Mission's guidelines for implementation of the rural water supply and sanitation programme (1). Water harvesting has also been advocated strongly by many NGOs and environmental pressure groups. In Andhra Pradesh, the Water Conservation Mission has allocated large amounts of additional funding for water harvesting measures (e.g. continuous contour trenching, roof water harvesting) under the Neeru Meeru programme. The net effect is that water harvesting is being promoted and practiced in many semi-arid areas of India on a scale that is seen in few other parts of the world.

Successful experiences with, in particular, water harvesting carried out as part of participatory watershed development projects have been reported by many authors (e.g. 2). This paper takes as starting point the fact that water harvesting has and is being used successfully on a large scale in India and that, justifiably, it has widespread public and political support. This said, the focus of the paper is on the potential unintended impacts of water harvesting on access and entitlements to water for domestic and productive purposes in semi-arid South India. An earlier related paper by Singh *et a.l* (3), discussed the impact of intensive water harvesting on the utility of traditional tank systems in the same region.

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2 STATUS OF WATER RESOURCES IN SEMI-ARID AREAS OF SOUTH INDIA

In recent years, there have been dramatic changes in the surface and sub-surface hydrology of many semi-arid areas of south India primarily as a result of inappropriate resource management and increased groundwater extraction for irrigation. The number of wells constructed per year in Kalyandurg Mandal in AP's Anantapur District during the 20th century is presented in Figure 1. In addition to showing the big increase in well numbers during the 1990's, the figure shows that in recent years, new wells have been predominantly deep borewells or in-borewells (i.e. borewells drilled into the base of existing open wells). Hence there has been a shift from groundwater that exploited the shallow aquifers, such as the crystalline basement regolith aquifer in Anantapur, to extraction from deeper aquifers. During the same period there has also been a rapid increase in the use of submersible pumps. Hence, there has been an increase both in the number of wells and volume of water extracted per well. This process has been driven by the relatively higher profitability of irrigated agriculture when compared to rainfed agriculture, grants or cheap loans for well construction and government policies such as free electricity for pumping groundwater.

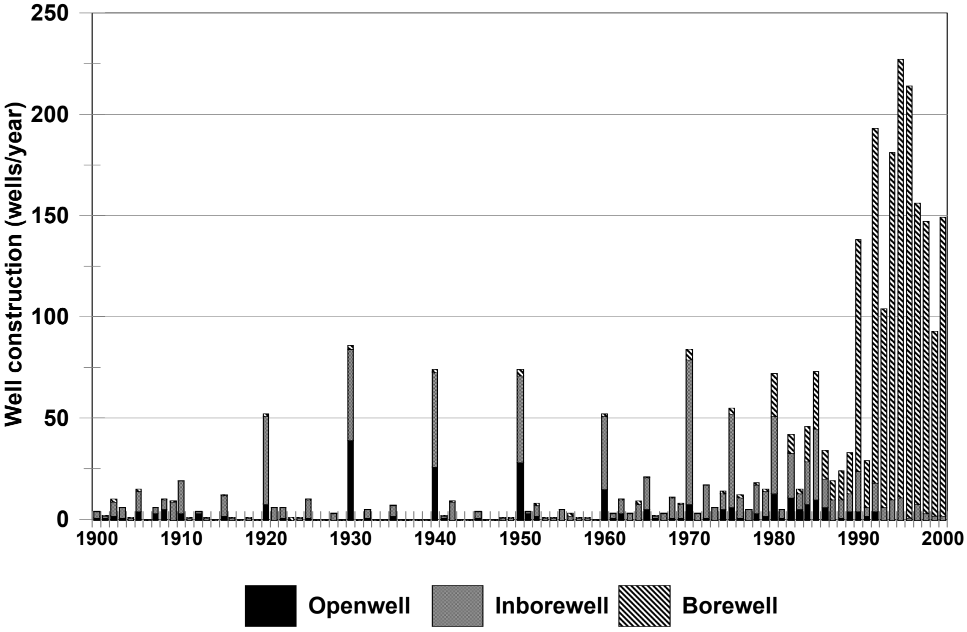

Figure 1. Well construction in Kalyandurg M andal, Andhra Pradesh (after 4)

As a direct consequence of increased groundwater extraction, groundwater levels have fallen and, in many areas, shallow wells have failed as borewells have been constructed and extraction from deeper aquifers has become the norm. Falling groundwater levels and increased rates of groundwater extraction have contributed to changes in surface hydrology. In many areas, springs and seepage zones have dried and now only flow or become saturated after exceptionally wet periods. Water harvesting, particularly when it has involved creating extra water storage along drainage lines (e.g. impoundments behind check dams) has also contributed to changes in surface hydrology. In many areas, flow in ephemeral streams now occurs less frequently, is reduced in magnitude and/or is less prolonged after large rainfall events.

