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ground water
Technical Commentary/

The False Promise of Sustainable Pumping Rates

by Eloise Kendy[1]

The water table has been dropping steadily for nearly 30 years, natural streamflow has almost completely ceased, salt water intrudes into previously freshwater aquifers, and the land surface is beginning to subside. In response, cash-strapped governments expend great sums of money to improve irrigation efficiency. Canals are lined, precision irrigation systems are installed, farmers are educated, and ground water pumping decreases significantly—in some places by more than 50% over a decade. Yet, the water table continues its precipitous decline.

A horror story? Yes. But a fantasy? Unfortunately, no. This is the true saga of the 320,000 km^2 North China Plain, home to well over 200 million people and producer of more than half of China's wheat and a third of its maize. In essence, it also describes the major grain-producing regions of South and Central Asia, North Africa, the Middle East, and the High Plains of the United States, among others. What do these disparate regions share in common? In every case, shallow, unconfined, alluvial aquifers supply water for vast expanses of irrigated cropland.

Theis (1940) first elucidated, and Bredehoeft et al. (1982), Bredehoeft (1997, 2002), and Sophocleous (1997) eloquently reiterated, that the level at which a water table stabilizes depends on the change in recharge and discharge induced by ground water development. That is, in order for the rate of change in ground water storage to be zero,

$$\Delta R_0 - \Delta D_0 = P$$

where ΔR_0 is change in the "virgin," or predevelopment, recharge rate, ΔD_0 is change in the virgin discharge rate, and P is the pumping rate. The virgin recharge rate, R_0, is irrelevant to sustainable ground water pumping.

The purpose of this commentary is to add that, in many important cases, the pumping rate, P, is equally irrelevant. Alley et al. (1999) pointed this out in the context of sustainable ground water development:

> In determining the effects of pumping and the amount of water available for use, it is critical to recognize that not all the water pumped is necessarily consumed. For example, not all the water pumped for irrigation is consumed by evapotranspiration. Some of the water returns to the ground water system as infiltration (irrigation return flow). Most other uses of ground water are similar in that some of the water pumped is not consumed but is returned to the system. Thus, it is important to differentiate between the amount of water pumped and the amount of water consumed when estimating water availability and developing sustainable management strategies.

In many shallow, unconfined aquifer systems, water that is not consumed returns to the aquifer. This is certainly true of the North China Plain, where surface flows diminish completely before reaching the sea, and salt water intrudes at the coastline. The only water that does not return to the aquifer is that which evapotranspires from crops and soils. Therefore, it is not pumping per se that depletes ground water storage, but only that component of pumped water that evapotranspires.

Figure 1 illustrates this concept. Luancheng County, Hebei Province, is a ground water–irrigated agricultural area of the North China Plain. The ground water budget indicates that lateral inflows balance lateral outflows (Kendy 2002), so only precipitation and evapotranspiration are shown in the figure. Average annual precipitation has decreased in Luancheng County, from ~54 cm/year in 1955–1980 to ~46 cm/year in 1971–2000. Evapotranspiration, meanwhile, has greatly increased, from ~46 cm/year when farmers grew only one rain-fed crop every year, to an average of 66 cm/year under the current, irrigated two-crop-per-year system. Thus, although potential evapotranspiration has not changed, actual evapotranspiration has increased substantially. Before irrigation development and during the early years of small-scale irrigation, precipitation exceeded evapotranspiration. Excess water recharged the underlying aquifer and at times even filled the aquifer to capacity, generating runoff. Later, as the irrigated area grew and double cropping became widespread, crop evapotranspiration increased until it surpassed precipitation. In

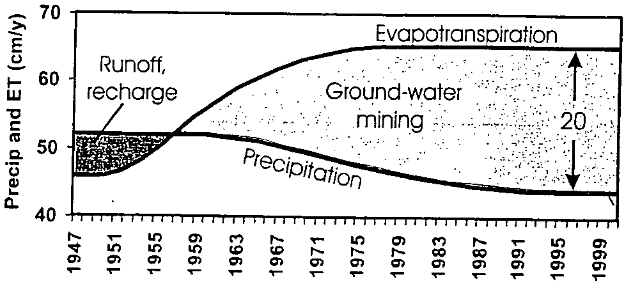

Figure 1. General relationship between precipitation and evapotranspiration for cropland in Luancheng County, PR China, 1947–2000. Actual evapotranspiration has increased over time as the area and duration of irrigation cropland has grown. Water-table declines indicate that ground water storage depletion is ~20 cm/year.

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order to maintain the continuous cropping pattern, another water source was needed to satisfy the deficit between precipitation and evapotranspiration. That additional water comes from ground water mining. The quantity mined, 20 cm/year, fully accounts for the observed water table declines.

