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Min Wang

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Perspective

Accelerating collaborative innovation in hydrological, engineering, and environmental fields

Min Wang

Vice Minister of the former Ministry of Land and Resources of the PRC, Beijing, China.

Editor's Note: To fulfill the new requirements of geological work in the modern era and explore the latest advancements in hydrogeology, ecological geology, and geothermal geology that contribute to the development of an ecological civilization and effective natural resource management, the academic symposium on "Synergetic Innovation and Green Development in Water-Heat-Ecology" took place from October 14th to 15th, 2023. Organized by the China Geological Society and collaboratively hosted by the Hydrogeology Professional Committee, Ecological Geology Professional Committee, and Geothermal Professional Committee, the event featured an insightful speech by Mr. Wang Min, former Deputy Minister of the Ministry of Land and Resources of the PRC. His perspectives offer valuable insights for current geological endeavours, and we have compiled the content of this speech into this article.

Respected academicians, experts, and colleagues, good morning!

Although the research and application fields of hydrogeology, ecological geology, and geothermal geology are different, they are intricately linked, sharing common roots within the geological domain. In the context of advancing ecological civilization construction, strengthening foundational work, tracing the origin, consolidating the foundation, enhancing interdisciplinary collaboration, broadening horizons, and inspiring innovation are of great significance. The annual meeting last year, jointly organized by several professional committees, achieved excellent results. This year, the three professional committees have once again united for an academic symposium under the theme "Synergetic Innovation and Green Development in Water-Heat-Ecology" closely aligning with the contemporary requirements of the new era. Through persistent efforts in collaborative innovation, we are optimistic about achieving substantial advancements that will undoubtedly shape the landscape of high-quality development in the water and environmental sector.

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The vibrant interconnectedness of mountains, rivers, forests, farmlands, lakes, grasslands, and deserts rely on the vital element of water. Harnessing the energy of the sun and the atmosphere, water conducts a natural symphony through evaporation, transpiration, precipitation, infiltration, adsorption, and surface and subsurface flows. This intricate dance sustains life, transforming once barren landscapes into thriving ecosystems.

Naturally, a watercourse, with its rivers, floodplains, wetlands, and widespread groundwater, sketches a vertical portrait of intertwined life. Across different times and regions, the interplay of surface water and groundwater nurtures each other, forming a network of rivers and an expansive groundwater realm. The rhythmic dance of water, both above and below ground, shapes the fundamental pattens and evolutionary trajectories of basins or watersheds, influencing the top-level design of ecological protection and restoration.

In historical contexts, our focus leaned heavily on the resource attributes of water. Yet, from an ecological standpoint, there were gaps. Over three decades ago, in-depth hydrogeological studies sought to enhance saline-alkali farmland. Results revealed that overly shallow groundwater levels hastened evaporation and salt buildup, leading to soil salinization. Conversely, excessive depths hindered soil support, causing surface dryness and hindering crop growth. Extensive research and monitoring underscored the importance of maintaining the phreatic water level around 2 meters in the Huang-Huai-Hai Plain for agricultural development. This insight emphasizes the intricate connection between phreatic and capillary water and the interplay of soil water potential within the unsaturated zone and the gravity field within the saturated zone. This not only holds significant resource value but also carries vital implications for the ecological environment. Studying the ecological environment demands a heightened focus on changes in groundwater levels and intensified monitoring of water characteristics in the unsaturated zone.

In the realm of ecological protection and restoration, it is crucial to acknowledge the significance of the burial depth of regional phreatic water levels as a pivotal regulatory factor. Additionally, while discussions of Darcy's Law and cohesive soil deformations tough upon bound water, there exists a notable research gap concerning its ecological and environmental implications.

In hydrogeology, the time-tested Darcy's Law, established in 1856, defined percolation, quantifying its relationship with a medium's permeability and hydraulic gradient. This law significantly advanced hydrogeology, serving as a timeless cornerstone. Darcy's Law and aquifer theory underpin numerous aspects, encompassing steady flow within island-like confined aquifers, the application of Theis Equation for transient flow, multi-layer 3D numerical simulations, and extending to diverse areas such as local water supply and regional assessment of groundwater resource in entire basins.

The Tóthian theory, originating in the 1960s and maturing refined in the 1980s, represents the theory of groundwater flow systems. It unravels the hierarchical nature and formation mechanisms of three-dimensional flow fields within these systems, intricately coupling percolation, hydrochemical, and temperature fields into a temporally and spatially ordered integral system. Additionally, this theory profoundly elucidates that flowing groundwater, as a ubiquitous geological force, serves as a fundamental driver in numerous natural processes and phenomena, laying the groundwork for hydrogeology's evolution from a practical discipline to a fundamental science within Earth system studies. However, despite continuous refinement, the Tóthian theory remains primarily theoretical, with very limited practical application. These insights are extensively discussed in *Fundamentals of Hydrogeology* (7th edition), primarily authored by Professor Zhang Renquan. In my experience of working in hydrogeology for many years, reflecting on the recent advancements and newfound insights in fundamental concepts and theories has proven highly beneficial. As a practical field and applied discipline with a strong emphasis on hands-on experience, hydrogeology urgently requires an acceleration of innovation in both theoretical frameworks and technical methodologies.