River gauging data show that annual surface runoff at the large watershed scale in many areas of South India is somewhat lower than is often reported or than accepted wisdom would suggest. Although there is large inter-annual variation, average runoff as a percentage of rainfall is around 6% and 2% for the Doddahalla and Chinnahagari Rivers respectively (5) and in the range 2-8% for the Hundri, Chitravati, Pennar and Vadvathi rivers (4). Although runoff for individual or sequences of rainfall events is often higher (as is runoff at the plot and field scale), this finding shows that there are not large volumes of additional surface water that can be harvested in many areas of semi-arid South India. The low values of runoff are not surprising given the physical characteristics of the region, the groundwater depletion (and, hence, the greatly reduced base flow) and the large number of tanks, check dams, nala bunds and contour bunds that have been constructed.

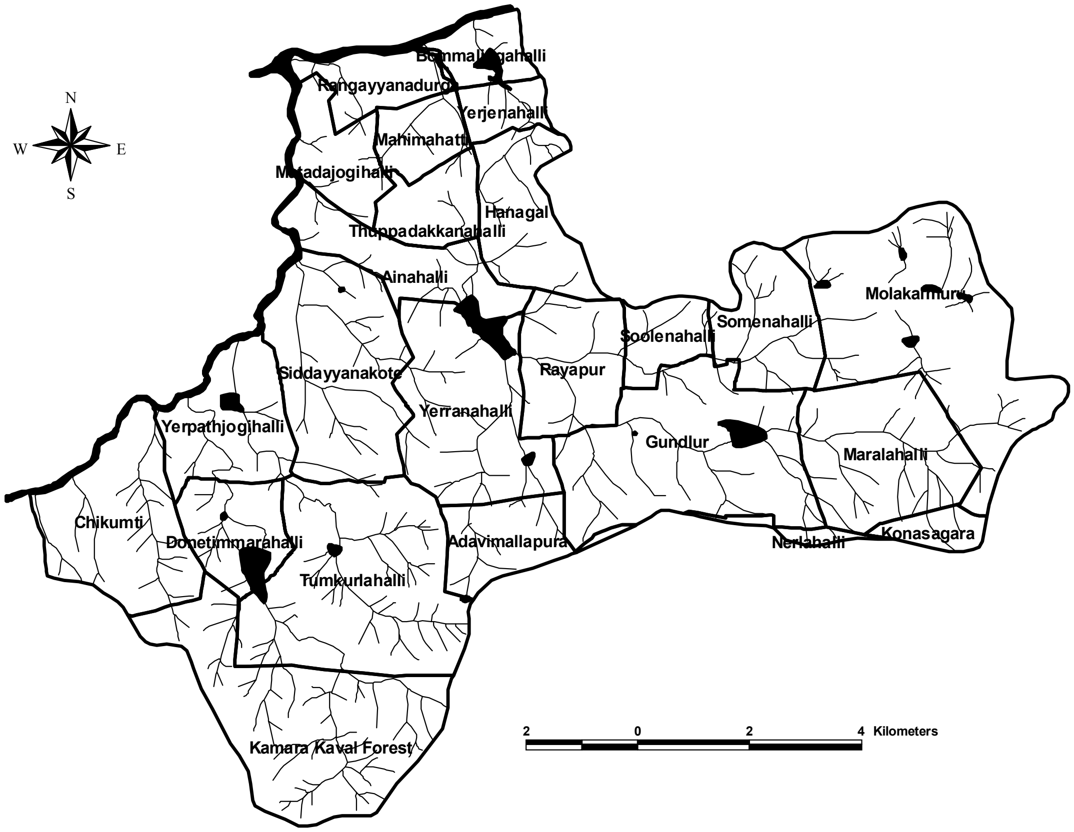

Figure 2. Chinnahagari watershed

3 IMPACTS OF WATER HARVESTING ON A REPRESENTATIVE WATERSHED

The catchment area of Gundlur tank is situated in the Chinnahagari watershed in Chitradurga District, Karnataka (see Figure 2). The catchment and original command areas are 1234 ha and 32 ha respectively. Soils of the catchment and command areas are predominantly red loams of variable depth, the geology is crystalline basement and slopes are typically in the range 0.5 - 2.5%. Although silted, the tank capacity is approximately 27 ham. Mean annual rainfall is 472 mm.

