From Groundwater Regulation to Integrated Water Management

The Biophysical Case

VEENA SRINIVASAN, SHARACHCHANDRA LELE

Groundwater over-exploitation poses a severe threat to food, water and livelihood security in India, but the approach to groundwater regulation has been guided by the simplistic prescription that to achieve sustainable use, pumping must be less than recharge. This article explains the hydrological cycle and the close relationship between groundwater and surface water, and argues that the conventional notion of sustainable groundwater use is fundamentally flawed. Groundwater, soil moisture and surface water are part of a single integrated resource, and cannot be regulated independent of each other. The solution is not sustainable use or the compartmentalisation of surface and groundwater but the fair and transparent reallocation of renewable freshwater resources.

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Veena Srinivasan (*veena.srinivasan@atree.org*) and Sharachchandra Lele (*slele@atree.org*) are with the Centre for Environment and Development at Ashoka Trust for Research in Ecology and Environment, Bengaluru.

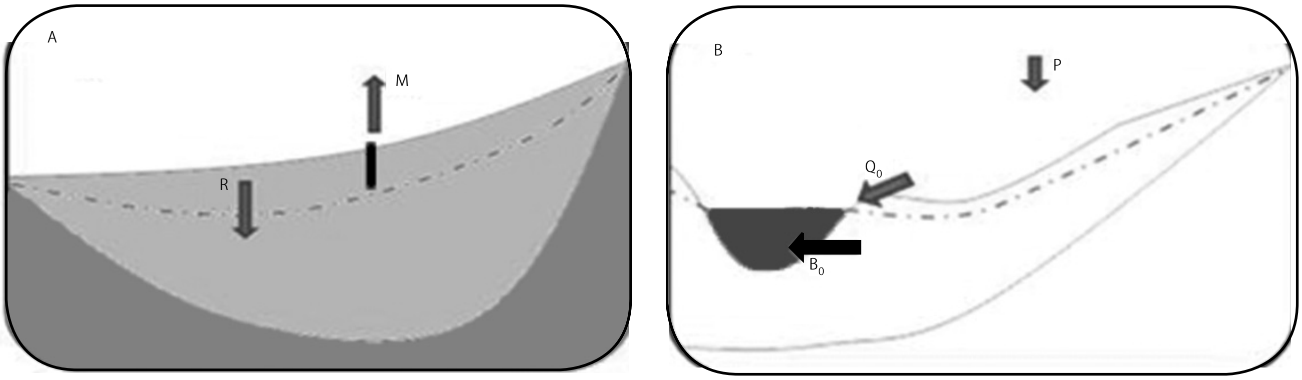
1 Introduction

India is the world's largest user of groundwater, withdrawing an estimated 250 cubic kilometres per year (km^3/year), more than twice that of the United States (US), the country with the second highest quantity of withdrawal. India currently has the largest land area under groundwater irrigation in the world (an estimated 27 million hectares in 2007), which amounts to 53% of its total irrigated area (Briscoe and Malik 2006). More than 50% of urban water and most of the rural domestic water supply in India is sourced from groundwater (Briscoe and Malik 2006). Equally important, the rate of growth in groundwater extraction has been phenomenal: from 10–20 km^3/year in 1960 to more than 250 km^3/year today (Shah et al 2007). However, this level of groundwater use cannot be sustained. Already, 16% of India's districts are classified as "overexploited" or "critical" (CGW 2011). The problem is particularly acute in western and north-western India as well as the hard rock regions of peninsular India.

Given the magnitude of use and the depleting groundwater resources, the need to regulate groundwater extraction is obvious. Indeed, there is a long history of attempts to regulate groundwater in India. A model groundwater regulation bill was drafted by the central government as far back as 1970, and then revised in 1992 and 2005 (MoWR 2005; Cullet 2012), and states were urged to pass it into law. Progress has been slow, partial and haphazard, but over the last decade a large number of states have enacted the law in some form.[1] A Central Ground Water Authority (CGWA) has also been formed under the Environment (Protection) Act,[2] which functions as part of the Central Ground Water Board (CGWB). While CGWB focuses on estimating potential, mapping, monitoring and developing methodologies, the CGWA issues guidelines regarding when and where to permit extraction of groundwater (CGWA 2012). Accordingly, it has notified 162 critical or overexploited areas across the country and is regulating industrial withdrawal in a large number of locations.

