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Commentaries

Enhancing China's Three Red Lines strategy with water consumption limitations

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Many countries face problems of scarcity and unsustainability in the water sector [1]. In China, overexploitation of water has resulted in rapidly declining aquifers in important grain-producing areas, greatly reduced river flows, and often severe river pollution [2,3]. Industrial water withdrawals have stagnated in recent years, but the share of water consumption has continuously increased in the manufacturing sector due to recirculation [4]. Revegetation and ecological restoration are approaching sustainable water resource limits in many regions of China [5]. Therefore, China has implemented several water policies reducing the impact of water shortages and pollution on the economy and domestic living standards and enforced a series of water laws since 2000. However, these efforts have not significantly reversed the trend of increasing water demand and quality degradation. In response, the Chinese government has established a "Stringent Water Resources Management System", or the "Three Red Lines" (TRLs, Table 1, http://www.gov.cn/zhengce/content/2012–02/15/content_2311.htm), as a long-term framework for addressing key water challenges.

The TRLs aim to ensure water sustainability by limiting water usage and improving water-use efficiency and water quality. The 2015 and 2020 figures are targets, while the 2030 indicator is binding. The rules, regulations, and indicators of the TRLs are further delineated in detail in series of China's policy documents. Under this system, targets are allocated for 31 provincial units (Supp-1 and Table S1 online), from which they are further broken down to more than 2500 county-level units, which consider local water availability and the need for social and economic development. Within this framework, governments at every level are accountable for meeting their own targets.

Annual reviews of the TRLs performance have been carried out since 2012 by the Ministry of Water Resources (MWR) (http://www.mwr.gov.cn/zwgk/zfxxgkml/201809/t20180918_1047934.html), which compiled provincial assessment reports based on county reports (Table 1, Supp-2 and Table S2 online). This process has successfully drawn attention to the need for radical action in the water sector by establishing national accounting and reporting procedures, but it is appropriate to consider, as experience has been gathered after 6 years, how well the process meets the country's needs and what can be improved to better support the country's robust and sustainable socioeconomic development (Supp-3 online).

(i) Indicator selection. With irrigated agriculture being the largest water consumer (Table 1, Fig. 1), the most significant indicators in the TRLs are the total water withdrawals and irrigation efficiency, which are measures to reduce water demand. Controlling water withdrawals reduces the total water use amount and improves irrigation efficiency to optimize the use of water in irrigated agriculture. Reported total water withdrawals decreased from 613 billion m^3 in 2012 to 602 billion m^3 in 2018, significantly below the original target of 670 billion m^3 for 2020. The amount of domestic water withdrawals increased from 54.63 m^3 in 2012 to 61.6 m^3 in 2018 per capita (Table S3 online); thus, the reduction was predominantly in irrigation withdrawals. However, the irrigated areas increased rapidly across China, from 62.5 Mha in 2012 to 68.3 Mha in 2018 (Table S3 online), i.e., a 9.25% increase, particularly in arid areas where crops rely on irrigation. For example, the irrigated area in Xinjiang increased by almost 21% between 2012 and 2018 (Table S3 online) [6]. Other sources [7] report much higher figures for total irrigated area and rate of increase (e.g., 63% from 2010 to 2017) (Supp-4 and Table S4 online).

An expansion of the irrigated area will increase water extraction, offsetting the reduction in water withdrawal related to an increase in water-use efficiency. Other things being equal (irrigation efficiency, weather, cropping patterns, etc.), if the irrigated area increases by 9.25%, the water withdrawal will increase by the same proportion. If the water withdrawal actually decreases, as reported, then irrigation efficiency is expected to have increased by more than 9.25%, whereas the reported increase in efficiency was only 5.4% from 2012 to 2018 (Table 1). In our view, other factors must have changed. For example, the cropped area decreased by approximately 1.893 Mha from 2010 to 2015, which led to a reduction in total cropland water consumption of 82.4 billion m^3 (−7.66%), including water from both rainfall and irrigation.

Hence, the selected indicators are incomplete for controlling water demand, especially in areas where irrigated agriculture is the main water use. For irrigation, increasing water-use efficiency may reduce the water applied to the field, implying that a higher proportion of water withdrawn for irrigation is actually consumed by plants. The consumed water is lost from the region or basin, and a lower proportion of water withdrawals for irrigation is returned

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Table 1
The "Three Red Lines" indicators, phased targets.

