The Idea and Key Technical Prospect on Integration between Underground Reservoir and Surface Water System

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Abstract. The problem of global water security is extremely serious due to the increasingly poor and uneven distribution of water resources and severe water pollution in some regions. Water security is a major long-term strategic demand of China, involving water resource supply, the prevention and control of flood, drought and water pollution, etc. In order to solve the prominent problems of global surface water shortage and the groundwater level drops caused by the over exploited of the traditional groundwater reservoir, the underground reservoir is proposed under the guidance of national strategy “Deep Into the Earth”. The protection and early warning of water security would be better through the interaction between underground reservoir and surface water system. This paper provides solutions for water security issues. In which, the preliminary concept of underground reservoir is defined, and the theoretical system of water security for underground reservoirs and surface water is put forward. Moreover, several key technologies are also proposed, including the distributed rainfall-runoff and water environment simulation with high precision, site selection and design of underground reservoir, the early warning and protection of water environment in underground reservoir, the joint operation of water quantity and quality between underground reservoir and surface water system, etc.

1. Introduction

Water is the source of life, the basis of production and ecology and the fundamental resource on which human beings depend for survival. The fresh water that is available to humans accounts for 2.5% of global water, but only 0.26% of which can be directly utilized after excluding the hard-to-exploit water in the Antarctic ice sheets, Greenland ice sheets and some mountain glaciers. Worse, the global freshwater is unevenly distributed, and 60% of which belongs to the top nine countries (Brazil, Russia, Canada, China, the United States, Indonesia, India, Colombia, and Congo), while 80 countries and regions with 1.5 billion people are short of fresh water[1]. Moreover, with the development of social economy, the problem of water environmental pollution is increasingly aggravated. More than 420 billion m³ of sewage are discharged into rivers, lakes and seas every year, polluting 5.5 trillion m³ of fresh water which is equivalent to 14% of global runoff[2]. It not only aggravates the shortage of available irrigation water to become an important constraint to food production, but also directly affects the safety of water drinking, food production with resulting in huge economic losses. According to the “United Nations World Water Development Report 2018”[3], the global demand for water resources is growing at a rate of 1% per year. About 5 billion people will live in water shortage areas by 2050 if there is no action been taken.
With the constant extension and expansion of definition, “water safety” has been replaced by “water security”. Generally, “safety” refers to the safe of human health and production technology activities, covering the natural attributes of “water safety”, such as water resource safety, water environment safety, etc[4]. However, “security” contains social and political security issues that can guarantee its stability and economic development[5], and it covers the social attributes of “water security”. Thus, “security” that has comprehensive implications has been used by a large number of scholars[6][7][8], such as the internationally recognized “food security”. In 2009, UNESCO(United Nations Educational Scientific and Cultural Organization) defined water security as the water resources that can ensure living and development of humans in quantity and quality, which can maintain the sustainable health of human and ecological environment, protect lives and properties from water disasters[8]. And the implication of “water security” has been extended to the resources, environment, ecology, society, politics and economy. Karen Bakker[9] discussed the challenges and opportunities of water security research, indicating that the problem of water security had received a great attention in the world.

In recent years, surface water conservancy projects have been built all over the world to solve the water security problems including water resource shortage and uneven distribution in time and space[10], such as the California Water Diversion Project, China South-to-North Water Diversion Project[11] and China Three Gorges Project[12]. However, the problems of water security cannot be completely solved by relying only on surface water systems. As early as 1998, Qian[13] predicted the prospect of underground space development, and considered the planning of which in recent years[14][15]. Chen[16] proposed the strategic concept of building a large-scale deep earth science and engineering laboratory in China, and showed that the need to develop underground space is becoming more and more urgent. Xie[17] also presented several ideas of deep earth science in hydraulic engineering. At the China National Science and Technology Innovation Conference in 2016, it was pointed out that “Deep Into the Earth” is a problem of science and technology strategy that must be solved in China[18], and water is the first factor for deep earth space utilization and deep resource development[19]. Therefore, the construction of the underground reservoir integrated with the surface water system would gradually form the early warning theoretical system of water security, which is a new way to solve the water security problems.

2. Development trend of underground reservoir

At the beginning of the 20th century, the practice of artificial groundwater recharge has been conducted in Japan, America, Soviet Union, Netherlands, France and other countries. In the 1950s, the freshwater storage experiments in the salt water layer were started in America[20] and the artificial recharge of groundwater was carried out by using natural aeolian dunes In Netherlands[21]. After the 1970s, ASR(Aquifer Storage and Recovery) was gradually formed in America, and until July 2002, there were 56 ASR in operation and more than 100 systems has been built[22]. Now, the ASR project has become an important part of CERP(the Comprehensive Wetland Restoration Plan). In order to solve the problems of water shortage and seawater intrusion, an artificial groundwater reservoir(the catchment area is 0.6 km² and the total storage capacity is 9000 m³) was built in 1972 in Nagasaki, Japan[23], which is the first one in the world. And the groundwater reservoirs in Miyako and Sunakawa of Okinawa[24] were successively constructed. In 1975, the Nangong Groundwater Reservoir(the total storage capacity is 480 million m³)[25], the first one in China, was built in Hebei Province. And then, the Jiahe Groundwater Reservoir and the Dagu River Groundwater Reservoir in Shandong[26], the Maguan Groundwater Reservoir in Guizhou[27] were gradually built.

