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COMMENTARY

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Wei-Zu Gu and the remarkable rise of hydrological process research in China

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1 | INTRODUCTION

All countries are on different trajectories in their process hydrological science evolution. China is on perhaps the steepest rise in terms of year-on-year gains in quantity and quality. Here, I reflect on the foundational work of Wei-Zu Gu that helped initiate this rise, his unique and remarkable Hydrohill catchment and the unprecedented ascent of process work in China—where in 2022, for the first time, China had the most accepted papers in this journal of any country in the world.

2 | MY EARLY INTERACTIONS WITH GU

I first learned of Wei-Zu Gu from my longstanding collaborator, Carol Kendall. In 1989 she, together with Jake Peters and Vance Kennedy, were invited as a USGS delegation to China to visit the Hydrohill catchment and Chuzhou hydrological station. Carol told me Gu had read their 1986 paper on soil water contributions to streamflow (Kennedy et al., 1986) that showed strong soil water contributions to stormflow in the Mattole River basin, California. This was indeed an important paper and was forcing hydrologists around the world to confront complexities of isotope hydrograph separations that, until then, were largely focused on a simplistic event and pre-event water classification. Gu suspected the same behaviour was occurring at his sites in and around Nanjing. Following the USGS delegation to China, the USGS team reciprocated, and Gu came to the United States about a year later and toured the Mattole watershed, the Panola watershed in Georgia and other USGS research sites.

As I continued to work with Carol, I was eager to meet this "Professor Gu" that she told me so much about. My chance came in 1998 when I had an invitation from IAEA to teach an isotope hydrology course in Nanjing. They told me that Prof. Gu would be there and that he would participate in the course as an IAEA representative in China. In the end, he did simultaneous translation of my week of lectures (!) and through it all, we became fast friends. My first impression was that contrary to his age—he was in his mid-60s at this time—he had the verve and enthusiasm of someone decades younger with a hydrological wonderment I have seen in only a few field scientists. He designed and constructed whole artificial catchments. He rode camels into the Gobi Desert to sample stable isotopes to uncover new processes in dune migration (published as a Nature paper in Chen et al., 2004). Gu's intense curiosity was matched by an unusual kindness and warmth that made quite an impression on me as an early career scientist.

3 | WEI-ZU GU AND HYDROHILL

Gu was a research professor at the Nanjing Institute of Hydrology and Water Resources when he set up the Chuzhou Hydrology Laboratory and now-famous Hydrohill catchment. It has been described this as "the greatest public works project in experimental hydrology" (Kendall et al., 2001) and I think this still holds true. Hydrohill was started by Gu in the late 1970s and completed in 1982. Today, it includes a mobile rainfall simulator and an impressive array of automatically recorded subsurface stormflow troughs (Figure 1).

Gu was decades ahead of his time in setting up Hydrohill and it remains a seminal contribution to process hydrology. Through the 1980s and 1990s, Gu authored a number of papers in the Chinese and English literature (Gu, 1987; Gu, 1988; Gu, 1990; Gu, 1992; Gu, 1995; Gu, 1996a, 1996b—summarized in an important review paper in Gu et al., 2018) that showed—in many cases for the first time—the controls on the spatial and temporal evolution of soil water, groundwater and streamflow from the catchment. With fully measured boundary conditions, Gu was able to close the water balance and to calculate catchment isotope mass balances. His work with

FIGURE 1 Prof. Gu at Hydrohill. This 490 m^2 catchment took 100 workers 5 years to construct, according to the many early conversations, I had with Gu in Nanjing in the 1990s. Source: Aimin Liao.

Carol Kendall (Kendall et al., 2001) showed how a large rain event could infiltrate more than half the input rainfall but displace only a few percent of the pre-event water out of the catchment. He showed too with the incredible trough system (Figure 2) how the 10% or so of pre-event water was sourced mostly from the transient water table in the deeper soils. With the spatial mapping of soil water and groundwater isotopic composition, he showed some of the first contour maps of pore water isotope composition with evidence of large spatial and temporal heterogeneity. These findings were crucial to re-thinking isotope hydrograph separation and the assumptions associated with it.

A lasting legacy of Hydrohill is its influence on other constructed hillslopes and watersheds across the globe. I was on the design team for the LEO slopes at Biosphere-2 in Arizona and through multiple meetings over 2 years of planning, we reflected heavily on aspects of Hydrohill to emulate at the LEO site.