Red Line	Indicator	Phased target			Annual review						
		2015	2020	2030	2012	2013	2014	2015	2016	2017	2018
Control of water resources development and utilization	Total amount of water use in the whole country (billion m^3)	635	670	700	613.1	618.3	609.5	610.2	604.0	604.3	601.6
Water-use efficiency	Water use per thousand yuan of industrial value added (m^3)	13[a)]	6.5	4.0	6.90	6.70	5.95	5.83	5.28	4.56	4.13
	Irrigation efficiency for whole irrigation system (%)	53	55	60	51.6	52.3	53.0	53.6	54.2	54.8	54.4
Restriction of pollution in water function zones	Water quality compliance for important rivers and lakes in the function zones (%)	60	80	95	63.5	63.0	67.9	70.8	73.4	76.9	-[b)]

a) 30% reduction from 2010; b) "-": data is unavailable.

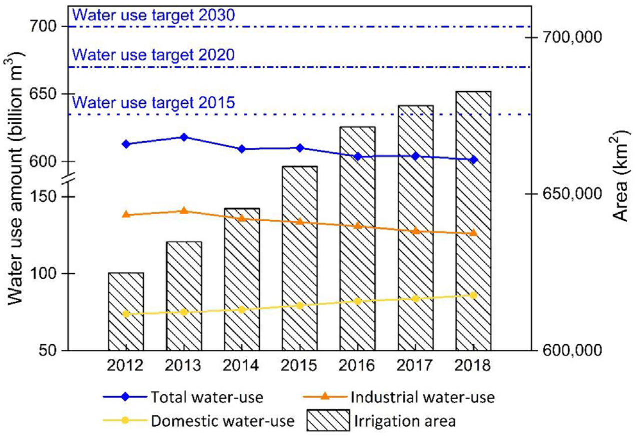

Fig. 1. Target and annual review of water use amount and irrigation area.

to the basin hydrological system. Improving irrigation efficiency will increase local crop yield, requiring more water for transpiration. Farmers tend to cultivate crops with higher water consumption or increase cropping intensity once water withdrawals are saved under higher water-use efficiency; under such conditions, the total water consumption amount may not decrease or may even increase. Consequently, less water is involved in basin water cycling [8], and return flows to other users must decrease.

Therefore, the pursuit of on-farm water-use efficiency may be counterproductive in terms of restoring a balance between demand and supply. In the absence of water consumption controls at the basin scale—the so-called "paradox of irrigation efficiency" [8]—results in either increased depletion of aquifers and rivers or reduced availability of water to other users [2,8]. Simple reliance on the control of withdrawals will tend to induce higher water consumption, as evidenced in the Murray Darling Basin, Australia, where substantial investments in on-farm efficiency have not generated measurable water savings [9]. Reduced water consumption must be a primary indicator [5].

While it is desirable to limit water withdrawals, an additional indicator of water consumption can confirm whether reported reductions in withdrawals are real, indicating whether water is actually being released to the environment as a result of reduced withdrawals and increased water-use efficiency. Thus, while withdrawals should continue to be monitored, additional independent data on water consumption should be collected and are readily available from satellite-derived evapotranspiration data [10,11]. Together, both would ensure better informed management decisions and a clearer indication of success in controlling water demand.

(ii) Setting the targets. China's climate varies from extreme aridity to wet, and this regionally uneven water scarcity is exacerbated by pollution [12]. Withdrawal limitations are necessary for arid regions but are not a priority in wet areas, where the main concern is inadequate quality. Only eleven of the thirty-one reporting regions are genuinely water scarce [13]. The water crisis occurs because of the spatiotemporal mismatch between freshwater demand and availability [1], which requires locally specified targets to recognize the importance of matching water policies to places [12]. Such targets should be adjusted to reflect the actual degree of local water scarcity in each region and province (Table S4 online).

Human activities and climate change have significantly influenced the natural hydrological cycle and altered water resource availability [14]. In recent decades, the natural landscape and associated hydrological characteristics have changed substantially worldwide as well as in China. It was observed that revegetation in China's Loess Plateau was approaching sustainable water resource limits [5,15]. The expansion of forests consumes more water, leading to a large decrease in the ratio of runoff to precipitation in many catchments [5].

Each of these interventions alters the spatiotemporal processes of the hydrological cycle, but these changes are not adequately reflected in the hydrologic models on which estimates of sustainable water use are based [5]. Therefore, a water consumption balance approach must be adopted to provide objective estimates of the available consumable water (ACW) for human use, i.e., the consumption cap at the basin or subbasin scale [10]. Such an approach would allow an analysis of the impacts of climate change, cropland expansion and large-scale revegetation programs. Furthermore, extended droughts or projected declines in precipitation due to climate change could be evaluated in terms of their impacts on the basin consumption cap [14], particularly for setting the 2030 targets.