Innovations stem from practical experience. Currently, field hydrogeologists/workers primarily advance their tasks in the form of production projects, adhering to established procedures. This, however, constrains opportunities for thorough problem exploration. Conversely, researchers often lack the firsthand experiences and insights gained on the field, leading to a significant gap between field investigation and research. To address such issues, it's crucial not only to deepen institutional reforms but also to enlist the heightened awareness and persistent efforts of geological experts. Achieving the integration of theory and practice, starting from real-world problems, overcoming challenges, and innovating are essential.

In the Hebei Plain, deep confined water has been subjected to prolong overexploitation, leading to concerns that the overlying saline water might migrate downward, contaminating deeper freshwater resources. However, after years of monitoring, there has been no significant change in the upper saline layers. From the perspective of cohesive soil compression and deep lateral replenishment, it becomes challenging to explain the water balance issue, which involves aquifer theory. Some argue that in nature, continuously stable distribution of aquifers and aquicludes (or weakly permeable layers) are seldom found. Weakly permeable layers often appear as lens-shaped, forming numerous 'skylights' between upper and lower aquifers. When extensive deep groundwater extraction occurs, there is a possibility that upper groundwater might flow downward through these 'skylights'. Moreover, the hydraulic gradients and cross-sectional area of this flow are much larger than those of horizontal flows, suggesting that a considerable portion of the water extracted from the deep confined aquifer comes from overlying aquifer recharge. However, if this were true, why is the saline layer unaffected? Could it be because these 'skylights' only contain small amount of cohesive particles, blocking salt but not water? This remains a speculative hypothesis. Scientifically unexplained problems often drive theoretical innovation. What appears to be a commonplace phenomenon on the surface may, in reality, involve significant foundational issues related to regional groundwater flow, resource evaluation and management, as well as geological environmental processes. Once breakthroughs are made in understanding, they have the potential to greatly propel progress in societal practice.

Numerous similar cases underscore the complexity of geology and hydrology conditions, challenging the limits of existing theories. To advance the field of hydrogeology, we must not be constrained by current theoretical knowledge. The development of hydrogeology as a discipline will be impeded by treating unusual phenomena as normal, staying indifferent to anomalies, or ignoring problems. In the 1980s, a renowned foreign expert in groundwater dynamics visited China. Upon seeing the hydrogeological sections of Heibei Plain, he expressed disbelief in their complexity, repeatedly questioning the authenticity of the diagrams, which reflects a severe detachment from reality. In such situations, we must maintain a high level of vigilance and genuinely enhance our sensitivity to innovation.

Geothermal resources stand as a valuable asset for human utilization. In theory, as we delve deeper below the Earth's surface, temperatures rise significantly, and these resources can be both inexhaustible and sustainable by rational exploitation. Additionally, geothermal resources are seldom influenced by external factors and are environmentally friendly, potentially surpassing to solar, wind, and hydraulic energies. As highlighted by Mr. Li Siguang, the Earth's subsurface stands as an immense heat reservoir, representing a novel and substantial natural energy source. Its discovery holds comparable importance to the revolutionary recognition of coal and petroleum as combustible resources. In recent years, development and utilization of geothermal resources has experienced rapid growth, emerging as a significant force in the new energy sector in China. However, their applications have predominantly focused on traditional areas like heating and bathing. This underscores the urgency accelerated advancements in theory and technology to explore new possibilities. A notable breakthrough in geothermal exploration was made in 2020 in Datong, Shanxi Province, where high-temperature, high-pressure geothermal fluids were discovered at a depth of 1,585 m, with temperatures reaching 167°C inside the boreholes and 160°C at the wellhead. This finding challenges our traditional understanding and holds significant implications for deepening the study on the formation mechanisms of geothermal resources, promoting theoretical innovations in geothermal science, and accelerating the rational exploitation and utilization of these resources. Leveraging this breakthrough, we must enhance our understanding, and strive for more breakthroughs similar to those in Datong. However, it is imperative avoid hastily undertaking large-scale development to mitigate potential issues. The responsible and thoughtful exploitation and utilization of geothermal resources remains both an honorable mission and a profound responsibility in building a clean, low-carbon, safe, and efficient energy system, thereby accelerating the green transformation of development methods.

I sincerely wish this conference great success! Thank you!