All these laws, guidelines and organisations have one thing in common: they directly or indirectly rely on the concept of "sustainable" groundwater extraction. For instance, the CGWB's "Groundwater Resource Estimation Methodology" report says that the development of groundwater must be "on a sustainable basis" (Groundwater Resource Estimation Committee 1997: 1). Other documents describe the need to

Figure 1: Early Conceptualisation of the Water Cycle by (A) Groundwater and (B) Surface Water Hydrologists



"promote sustainable groundwater use in the public interest" (Planning Commission 2011) or "to control indiscriminatory [sic] exploitation of groundwater" (GoK 2011). However, researchers are increasingly questioning what "sustainable groundwater use" actually means and whether it is an adequate and scientifically sound goal for water policy. An extensive debate amongst hydrologists in Western countries has led to the conclusion that groundwater cannot be regulated independent of surface water. More recently, a committee was set up by the Government of India to explore the integration of surface and groundwater institutions in India (COR 2016).

This article focuses on identifying the appropriate goal of groundwater regulation. We do not, however, deal with how this goal is to be achieved, including considerations of law, enforcement, pricing and fine-tuning by aquifer types (as in Kulkarni et al 2015). We begin by explaining the functioning of the hydrological cycle, the close relationship between groundwater and surface water, and consequently, the inappropriateness of conventional notions of sustainable groundwater use. We then present empirical evidence in support of this theoretical argument in the Indian context. We show why the conventional approach to groundwater policy and regulation in India is fundamentally flawed. We end by making a case for integrated management of ground and surface water resources in India. Finally, we present an alternative integrated approach that correctly accounts for biophysical linkages and spells out its implications.

2 Conceptualisation of the Water Cycle

2.1 Early Compartmentalisation

Until quite recently, groundwater and surface water hydrology have tended to be taught, studied and applied by distinct scientific communities. Most groundwater hydrologists ("hydrogeologists," usually with a background in geology) are concerned only with the groundwater or "saturated"[3] zone of aquifers. The groundwater table is the upper boundary that separates the saturated zone which lies below it from the aerated or vadose zone above it.

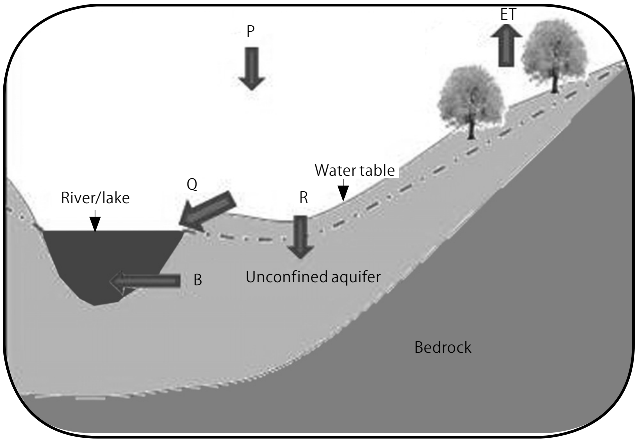
Early groundwater hydrologists conceptualised the aquifer as a bucket into which water enters and from which water is extracted, as shown in Figure 1A, where R is recharge (water that infiltrates and reaches the groundwater table) and M is pumping. Based on this conceptualisation, they made simplistic assumptions about what sustainable groundwater extraction meant. "Safe yield" was defined as "the limit to the quantity of water which can be withdrawn regularly and permanently without dangerous depletion of the storage reserve" (Pierce et al 2013). The "bucket model" led to the prescription that to achieve sustainable use, pumping must be less than recharge (that is, $M \leq R$). Thus, the assumption was that all recharge was available for extraction and use.

However, this conceptualisation does not accurately reflect reality and is in fact physically impossible. One way to understand this is to visualise what would happen in Figure 1A if there was no pumping. Each year, rain would fall and recharge the aquifer. Over millions of years, the aquifer would fill up, eventually bringing the water table to the land surface. Since even in prehistoric, pristine conditions, the entire land area of the planet was not covered by marshland, there has to be a pathway for the water entering the ground to exit the aquifer, suggesting that the bucket model is fundamentally flawed; any conceptualisation of aquifers must include an exit pathway.