4 | THE REMARKABLE RISE OF PROCESS HYDROLOGY IN CHINA

Gu was at the leading edge of process hydrology in China during its remarkable ascent in the past several decades. Gu led the first internationalization efforts in China in isotope hydrology with the UN's International Atomic Energy Agency. Wang and Sun (2001) note that with Gu's involvement, the first 10 Global Network of Isotopes in Precipitation (GNIP) stations (of the ~30 now in operation) were initiated in China and sponsored by the China Ministry of Water Resources. Along the way, Gu led with synthesis efforts including his important 2011 text "Isotope Hydrology" (in Chinese), the definitive summary of work at the national level (Gu et al., 2011).

It is interesting to reflect on Gu's early and sustained leadership in process hydrology and China's current standing in global hydrology. According to the 2022 Shanghai Index, 5 of the top 10 Water Resources programs are now in China, including the top-ranked program on that list. And in 2022, China has surpassed the United States in annual output of peer-reviewed papers in this journal, Hydrological Processes. Figure 3 shows that starting around 2008, China separated from the top 10 contributors to Hydrological Processes with a distinct and renewed upward trajectory in 2014. These trends mirror recent analysis by Lau (2022) who notes similar trends for science in general. And in particular, she notes that it puts "China's share of the top 1% most-cited papers—based on a fractional count of author affiliations—at 27.2% for articles published between 2018 and 2020, compared with 24.9% for the United States." These data show how, in addition to quantity, the quality gains in Chinese research are increasing too.

Reflecting further on Figure 3, it is interesting to note that 163 of the 827 accepted manuscripts in this period from 2006 to 2022 (about 20%) fall into a keyword category linked to the term "isotopes." I would hazard a guess that this percentage of papers with an isotope linkage is larger than from the other nine countries in the figure and highlight the enormous influence of Gu on the uptake of isotope hydrology research in China.

5 | FINAL REFLECTIONS

Liu et al. (2018) note in their review of Gu and his work that he started much of his experimental work in the mid-1970s following "his peasant life." Of course, they are referring to the period of the Cultural Revolution in China, a time that suspended Gu's research activities and greatly shaped him, according to the many stories of that time he relayed to me. I think one of the attributes that most impressed me with Gu was his indominable spirit, a trait that Beveridge (1950) notes as an attribute of almost all successful scientists. Today we might call it grit—and countless books and articles have been written on this (e.g., Duckworth, 2016). In my mentoring work with early career scientists (McDonnell, 2022), I often reflect on Gu's incredible grittiness, following his "peasant life." Gu's grit was further