Although the tank itself is situated in Gundlur village area, the catchment area cuts across parts of four additional village areas, namely, Maranahalli, Konasagara, Molakalmuru and Nerlahalli. The command area of the tank is entirely within the Gundlur village area and there are additional tanks downstream that can capture and benefit from water surplusing from this tank. The population of the village is approximately 340 and there 64 households of which 5 are scheduled castes, 11 are landless and 10 have land holdings with an area less than 1 ha. During the last three years, the Karnataka Watershed Development Society (KAWAD) has been successful in promoting four self-help groups and various soil and water conservation activities in this village. Government programmes prior to KAWAD were responsible for the construction of a large number of check dams and nala bunds in the tank catchment area. More recently, the Gundlur Tank has been selected for rehabilitation under the World Bank-supported Karnataka Community-based Tank Management Project. An integrated tank development plan has been prepared and work on the ground is expected to start soon.

Water-related data for the whole of the Chinnahagari watershed were consolidated and analysed as part of the KAWAD Water Audit (5). As part of the study reported in more detail in Singh *et al.* (3), the catchment area of the tank was delineated and, with the assistance of MYRADA staff[2], water-related data from the earlier study were checked and updated. These data included numbers of structures, number of wells, area under irrigation, numbers of irrigator farmers and the status of the tank and command area structures. Measurements were made of the upstream crest height of every check dam and nala bund so that the potential storage of these structures could be estimated.

Using 11 years of daily rainfall data, the SCS method was used to calculate runoff on a monthly basis using the assumption that runoff would only occur when daily rainfall exceeded 20 mm. The maximum potential runoff retention of the tank catchment area was estimated with and without the additional storage created by check dams and nala bunds. A simple "bucket-type" model was used to take account of the additional storage created by new water harvesting structures. This made the assumption that structures were uniformly distributed around the tank catchment area and that all runoff that was not impounded flowed into to the tank. Evaporation losses from structures were calculated using potential evaporation data for open water and on the basis that water remains ponded behind nala bunds and check dams for 21 and 7 days respectively. These figures were based on visual observation and discussions with local people, NGOs and relevant specialists. It was assumed that water that did not evaporate from behind structures went to groundwater recharge. Evaporation and percolation losses for the tank were estimated as 15% of the net inflow to the tank. Finally, the main findings from the water balance calculations were cross-checked against the perceptions and knowledge of MYRADA staff and the Gundlur villagers.

Table 1. Changes in Gundlur tank and command/catchment areas

Attribute	Before 1990	January 2002
No. of wells in the catchment area	11 open wells & 3 borewells	12 open wells & 80 borewells
No. of nala bunds and check dams in catchment area	4 nala bunds & 0 check dams	7 nala bunds & 15 check dams
No of irrigator farmers in catchment area	8 farmers	93 farmers
Irrigation in command area	Approximately 32 ha using surface water released from tank	Approximately 32 ha using groundwater[1]
Frequency of tank surplusing	On average every 2-3 years	No spillage during last 11 years [2]
Inflows to tank	Reliable inflows resulting in the tank holding water in all but the driest years	Much reduced inflows during last 11 years. This combined with broken sluices resulted in tank drying out during the summer months

[1] Fields irrigated in the command area before 1990 and in January 2002 are not the same. Some parts of the original command area have been abandoned and/or are now owned by people in Molakalmura village.
[2] Lack of surplusing during this period was due to a combination of reduced inflow and broken sluices.