While groundwater hydrologists were primarily concerned with water below the ground, surface water hydrologists (mostly civil engineers) tended to be equally myopic in focusing on water above the land surface. They were concerned mainly with the relationship between rainfall (P) and streamflow (Q) as shown in Figure 1B. Since many rivers continue to flow for months after the rains stop, surface water hydrologists have long understood that the dry season flows originate from groundwater seeping into streams; they termed this baseflow (B). Though they recognised the existence of baseflow, their focus has been on quantifying it without paying too much attention to what might cause it to increase or decrease. Moreover, because rainfall varies within and across years, the field of surface water hydrology was dominated by concerns of how to store and use an unpredictable endowment of water. "Dependability" rather than "sustainability" was the management goal. As a result of this conceptualisation, the effect that excessive groundwater extraction might have on streamflow did not receive much attention until recently.

In the last two decades, advances in eco-hydrologic research have drawn attention to another gap: the role of vegetation,

Figure 2: Components of the Water Cycle in a Pristine Watershed with Minimal Human Interference



which was hitherto neglected by both ground and surface water hydrologists. It has become increasingly clear that in most semi-arid landscapes natural vegetation may uptake and transpire anywhere between 50% and 80% of the rainfall before it ever reaches a stream or aquifer. Therefore, changes in land cover can have a dramatic impact on both surface and groundwater availability.

2.2 Integrated Understanding of the Water Cycle

Recent research has allowed us to arrive at an integrated understanding of the water cycle. The water cycle under pristine (non-human-influenced) conditions is depicted in Figure 2 in a simplified form. The key components of the water cycle are:

(i) Precipitation (P) brings water from the atmosphere onto land.

(ii) A fraction of the precipitation enters the soil as infiltration (I); the rest runs off the land as surface run-off (Q) and ends up in stream and river channels.

(iii) The infiltrated water becomes soil moisture. As the water moves through the soil column, some of it is used by trees and plants and returns to the atmosphere through evapotranspiration (ET).

(iv) Some of the infiltrated water makes it past the roots of plants and trees and eventually reaches the groundwater table. This process is called recharge (R).

(v) As the groundwater table rises, it may eventually intersect a stream channel, at which point the groundwater seeps into the channel. This process is called natural groundwater discharge (when described from a groundwater perspective) or baseflow (when described from the stream's perspective) (B). The most visible example of natural discharge or baseflow is the flow we would see in peninsular (non-snow-fed) rivers long after the monsoon is over.

Under pristine conditions (Figure 2), if the average groundwater level is more or less stable, any recharge must be accompanied by an equal discharge into streams, rivers or the ocean. The principle that water is not created or destroyed, and therefore all water that enters a watershed must exit or add to storage, is called a water balance.

The water balance equations under pristine conditions (minimal human interference in the water cycle) are presented below.

Eq i-a below represents the water balance if the frame is drawn "above the ground." It suggests that any rain falling on the surface must run off or infiltrate, and any water that infiltrates must either be transpired by vegetation or gradually make it down to the groundwater table as recharge.

$$P = ET_o + R_o + Q_o \quad \text{... (i-a)}$$

where P is precipitation (rainfall), ET is evapotranspiration, Q is run-off in the stream, and R is recharge. The subscript zero denotes pristine conditions (and is not applied to precipitation under the assumption that anthropogenic changes in a catchment do not affect precipitation).

Eq i-b represents the water balance if the frame is drawn "below-the-ground." In the absence of pumping, any recharge that makes it to groundwater must, on average, exit the system as baseflow or sub-marine discharge.

$$R_o = B_o \quad \text{... (i-b)}$$

where B is baseflow discharged to the stream (or submarine discharge if the aquifer extends past the coastline).

Adding the two equations, the integrated water balance equation across ground and surface water is

$$P = ET_o + (Q_o + B_o) \quad \text{... (i-c)}$$

It is worth noting that recharge does not appear in eq i-c. Recharge is merely a process that shifts water internally from one pool (surface water) to another (groundwater); it does not create new water. Thus, in the big picture, all rainfall must eventually end up in only one of two places—evapotranspiration or discharge to the ocean.

Humans make changes to several components of the water cycle. The effects of pumping and land use change are shown in Figure 3A (p 110). With pumping, a cone of depression forms around pumping wells. In unconfined aquifers, as the cone of depression spreads, the groundwater table drops. When the groundwater table close to the stream drops, baseflow decreases.

Under human-influenced conditions, the "above-the-ground" water balance would be:

$$P = ET_H + R_H + Q_H \quad \text{... (ii-a)}$$

where R_H is the recharge, ET_H is the evapotranspiration and Q_H is the streamflow under human-influenced conditions.