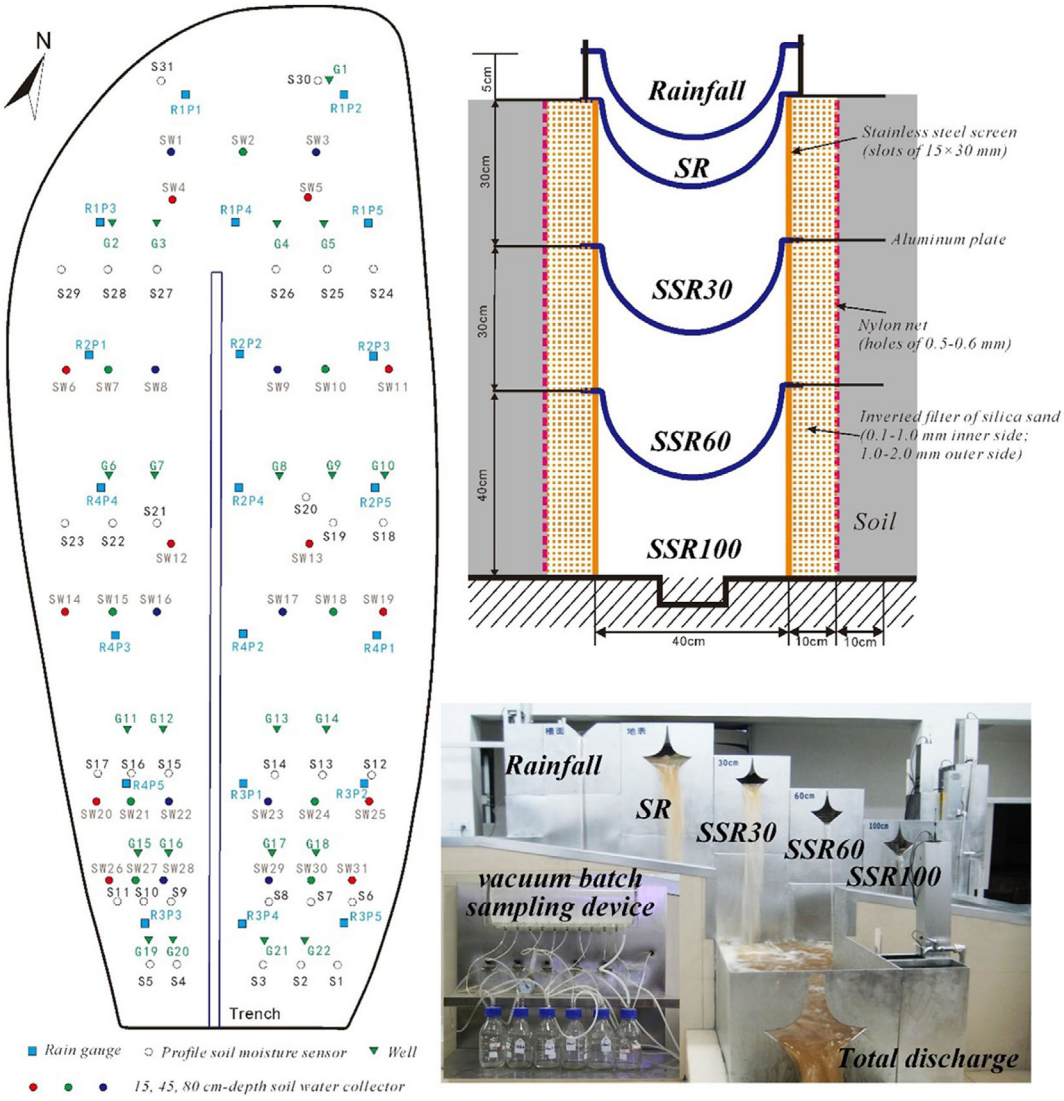
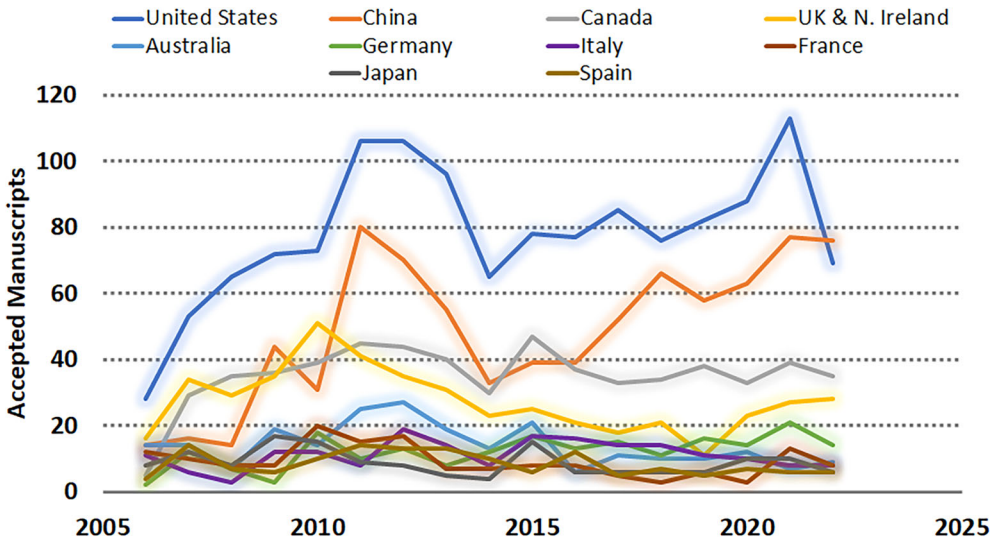


FIGURE 2 The monitoring system at Hydrohill where stacked troughs collect runoff at different depths and flow gauging structures for different runoff components (now equipped with "vacuum batch" sampling device) are located in a control room at the base of the catchment. Figure from Yang et al. (2020).

FIGURE 3 The most recent data from John Wiley and Sons on paper acceptance statistics for the journal *Hydrological Processes*. The top 10 countries are shown. Note that this past year China surpassed all countries in terms of number of accepted manuscripts. I suspect that this is similar to other journals in our field of hydrology.



evidenced by his determination to advance research in the face of enormous obstacles. I learned on our walks together during that late 1990s IAEA course how access to journals—then in a pre-digital age—were still tough to come by in China with only a small handful of universities and research institutes at the time having subscriptions to *Hydrological Processes*, *Water Resources Research*, and *Journal of Hydrology*. Through it all, Gu accessed the world's hydrological literature and soldiered on, long before the amazing gains in research funding occurred into the 2000s.

In closing, I recall that every e-mail and greeting from Gu to me started off with "to my great friend and teacher." Of course, he was the teacher and me the student: of hydrology, of Chinese history, and of how to mentor the next generation. He is missed, but his legacy lives on through the future generations of process hydrologists in China and globally. I hope we can all continue to learn from his indominable spirit, his push for internationalization and his extreme curiosity and collegiality. He lives on through Hydrohill and the many generations of graduate students and colleagues who continue to work there.

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DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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