During the last eleven years, there have been major changes in the catchment and command areas of Gundlur Tank. These are summarised in Table 1 along with some of the main changes in the status of the tank itself. During this relatively short period, the tank-based irrigation scheme that functioned in the command area for around 300 years was replaced by groundwater-based irrigation of approximately the same area. Also during this period, there was a huge increase in groundwater-based irrigation in the tank catchment area. Of the 85 additional irrigator farmers, 30 are from Gundlur village, 49 are from Maranahalli village and 6 from Rayapura village. In terms of the wealth ranking, 49%, 31% and 20% of the irrigator farmers in the tank catchment area have land holdings of: 5 ha or more, 2.5 - 5 ha and 2.5 ha or less respectively.

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[2] MYRADA are a large Bangalore-based NGO. They are KAWAD's implementing agency in the Chinnahagari watershed.

Figures 2 and 3 are schematic diagrams that show the main components of the tank water balance before 1990 and for present day conditions. The figures presented are averages and it must be stressed that there is a considerable variability in water balance components that is related primarily to inter and intra-annual rainfall variability. This variability is illustrated by the fact that coefficients of variation for tank inflows before 1990 and present day conditions were 48% and 66% respectively. Similarly the coefficients of variation for tank spillage before 1990 and present day conditions were 86% and 114% respectively.

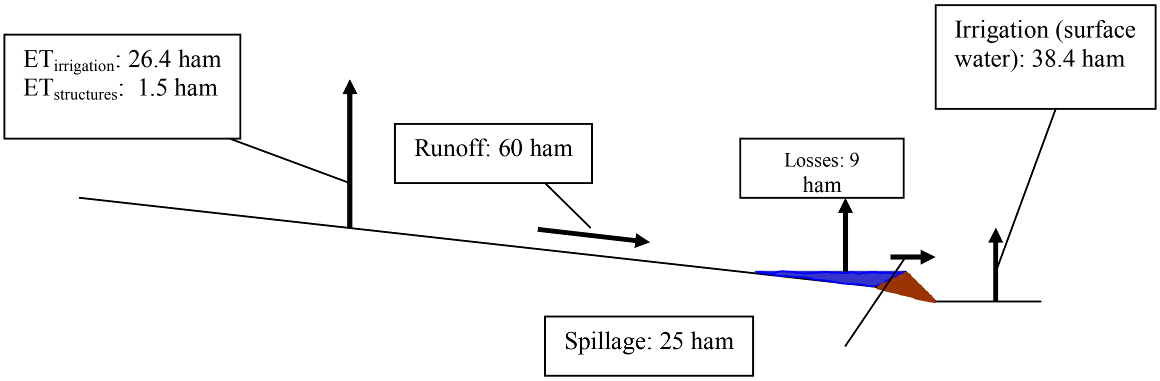

Figure 2. Gundlur tank water balance components before 1990

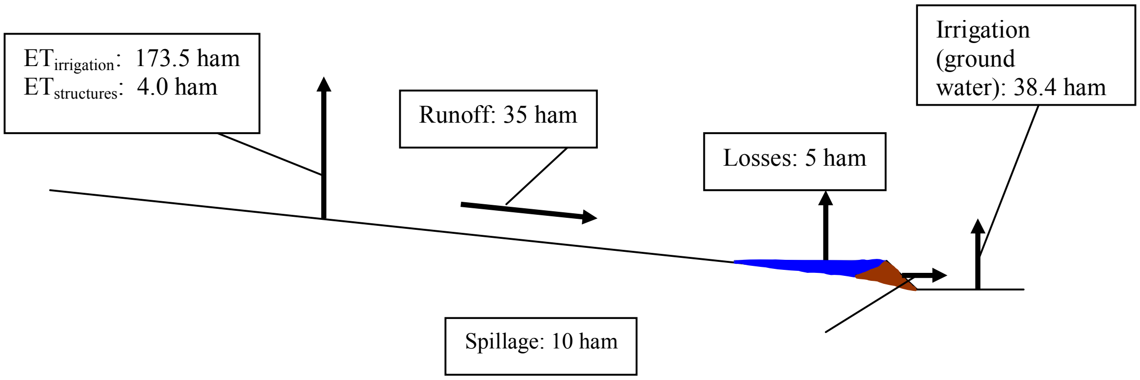

Figure 3. Gundlur tank water balance components – present day conditions

The water balance estimates suggest that during the last 11 years there has been a six fold increase in evaporation (ET) from irrigated areas and structures in the tank catchment area. This increased irrigated water use has been made possible by the sinking of 77 borewells and construction of 3 nala bunds and 15 check dams. Although the relative importance of the two contributory factors is unknown, it is clear that the combination of increased water harvesting and increased groundwater extraction has reduced inflows of water to the tank. On average, inflows of water to the tank have decreased by around 40%. However, percentage reduction of inflows is much greater during low rainfall years because a relatively larger proportion of streamflow is impounded behind the water harvesting structures.