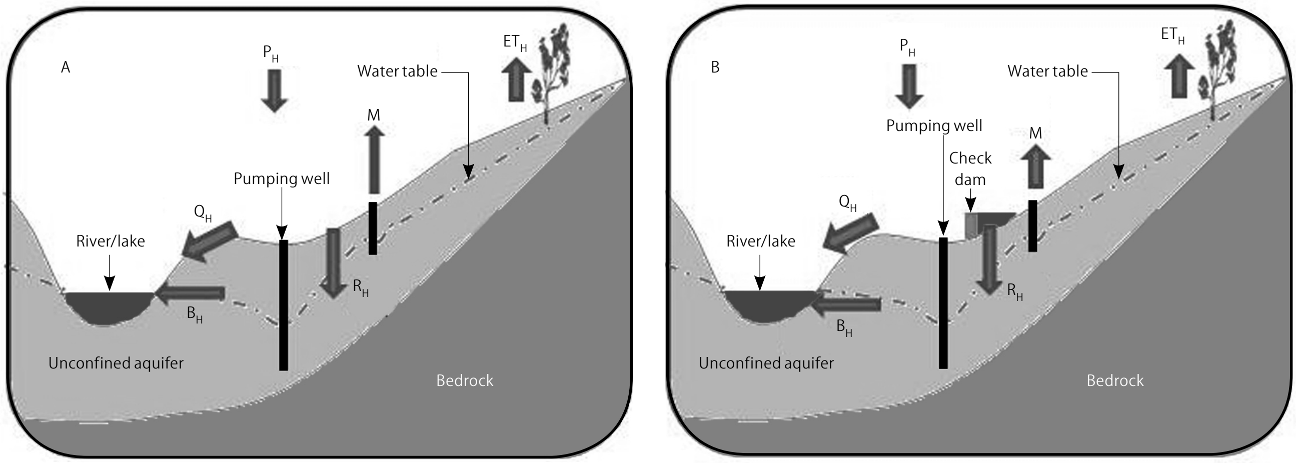
It is assumed that direct human alterations in the local watershed do not change precipitation significantly (though of course larger global planetary change may).

Then, if groundwater has not reached a new equilibrium, the "below-the-ground" water balance would be:

$$dV/dt = R_H - B_H - M \quad \text{... (ii-b)}$$

where V is the amount of groundwater in the aquifer, M is the net pumping (use of groundwater, which is the gross amount pumped minus return flows) and B_H is the baseflow discharged to surface waterbodies under human-influenced conditions

Figure 3: Conceptual Models of the Aquifer and Their Implications



(A) is the correct model of unconfined aquifer with pumping and land cover change, showing connectivity to surface waterbodies. (B) is an unconfined aquifer with check dams, land cover change and pumping.

(typically lower than B_o). Eq ii-b indicates that the change in groundwater storage is the difference between water entering groundwater (recharge) and water leaving groundwater (baseflow and pumping).

Note that R_H may be higher or lower than R_o. Deep-rooted exotic plantations may transpire more than natural vegetation, decreasing recharge in human-modified watersheds. Alternatively, if the water table drops below the streambed, the stream may begin to recharge the aquifer instead of the aquifer contributing to the stream (Figure 3A).

Subtracting the two equations, the integrated water balance for both ground and surface water is:

$$P - dV/dt = ET_H + (Q_H - B_H) + M \quad \text{... (ii-c)}$$

Now, if sustainable extraction is defined as the net pumping rate that ensures that groundwater levels are (on average) stable over time, then dV/dt must be equal to zero. So, subtracting eq ii-c from ii-a, we get

$$0 = (ET_o - ET_H) + (Q_o - Q_H) + (B_o - B_H) - M \quad \text{... (iii-a)}$$

That is,

$$M = \Delta ET + \Delta Q + \Delta B \quad \text{... (iii-b)}$$

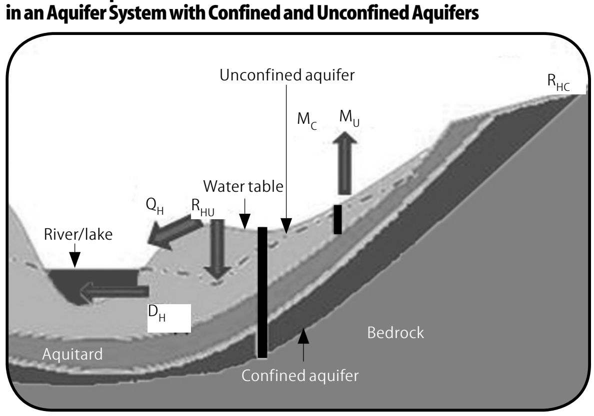
In simple terms, to avoid depletion under pumping, any net water extracted by pumping must be compensated by reductions in natural evapotranspiration, surface run-off and/or baseflow.