As an effective, economic and environmental friendly underground development project, the groundwater reservoir has been developed rapidly, and it is known abroad as “aquifer recharge” or “aquifer storage and recovery”. Most scholars believe that the groundwater reservoir is a groundwater development project that uses the natural water storage space within the earth's crust to store water resources[28]. However, the underground reservoir proposed in this paper is different from the traditional groundwater reservoir. It is preliminarily defined as the reservoir that built artificially at a
certain depth underground, with surface water dispatching or natural recharge as the main water source. And the project which is similar to this concept is the “Outside Drainage System of the Capital Area” that was built between 1992 and 2006 in Tokyo[29], which is the most advanced sewer drainage system in the world. The Tokyo drainage system is located about 50 meters underground along the Sixteenth National Highway in Kasugabe City, and the total length of which is 6.4 kilometers. There are five giant shafts with a height of 65m and a width of 32m, and an artificial underground reservoir with a length of 177m, a width of 77m and a height of about 20m, which is supported by 59 large columns with a height of 18m and a weight of 500 tons[30].

The underground reservoir has many advantages, including no land occupation, no immigration, no damage to the ecological environment, no risk of flooding and dam failure, the reduction of water loss caused by evaporation and the provision of foundation for deep water networks. Especially, it can avoid the problem of groundwater over-exploitation and effectively solve the problem of uneven spatial and temporal distribution of water resources. The underground reservoir can be used as a source of water supply to solve the problem of water shortage, which improves the existing traditional mode of water resources development, flood prevention and mitigation, and water environmental protection. And through the comprehensive operation with surface water, it can improve the utilization of water resources and protect the surface water environment. In the flood season, it can also be used as a flood discharging pool to achieve flood control and disaster mitigation. Furthermore, the underground reservoir group, which is constituted by a number of independent or connected underground reservoirs based on regional hydrometeorology, topographical geology, water supply and water environmental protection requirements, is linked and coordinated with the surface water system to solve the water security issues jointly.

3. The prospect on theory and key technology of integration between underground reservoir and surface water system

The study of underground reservoir and its linkage with surface water system needs interdisciplinary integration. This research has the dual characteristics of theoretical science and technical science. The basic theories involve mathematics, physics, geography, geology, ecology, environmental science, material science, control science, management science, etc., and the basic technologies include measurement technology, control technology, computer technology, information technology, etc. The theoretical study of the integration between underground reservoir and surface water system mainly involves three aspects: (1) The basic theory research of underground reservoir and underground reservoir group, such as the precisely definition of underground reservoir, the main function of underground reservoir, and the construction area that need to be studied. (2) The design theory of underground reservoir. The design concept, design principles, design standards and design methods should be studied from the perspectives of hydrometeorology, water environment and water security. (3) The scientific basis and method of the integration between the underground reservoir and surface water system in water quantity and quality, and the early warning system of water security by integrating underground reservoirs with surface water system should be formed eventually.

3.1 Key technology of distributed rainfall - runoff - water environment simulation and early warning with high precision

The distributed meteorological, hydrological and water environment integrated simulation model is developed to provide high-precision hydrological and water environment forecast information for the coordinated and optimized operation of underground reservoirs and the linkage with surface water system. The main research contains four parts. (1) To develop a watershed scale rainfall forecasting model with higher resolution and precision. (2) To develop a physically distributed hydrological model with more comprehensive and scientific structural system. (3) To build a distributed coupled forecast model with integration of meteorology, hydrology and water environment. (4) To build the parameter transfer function that indicates the quantitative relationship between parameters and the
physical characteristics of the underlying surface, it can effectively solve the key problem of hydrological forecasting in the widespread ungauged basins.

3.2 Key technology of site selection, storage capacity design and early warning of underground reservoir
Considering the basin composition characteristics, rainfall, water quantity, topography, water resource demand and allocation and water environment endowment, the site selection of underground reservoir should be carried out by using remote sensing and GIS technology, and many analysis methods including fuzzy comprehensive analysis, analytic hierarchy process, etc. To study the system and method of early warning index of underground reservoir, the design of capacity, elevation and water function should be based on the simulation results of regional water resources and water environment conditions by using integrated forecasting model of meteorology, hydrology and water environment.

3.3 Key technology of early warning and protection of water environment simulation for underground reservoir
Underground reservoirs are in the special environmental conditions, such as no sunlight, low velocity of flow and wind, long storage time of water body with weak self-purification ability. Thus, the environmental hydraulics, microbiology and other interdisciplinary scientific theories and technical methods need to be applied to research the water quality, evolution rule, early warning index system as well as the water environmental protection technology of the underground reservoirs.

4. Conclusions
There is a shortage of fresh water resources available for humans, although the amount of water on the surface of the earth is large. In recent years, with the rapid development of global economy and population, water security has been seriously challenged. However, the problems of water environment security, water resources security, water ecological security and water disaster avoidance security cannot be effectively solved by relying only on the surface water system. And the traditional ground reservoir cannot fully ensure the region water security due to the geographical limitations, the over-exploitation of groundwater and so on. In order to realize the efficient utilization of water resources and to solve the problem of water security, the idea of improving the water security and early warning system by using deep earth space and establishing the integration system of underground reservoirs and surface water is put forward. In this paper, the underground reservoir is preliminarily defined, and three scientific theoretical problems are summarized: the basic theory of underground reservoir, the design theory of underground reservoir, the integration theory of underground reservoir and surface water system in terms of water quantity and quality. In addition, several key technologies are proposed including the distributed high precision rainfall-runoff-water environment simulation, site selection and design of underground reservoir, the early warning and protection of water environment in underground reservoir, the joint operation of underground reservoir and surface water system, etc. In a word, this paper provides solutions for water security problems, and it is expected to effectively solve the uneven spatial and temporal distribution of water resources, and to promote the development and utilization of deep earth space.

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