During the last 11 years, losses from the tank have reduced as a result primarily of the tank being dry for a greater proportion of the year. However in terms of overall water use efficiency or productivity, this reduced loss is counterbalanced almost exactly by increased evaporation losses from water impounded behind the new water harvesting structures. Estimates suggest also that on average, once the sluices are repaired, surplusing from the tank under present day conditions will be 60% less than before 1990. Average annual tank storage or stored inflow has declined from 26 ham to 20 ham. A reduction of around 20%. This relatively smaller reduction in storage begs the question to what extent the "non-irrigation" utility of the tank can be improved by repairing the leaking sluices. Clearly, the repair of the sluices will have a positive impact on the tank utility, however, groundwater depletion in the tank command area, silt extraction and digging of brick pits will all have helped to increase percolation losses from the tank. At the wider level, improved tank utility and reduced surplusing has a negative tradeoff in that it will reduce water availability for downstream users.

Provisional results from studies of the impacts of water harvesting on patterns of water use around other tanks in north-eastern Karnataka and southern Andhra Pradesh show similar changes as those seen at Gundlur. For example, average annual inflows to the Yapadinne, Inchigeri and Anbur tanks have been estimated as having reduced by 25%, 49% and 70% in recent years. As with Gundlur, these changes are linked with increased water harvesting and groundwater-based irrigation in the tank catchment areas and not with any systematic changes in rainfall regime.

4 DISCUSSION

At the basin scale, the net effect of increased water use in South India is that many watersheds or river basins that originally had uncommitted utilisable outflows can now be regarded as being closed basins in years of normal rainfall (i.e. their utilisable outflows are now fully committed except during years of high rainfall). A similar situation exists with groundwater resources in that levels of depletion have reached such a level of intensity that, in some hard rock aquifers at least, groundwater extraction is approximating to groundwater recharge except during periods that are conducive to high levels of groundwater recharge.

At the watershed scale, the results presented here illustrate the combined impact that water harvesting and increased groundwater extraction has had on patterns of water use in the catchment area of a typical tank. In the Gundlur case, the changed pattern of agricultural water use during the last 11 years has resulted in an additional 80 farmers having access to irrigation. Given the relatively high profitability of irrigated agriculture in this region (5), the additional and more reliable income generated will have had a significant impact on the livelihoods of these farmers and their households. Interestingly, reduced inflows to the tank have not led to a reduction in the total area irrigated in the tank command area because farmers that used to rely on tank releases now use groundwater as a water source. In most cases, these farmers are now using borewells because the shallow aquifer has become depleted and, as a consequence, open wells have become unreliable. From the irrigation perspective and assuming that current levels of groundwater extraction are sustainable, changes during the last 11 years have been entirely positive not least because these changes have benefited poor and marginal farmers as well relatively richer farmers. However, if the non-irrigation uses of the tank are considered, it becomes obvious that the "irrigation" benefits have come at a social and economic cost. In the last 11 years the utility of the tank has declined for activities such as washing, bathing, watering livestock and pisciculture. Although this is not currently causing problems, the tank is no longer a perennial source of recharge for wells in the command area and possibly for wells that meet the domestic water needs of the village. The quantity of water surplusing has been reduced and, hence, less water is available to downstream users. Whether the benefits resulting from changed pattern of water use warrant the negative tradeoffs depends on which social group is considered. It also depends on the scale at considered. At a wider scale, the increased agricultural production and potentially more productive water use may be more acceptable than might be the case at the household scale