In the last few decades, in response to declining groundwater tables, efforts have been made to raise recharge by building check dams or other artificial recharge structures (Figure 3B). As pointed out above, however, recharge does not figure in the final eq iii-b. All that check dams do is increase recharge at the expense of run-off. Check dams or other recharge structures cannot create any "new" water. They can only reallocate it.

To summarise, a detailed consideration of the hydrological cycle shows that the bucket model, which underpinned much of early groundwater regulation, is flawed. From an integrated perspective, any pumping for consumption must result in reductions in baseflow (often called discharge capture), or reduction in evapotranspiration (ET capture), or in surface run-off (run-off capture), even if groundwater levels are maintained constant (Bredehoeft 2002).

Now, as a society, we may choose different options—we may engage in no pumping and simply replace one type of vegetation (say forests) with another more useful one (say agriculture) with similar evapotranspiration, thereby leaving surface run-off and baseflows largely unchanged—this was probably the case before the advent of large-scale surface or groundwater irrigation. We may divert surface flows to irrigated agriculture using dams, thereby obviously reducing

Box 1: Conceptualisation of Groundwater-Surface Water Interactions in an Aquifer System with Confined and Unconfined Aquifers



In confined aquifer systems (like the one in the figure above), the aquifer may not have an exit pathway, which means that under pristine conditions the aquifer is fully saturated, and therefore recharge is zero. All the rain that falls in the recharge zone (the right end of the figure) must flow off the land surface and contribute to streamflow. So, instead of discharging at the downhill end as in the case of the unconfined aquifer, the confined aquifer "discharges" or "rejects recharge" at the *uphill* end (Ponce 2007). Any pumping from this aquifer will then lead to that much recharge at the uphill end, reducing the uphill end discharge or rejected recharge by that amount. The basic argument—that net pumping will lead to either declining levels in the aquifer and/or declining surface run-off or discharge (in this case by capturing the rejected recharge)—still holds.

discharge to the ocean. Or we may pump groundwater at the expense of the stock of groundwater (making *dV/dt* non-zero). Alternatively, we may try to maintain groundwater levels steady by capturing flows that were going into oceans or the evapotranspiration from wetlands. These are all trade-offs that a society has to make through the political process. "Maintaining non-diminishing groundwater levels" is neither an "objective" nor a useful societal goal by itself.

Note that the situation described in Figures 3A and 3B pertains to an "unconfined aquifer," an aquifer into which water seeps from the ground surface directly above it. Even with a more complex aquifer system, with both confined and unconfined aquifers, the basic argument does not really change (see Box 1, p 110). In the case of a fossil aquifer which has no connection to any surface waterbody and hence no recharge or discharge, there is no question of sustainable use. All pumping is unsustainable, and the relevant question becomes over what time frame and under what circumstances it ought to be depleted. Thus, sustainable use is not a very useful concept in any conditions.

3 Water Policy and Regulation in India

These ideas, recognised by hydrologists the world over for some decades now, have been slow to make their way into regulatory thinking and policies in India. The main groundwater regulatory agency in India, the CGWB, still appears to subscribe to the concept of safe yield or sustainable yield, and therefore implicitly to the bucket model. This seems clear from the methodology laid out by CGWB's Groundwater Resource Estimation Committee (1997) for classifying an area into one of four categories:

(i) Safe areas that have groundwater potential for development,
(ii) Semi-critical areas where cautious groundwater development is recommended,
(iii) Critical areas, and
(iv) Overexploited areas, where there should be intensive monitoring and evaluation, and future ground development should be linked with water conservation measures.

These categories are supposed to reflect the extent to which groundwater extraction in a particular district is sustainable. The categorisation is arrived at using two variables: the long-term trend in groundwater levels and the extent (or "stage") of groundwater "development." Long-term groundwater level trends are generally computed for a period of 10 years. A significant rate of water level decline is defined as more than 10 cm to 20 cm per year, depending upon local hydrogeological conditions.