The redline on water withdrawals helps ensure reallocation to environmental flows but does not capture the changes in ecological water consumption. Most rainfall is consumed locally by the natural landscape on which it falls—forests, grassland and wetland. These areas dominate the water consumption in arid or semiarid basins. Therefore, the ACW method, through summing the water consumption of the natural landscape, provides a basis for the rational tradeoff between the TRLs targets and environmental restoration, preventing water from being overallocated for afforestation and under allocated for human use [10]. This is especially relevant in China, which is experiencing significant greening of forests [5] (Table S3 online).

The target for industrial water-use efficiency was set low to be easily achieved, with the 2020 target already being exceeded in 2014 and the 2030 target being approached by 2018. Other government statistics report that industrial water-use efficiency increased from 5.46 m^3/1000 yuan in 2012 to 3.35 m^3/1000 yuan in 2018 (Table S5 online), which was significantly lower than the data reported in the annual review (6.9 and 4.13 m^3/1000 yuan, respectively) (Table 1). It seems that the target was set very low and has not been appropriately specified, thereby failing to consider the rapid industrial development and the evolution to higher value-added, less water intensive industry.

(iii) Independent assessment. Without credible capacity to monitor and enforce agreed norms, the TRLs could be weakened, derailed, or ignored. The MWR prepared their evaluation based on provincial reports, and it was not realistic for the MWR to verify the information based on conventional data collection methods. Furthermore, the data that are reported under the TRLs program are not routinely compared to other sources for consistency or validation. Therefore, it is essential to develop an independent performance review process to track the implementation of the TRLs using independent data sources with support by cutting-edge and cost-effective technologies (e.g., remote sensing, artificial intelligence, and big data).

Remote sensing provides a powerful complementary tool to conventional data sources. It can accurately directly monitor changes over time in indicators such as evapotranspiration [11], precipitation and soil moisture data, water surface areas, urban development and land-use patterns. These data contribute substantially to preparing a water consumption balance [10]. The declining trend in total water use was confirmed from the cropland reduction derived from land cover products [7]. Water consumption has been successfully obtained through remote sensing of evapotranspiration in major basins in North China, such as the Turpan Basin (Supp-5 online), Hai Basin, and Heihe Basin, over daily, monthly and annual time steps, covering 2000–2020. The costs of deriving these data through remote sensing are low—much less than maintaining the cost of water-metering equipment. This independent system can underpin the performance review to rigorously evaluate the outcomes of TRLs. The incorporation of ground measurements and crowdsourcing data is essential for independent assessment, not only for calibration and validation but also for supplementary data, e.g., the measurement of industrial and domestic water withdrawals and return flows to derive consumptive water use. Such successful independent assessments require high-quality data, adequate financial support and legal system guarantees to ensure sustainable and fair evaluation processes.

Overall, good governance requires a sound physical understanding of the resource, institutional accountability, transparency, legitimacy, public participation, justice, and efficiency. In establishing the TRLs, the government of China has improved accountability at all administrative levels, which are encouraged to find appropriate solutions, create a national program for reporting, and establish political commitments to targets to restore sustainable water use. These methods help with addressing the difficult issues where such problems are widespread [2,3]. Introducing consumptive use as an indicator enhances the clarity of objectives, the design of interventions, and the monitoring of outcomes for the TRLs program. Setting targets with an adequate reflection of local water scarcity and the impacts of human activities and climate change can make the goals more realistic and easier to implement and assess with regional specificity and priorities. Introducing independent assessments with remote sensing and cutting-edge technology, such as artificial intelligence and crowdsourcing data, will significantly increase the fairness, justice, and efficiency of implementing the TRLs in China. The changes recommended above would make the TRLs more effective in meeting the objectives established by the government, grounding the scientific foundation of the process. The World Bank Turpan project provides a paradigm (Supp-5 online), although it was not designed particularly for the TRLs.

Experiences over the past 6 years have shown that such programs are feasible in China, though perhaps less so in countries with different political institutions [14] (Supp-5 online). In fact, accountability at all levels of government is lacking in much of the world. Water is a common good, and a market-based approach, especially if inadequately grounded on the details of the hydrological system, cannot solve the problem, as evident from Australia's experience [9]. In our view, centralized control and bottom-up solutions with economic incentives using water consumption as a fundamental variable within a changing environment could ensure the implementation of remedial activities to achieve reallocation of water to the environment while allowing other sectors to continually grow.

Conflict of interest

The authors declare that they have no conflict of interest.

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Appendix A. Supplementary materials

Supplementary materials to this article can be found online at https://doi.org/10.1016/j.scib.2021.06.012.

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