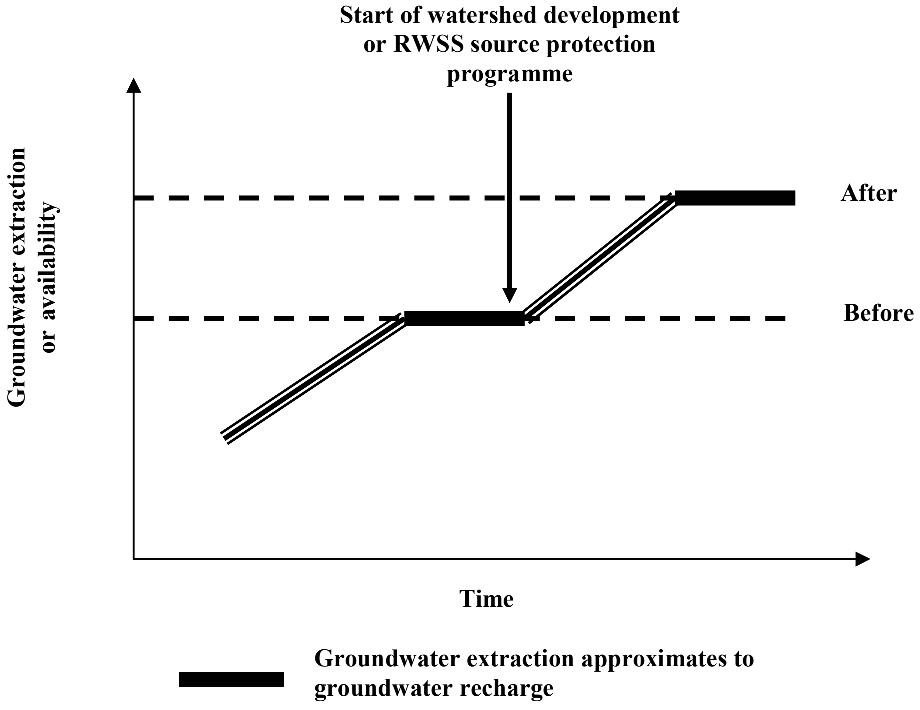

Figure 4. Trend in groundwater extraction and availability

Although there is clearly not an exclusive causal link between increased groundwater extraction and construction of check dams and other structures, water harvesting can be very effective in improving groundwater availability and meeting the high demand for groundwater albeit temporarily. Consequently, increased groundwater availability can be a factor that leads to increased groundwater extraction. Figure 4 is a schematic diagram that seeks to illustrate this process. Groundwater extraction is driven by a number of factors, some of which are listed earlier in this paper and, consequently, groundwater extraction is increasing with time. There are, however, limits on the quantity of groundwater that can be extracted from an aquifer. Once these are reached wells will fail, if not every year, at least in years when recharge has been poor. In these circumstances, groundwater extraction is very approximately equivalent to and even higher groundwater recharge. If water harvesting is promoted as part of watershed development or rural water supply and sanitation (RWSS) programmes, groundwater recharge rates can be improved and groundwater availability can be increased. However, in many areas this additional water is utilised by measures such as construction of additional borewells or installation of higher capacity pumps in existing wells.

As discussed earlier, high levels of groundwater exploitation can have a direct positive impact on the livelihoods of irrigation water users. It can also have a less direct but positive impact on the livelihoods of people who are employed by the irrigation users or who provide goods and services to these users. In many areas, high levels of groundwater extraction, although of environmental and ecological concern, may not have any negative impacts. In other areas, however, increased water use impacts can impact significantly on the access and entitlements of other users. This unintended impact can be most severe, when the impact is on domestic water supplies. This impact could be mitigated by adopting approaches to water allocation that are starting to be implemented in South Africa. These approaches are based in identifying and protecting a *basic human needs reserve* which is essentially a stock of water that ensures that daily entitlements to drinking water are met 365 days/year even during drought years. A detailed discussion of this approach can be found in Pollard *et al* (6).

5 CONCLUSIONS

Although there is a tendency to consider government programmes aimed at increasing water harvesting (e.g. watershed development programmes, the source protection component of rural water supply programmes) to be entirely benign, it is clear they can have a big impact on patterns of water use and on access and entitlements to water for productive and domestic purposes. In some cases, tradeoffs exist whereby the improved access and entitlements of users at one place or during one time period is at the expense of other user groups. Although these tradeoffs might be acceptable and, in some circumstances highly desirable, they should be taken explicit account of in strategic-level and village-level decision making processes. These ideally should be based on principles of integrated and adaptive water resource management (7). It is clear also that, as competition for water resources increases, much more attention needs to be given to the identifying and mitigating the unintended negative impacts of water harvesting.

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