The stage of groundwater development is calculated as:

$$\text{Stage of groundwater development} = \frac{\text{Annual gross groundwater draft}}{\text{Net annual groundwater availability}}$$

Here, net annual groundwater availability is simply taken as recharge, less a small allocation for natural discharge (baseflow), *which is set at 5% to 10% of the annual recharge*.

Using these two variables, categorisation of a particular area is based on the rules in Table 1.

Table 1: Method of Categorising Groundwater Status of an Area

Sr No	Stage of Groundwater Development	Significant Long-term Decline		Categorisation
		Pre-monsoon	Post-monsoon	
1	<= 70%	No	No	Safe
2	>70% and <=90%	No Yes/no	No No/yes	Safe Semi-critical
3	>90% and <=100%	Yes/no Yes	No/ yes Yes	Semi-critical Critical
4	>100%	Yes/no Yes	No/yes Yes	Overexploited Overexploited

Source: Central Ground Water Board, Ministry of Water Resources, Government of India, http://cgwb.gov.in/.

In light of the contemporary scientific understanding of the hydrologic cycle, however, this approach is highly problematic. If 90% or 95% of recharge is considered available for extraction, then it is obvious that the CGWB is operating on a bucket model or a "slightly leaky" bucket model (wherein a small but fixed allowance is made for natural discharge to rivers). This introduces two biases. First, it sets too generous a limit on groundwater extraction. For instance, if 80% of the recharge is being extracted, but pre-monsoon groundwater levels are not currently declining, then, as Table 1 shows, the status may even be considered "safe." However, in fact, it is possible that pumping has been at the expense of drying wetlands or reduced streamflow. Second, if recharge is augmented through recharge structures such as check dams, then water levels are maintained despite increased pumping; but this approach ignores the fact that the increased recharge has come at the expense of surface run-off.

It is not that CGWB is entirely unaware of the developments in thinking on groundwater sustainability outlined earlier. In a recent publication, which is a global review of concepts and methods, Chatterjee and Ray (2014: 68) from CGWB have acknowledged that "sustainable yield policy, which ensures a minimum discharge, is generally regarded as the preferred option." Unfortunately, the review stops short of recommending a fundamental change in the conceptual foundations of India's policy on sustainable groundwater use.

Likewise, historically, in surface water regulation, the link between groundwater and surface flows has been recognised only slowly and partially. One forum where the link has been extensively debated is in the interstate water disputes tribunals that have tried to apportion river waters between states. For instance, deliberations of the Krishna Water Disputes Tribunal (KWDT) in 1962 acknowledged that groundwater should also be allocated. However, the KWDT eventually decided that in the absence of data, underground water resources of the states concerned would not be taken into account in determining equitable distribution of the waters of the Krishna basin (D'Souza 2006). The Narmada Water Disputes Tribunal (NWDT) and Godavari Water Disputes Tribunal (GWDT) also took similar positions: that because groundwater flows cannot be accurately estimated from the technical point of view, they are not legally cognisable and should be omitted altogether in considering allocation of interstate rivers (GWDT 1979; NWDT 1978).

Three decades later, when the Cauvery Water Disputes Tribunal (CWDT) gave its award, scientific understanding of groundwater as well as the importance accorded to it had evolved considerably. The CWDT award of 2007 has in fact devoted almost 60 pages to groundwater, albeit in a lopsided manner. Groundwater is taken into account only in the context of recharge in command canal areas and the extent to which existing groundwater use should be counted as part of Tamil Nadu's allocation. With Tamil Nadu and Karnataka agreeing early on to consider only groundwater in the Cauvery delta area for assessment and allocation, groundwater extraction in the non-deltaic parts of Tamil Nadu and Karnataka, lying within the Cauvery basin, was not considered (CWDT 2007: 112–71). The idea that excessive groundwater depletion outside of the delta region could reduce streamflow is not acknowledged anywhere. Indeed, in allocating Bengaluru's share, the tribunal assumes that 50% of Bengaluru's domestic water needs can be met from groundwater (CWDT 2007: 103), interpreting groundwater as a resource independent of the surface waters of the Cauvery basin.

In the broader sphere of water regulation in India, there has been some movement towards recognising the link between groundwater and surface water, but it is again quite slow. The National Water Policy documents of 1987 (MoWR 1987) and 2002 (MoWR 2002) did not seem to recognise this issue at all. The model groundwater bill of 2005 (MoWR 2005) drafted by the central government contained no mention of natural discharge or baseflow. In fact, sustainable yield is not mentioned at all in this bill—the goal is simply to regulate groundwater development. This lacuna is replicated in most of the state acts that were modelled on this bill—the purpose and criteria of groundwater regulation are not mentioned. Similarly, water resource regulatory authorities such as the one set up by Maharashtra in 2005 are mainly focused on setting tariffs and assigning surface water entitlements (Koonan and Bhullar 2012) and also cover only surface water issues, perpetuating the same compartmentalised thinking.