Thus, despite a significant decrease in pumping, the water table has declined at a nearly constant rate of ~1 m/year (specific yield is ~0.2) since the mid-1970s, when double cropping became extensive. All crops require a certain quantity of water—*in this case 66 cm/year*—regardless of the amount applied. If they receive 100 or 1000 cm/year, they will still evapotranspire 66 cm/year, and the rest will drain through the soil profile. As long as all crop-water requirements are met, any reduction in pumping triggers a corresponding reduction in ground water recharge from irrigation drainage. The net impact on water-table declines is nil. In other places, where unirrigated land is still available for conversion, irrigation efficiency can actually worsen the ground water situation. For example, improved irrigation efficiency in the High Plains of the United States has allowed farmers to irrigate more cropland, thereby accelerating aquifer depletion (Dennehy 2002). To arrest water-table declines beneath these ground water–irrigated areas, evapotranspiration has to decrease. Thus, sustainability (defined here as stabilizing ground water levels) begins not with reducing irrigation pumping per acre, but rather with reducing the total acreage of irrigated land.

Somehow, this message is not reaching water-resource analysts, managers, and users, whose energy remains focused on pumping rates. For example, well-respected China water expert James Nickum (1998, p. 886) optimistically concluded: "Groundwater overdraft does not deplete the resource, which is continuously renewed . . . Aquifers will replenish with reductions in withdrawals." Following this thinking, everyone from Worldwatch Institute to the World Bank touts irrigation-efficiency improvements as the panacea for ground water declines, regardless of the physical configuration of the hydrologic system (Hawken et al. 1999; Postel 1999; Shin 1999; World Bank 2001). Yet, hydrogeologists have always known that reducing pumping and recharge concurrently does nothing to increase heads.

There exist several possible explanations for the incongruity between what hydrogeologists know and what water managers understand. One is that, whereas data for ground water pumping are routinely compiled and published (Gleick 2000; Price and Clawges 1999; United Nations 1997), water-consumption rates are notoriously difficult to find. Hence, advocates for water sustainability routinely cite water use—rather than consumption—statistics, implying that withdrawals alone constitute the problem facing water managers (Hawken et al. 1999; Postel 1999; Wood 2001). Another reason is that high-tech "solutions" such as precision irrigation systems tend to be more politically palatable than reducing crop production.

To contribute meaningfully to ground water sustainability, hydrogeologists must collaborate with a wide range of professionals (Loucks 2000). Successful collaboration requires that we communicate effectively both within and across disciplines. Keller and Keller (1995, 1996) introduced a new paradigm for evaluating irrigation-system performance, which bridges the communication gap. By considering effective irrigation efficiency at the basin scale, rather than classical irrigation efficiency at the field scale, excess irrigation water that returns to the system for further diversion and application elsewhere no longer represents water consumed (Keller and Keller 1995; Keller and Keller 1996). Molden and Sakthivadivel (1999) incorporated this paradigm into the traditional water-balance approach by classifying outflows from a hydrologic system according to availability or potential availability for future use. Perangininangin (2001) adapted their approach to ground water management. The information thus generated by quantifying and distinguishing beneficial from nonbeneficial depletion gives policymakers and water users a much clearer understanding of water-management options than water-balance or water-use data alone.

Regardless of the analytical approach, sustainable water management depends on accurate water-consumption data (i.e., water lost by evaporation and transpiration or otherwise not returned to the hydrologic system). Without this information, policymakers lack the quantitative analyses needed to back up potentially unpopular decisions. In the North China Plain, we know that evapotranspiration needs to be reduced, but in this densely populated area, land fallowing is hardly an option. Urbanization, in contrast, offers social and economic benefits that governments support.. However, many analysts mistakenly believe that, because urban areas generally pump more ground water per acre than irrigated rural areas, their hydrologic impacts are more severe. In reality, most municipal water eventually returns to the hydrologic system, rather than evapotranspiring or being incorporated into products for export; therefore, it is generally accepted that efficient domestic and industrial land use consumes less water than irrigated cropland (Seckler et al. 1998; Alcamo et al. 2000). If these consumption rates were quantified, then the method of Molden and Sakthivadivel (1999) could provide policymakers with clear-cut distinctions between hydrologic impacts of different land uses. But until actual numbers are available, policymakers have no choice but to continue responding to land-use changes as they occur, rather than to plan for those changes rationally, according to water availability.

Stabilizing the water table means balancing the water budget of the entire hydrologic system, not just the aquifer. A careful accounting of all water consumption—past, present, and future—is essential for managing the land and water uses associated with each. Although hydrogeologists sometimes are not directly concerned with the fate of ground water after it has been pumped, it is aboveground consumption rates that are key to sustainable pumping from shallow, unconfined aquifers, regardless of the rate at which that water is pumped.

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