In mid-2016, the Ministry of Water Resources put out a draft groundwater bill for public comment (MoWR 2016). In its preamble, the bill clearly recognises that "water is unitary in nature, requiring the integration of surface water and groundwater," and that "ensur[ing] conjunctive use" is one of the legislation's objectives. By setting "sustainable water use" as another objective, however, and not spelling out what sustainability means in this integrated context,[4] the bill only creates confusion. After the initial preamble, nowhere does the bill mention the need for regulating local groundwater use and accounting for upstream and downstream water use (including minimum environmental flows).

In the absence of a widespread understanding and internalisation of the integral link between surface and groundwater, it is not surprising that efforts to tackle groundwater depletion are isolated, with little regard to their consequences for surface water. The large-scale efforts to increase recharge through watershed development programmes (Sakthivadivel 2007) and more recently through use of "injection wells" directly into the aquifer (Kavuri et al 2011) are examples of this. Critical voices such as Dinesh Kumar et al (2008) have been rare and largely ignored.

4 Empirical Evidence

The theoretical explanations above clearly show that compartmentalised thinking and especially the bucket model are fallacious. However, there is also substantial empirical evidence to support the argument that groundwater pumping does in fact affect river flows.

A number of studies in the US have already shown the relationship between pumping and declines in baseflow of streams with which the aquifer is connected. For instance, Sophocleous (2000) has shown that the network of perennial streams within the High Plains aquifer region of Kansas state shrank significantly over a 33-year period when groundwater pumping had increased. Zeng and Cai (2014) show that groundwater extraction reduces baseflow and makes the surface flow response much more erratic in the Republican River Basin.

In India, however, there are only a handful of empirical studies linking groundwater pumping to surface flows. Ranade (2005) was perhaps the first to attempt to estimate the amount of upstream groundwater use in the part of the Narmada river basin that lies in Madhya Pradesh. He estimated it to be as high as 15% of Madhya Pradesh's share of river waters and argued that groundwater abstraction should be included in the NWDT's decisions. Subsequently, a study of the Malaprabha basin found that sugar cane cultivation had dramatically expanded in the Malaprabha dam catchment (Heller et al 2012). This cultivation was being carried out using a combination of groundwater pumping and direct lift from the river and can explain the decline in the inflows to the dam (Reshmidevi and Badiger 2009). Recent work in the Arkavathy basin provides further evidence of this phenomenon (Srinivasan et al 2015). The study found that flows reaching the Thippagondanahalli reservoir (west of Bengaluru) had declined by more than 75% over a 40-year period. The study systematically tested and eliminated alternative explanations for this decline, including changes in rainfall patterns, rise in temperature leading to increased evapotranspiration, and stream channel blockages.

A few others have demonstrated these effects in the context of watershed development programmes. These programmes involve the construction of recharge structures such as gully plugs, check dams, nullah bunds or continuous contour trenches, typically at a "micro-watershed" scale of about 500 hectares. The local benefits of these "treatments" are tangible, and result in immediate increases in groundwater-irrigated areas. But when scaled up to entire milli-watersheds of say

10,000–20,000 hectares, such watershed "development" and consequent increases in net pumping have been shown to reduce inflows into irrigation tanks at the bottom of such milli-watersheds (Batchelor et al 2000; Batchelor et al 2003; Glendenning and Vervoort 2011). Overall, however, hydrologists in India are only gradually beginning to make the causal link between groundwater withdrawal and decline in surface flows.

5 Towards Integrated Ground and Surface Water Policies and Institutions

Once we reject the bucket model and therefore the idea of sustainable yield, how do we proceed to operationalise integrated ground and surface water management?

The first step would be to make the shift in scientific circles. Hydrologists must stop describing the total annual utilisable water resources of India as so many km^3 of surface water and so many km^3 of groundwater, because this erroneously suggests a fixed partitioning between surface and groundwater. It also frequently results in a "double accounting" problem, where the same unit of water is counted twice: once as groundwater recharge, and once as baseflow. Instead, surface and groundwater hydrologists must jointly make a nationwide effort to measure the water entering and exiting the system—rainfall, evapotranspiration and discharge to the ocean (both surface discharge via rivers and sub-marine discharge from groundwater). Basin-scale models must be rebuilt to include the effects of hundreds of small dams, thousands of check dams, lakhs of borewells and the newly added areas under deep-rooted vegetation such as eucalyptus, and thus represent real-world changes realistically. These models need to be linked to hydrogeological investigations that seek to delineate aquifer types, forms, and boundaries, keeping in mind that aquifers and watersheds may not coincide and that aquifers are not buckets.

The second step would be to make the necessary changes in the legal framework. We need to question whether a model groundwater bill separate from a draft national water bill is even necessary. Even if they are deemed necessary, the bills must mirror each other and use a consistent set of hydrologic and legal assumptions. As long as surface water is allocated, while groundwater remains open access, overexploitation and conflict are inevitable. Any water law must aim to ensure fair allocation of the total annual available water flows between different types of uses, including ecological uses, at multiple scales. The focus must shift from sharing the surface water pie to sharing the rainfall pie. Where water resources regulatory authorities have already been set up, as in Maharashtra, their mandates will have to be amended to include ground and surface water use in all its forms.

The third step would be to get agencies to acknowledge that decisions on fair allocation between users are not scientific or technical decisions. Any water use (water abstracted minus return flows) at any point, whether of surface or groundwater, reduces the availability at some other point in space and time. How much water may be used by whom, where, for what purpose, and over what time frame then becomes a normative question. Moreover, the lens of equity or fairness becomes more relevant than that of sustainability.

Abandoning the safety of an "objectively" defined criterion such as $M \leq R$ and venturing into the subjective determination of a fair and equitable allocation of the total annually renewable water resource is of course highly discomfiting for regulators brought up with the idea of "leaving it to the scientists." However, subjectivity need not imply arbitrariness, if institutions for systematic and transparent decision-making, involving multiple stakeholders, are put in place. This will require a continuous interaction between scientists, water users, and decision-making bodies through something like "cooperative modelling," using the kind of decision-support systems indicated by Pierce et al (2006). These models enable stakeholders to see the consequences of the choices they make.

To build confidence in such decision-making processes, they should be preceded by transparent and participatory information generation, that is, water budgeting processes that are a combination of top-down and bottom-up exercises. The top-down exercise would begin at the basin scale (or if water in a basin has already been allocated between states by a tribunal, then at the within-state basin scale), make further assumptions about minimum environmental flows, and outline scenarios for the use of ground and surface water in different sub-basins/watersheds and their consequences for smaller units. The bottom-up exercise would involve budgeting at, for instance, a gram panchayat level, in which different water users and their uses of water would be estimated and tweaked such that only the renewable flow, including receipts from upstream but also including commitments to downstream, is allocated and used. When compared with current consumption, the stakeholders will see whether they need to reduce use somehow, whether they have the space to grow, or whether they need to negotiate changed allocations with other users in the basin.

6 In Conclusion

What began as a critical examination of the biophysical basis for regulating groundwater use eventually made it clear that water consists of an interconnected set of flows, wherein the issue is one of fair and equitable allocation of all water available. In this article, we make three central arguments: first, groundwater, soil moisture and surface water are really a single integrated resource and therefore must be regulated as such. Second, since all rain that has ever fallen on the earth has left the watershed either as evapotranspiration or discharge to the ocean, any new human-induced water use, whether groundwater or surface water, must involve replacing one of those prior uses. Third, because all water use involves trade-offs between human and ecologic water uses, neither "restoring pristine flows" nor "maintaining groundwater undiminished" constitute objective criteria for regulation. All decisions should be about fair and equitable allocation to users—human and non-human users, surface and groundwater users, upstream and downstream users, and so on. This shift in conceptualisation must then translate into integrated monitoring, holistic laws and institutions, and participatory water budgeting at multiple scales, aquifer types and demands on the resource via transparent, inclusive processes.

Notes

1 http://www.ielrc.org/water/doc_gw.php.
2 http://cgwa-noc.gov.in/.
3 The saturated zone is that part of the aquifer where the soil or rock pore spaces are filled with water. The vadose or unsaturated zone lies between the land surface and the groundwater table. In this zone, some water clings to soil particles but the pore spaces are not completely filled with water.
2 Note that sustainability as an objective has never been proposed for surface water—the focus there is clearly on fair allocation.

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