Three-Level Multi-Objective Water Cycle Regulation Theory and Engineering Technology System Postprint

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Date: 2019-09-11T00:00:00+00:00

Abstract

Taking typical arid inland river basins in Xinjiang as the research object, this study systematically analyzes geographical, geomorphological, and hydrometeorological conditions along with watershed water cycle characteristics to identify three major problems in water resource development and utilization: severe water scarcity with pronounced spatiotemporal distribution imbalance and prominent water security issues in transboundary rivers; excessive water resource development leading to severe structural imbalance between artificial and natural oases and ecological environment deterioration; and low water use efficiency and benefit, coupled with supply-demand contradictions and loss of control over water-salt balance. Guided by water problems and demands, combining engineering measures with ecological protection, and employing fundamental theories and analytical methods of systems science, a three-tier multi-objective water cycle regulation theory and engineering technical system is constructed. From macro, meso, and micro levels, scientific models and key technologies for water cycle regulation and efficient water resource utilization are proposed at regional, watershed, and irrigation district scales. Considering regional topographic and geomorphological characteristics and water resource endowment conditions, water cycle regulation frameworks with "network-type" structures for northern Xinjiang, "ring-type" for southern Xinjiang, and "string-type" for eastern Xinjiang are established to enhance the regulation capacity for rational allocation of regional water resources. Addressing watershed water cycle characteristics, an integrated regulation mode is proposed, featuring mountain reservoirs replacing plain reservoirs, a "three-seven regulation" split between intra-channel and extra-channel water diversion, and a "fifty-fifty accounting" approach for economic and ecological water consumption. Focusing on modern irrigation district construction and its challenges, the study indicates that establishing a "four-in-one" integrated regulation technical system for efficient water resource utilization—encompassing water-saving irrigation,

water-salt regulation, groundwater utilization, and ecological protection—represents the direction for sustainable development of oasis agriculture in arid regions.

Full Text

Water Cycle Regulation Theory and Engineering Technology System in Arid Regions

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Abstract

Taking typical inland river basins in China' s arid Xinjiang region as the research subject, this paper identifies three major problems in water resources development and utilization: (1) water shortage with serious spatial-temporal distribution imbalance and notable trans-boundary river water safety issues; (2) over-development of water resources with serious structural imbalance between artificial and natural oases and ecological environment deterioration; and (3) low water use efficiency with water-salt imbalance and systematic contradictions between water supply and demand. Based on systematic analysis of local geography, landform, hydro-meteorological information, and basin water cycle characteristics, this study establishes a three-scale (macro-, meso-, and micro-scale) multi-objective water cycle regulation theory and engineering technology system. This provides scientific models and key technologies for water cycle regulation at regional, basin, and irrigation zone scales, as well as for high-efficiency water resources utilization, led by water problems and their requirements, with simultaneous development of engineering measures and ecological protection, adopting systematic scientific theory and analysis methods.

Keywords: arid region; water resources; regulation theory; key technology; engineering measures

1.2.1 Water Resources Zoning and Statistics

Xinjiang covers a total area of 1.66×10 km², with mountainous areas accounting for 42.7% and plain areas for 57.3%. The region' s water resources total 834.9×10 m³, comprising surface water resources of 788.7×10 m³ and groundwater resources of 454.0×10 m³. Mountainous areas are the primary source of water, contributing 879×10 m³ to the total resources.

The water resources are divided into three major zones: Northern Xinjiang,

Southern Xinjiang, and Eastern Xinjiang, each with distinct hydrological characteristics and utilization patterns.

1.2.2 Characteristics of Water Resources

The spatial distribution of water resources in Xinjiang is extremely uneven. Mountainous areas receive abundant precipitation while plain areas are extremely arid. The population and economic activities are concentrated in oasis areas, creating significant pressure on water resources.

In 2016, Xinjiang' s population reached 2398×10 , with urbanization at 48.4%. The region' s GDP was 9650×10 yuan, with per capita GDP of 4×10 yuan. Total water consumption was 9614×10 m^3, with per capita water consumption of 3.75 m^3 and per capita grain possession of 631 kg. Grain output reached 420×10 tons, with water consumption per unit of GDP accounting for 79% of the national average.

The total water supply in 2016 reached 565.3×10 m^3, with surface water supply accounting for 533.3×10 m^3 (94.3% of total). Agricultural water consumption dominated, accounting for 94.3% of total water use, reflecting the region' s agricultural economy characteristics. Water use efficiency varies significantly across regions, with some areas showing utilization rates of 78.9% and others 21.0%.

3.1.2 Water Cycle Regulation Theory

Based on the unique water cycle characteristics of inland river basins in arid regions, this study proposes a comprehensive regulation model that replaces plain reservoirs with mountain reservoirs. The "Three-Seven Regulation" and "Five-Five Control" frameworks are established to balance ecological and economic water uses.

The regulation theory emphasizes: 1. Mountain reservoir construction to enhance regulation capacity 2. Optimized allocation between upstream and downstream water uses 3. Ecological protection measures integrated with engineering solutions

The system aims to achieve a 64% regulation capacity through mountain reservoirs, improving water use efficiency by 25-50%.

[Figure 3: see original paper]

[Figure 4: see original paper]

3.1.3 Water Resources Utilization Technology

Aiming at the characteristics of oasis agriculture in arid regions, this study establishes a "Four-in-One"comprehensive regulation technology system for high-efficiency water resources utilization, integrating: 1. Water-saving irrigation

technology 2. Water-salt regulation 3. Groundwater utilization 4. Ecological protection

This system represents the development direction for sustainable oasis agriculture in arid regions. Implementation of this system has shown improvements in water use efficiency, with some areas achieving 98% efficiency in water utilization.

[Figure 5: see original paper]

3.2 Water Management Approaches

Different management strategies are proposed for various water use scenarios: - "Water-saving irrigation" for agricultural water use, targeting a 50% reduction in water waste - "Water-salt regulation" for maintaining soil health and preventing salinization - "Ecological water use" for environmental protection, ensuring 30% of water resources are allocated to ecology - "Groundwater management" for sustainable aquifer use, limiting extraction to 70% of recharge

4 System Framework and Conclusions

The water cycle regulation system in arid regions requires an integrated approach combining engineering measures, ecological protection, and scientific management. The framework includes:

1. Regional-scale regulation networks (net-type for Northern Xinjiang, ring-type for Southern Xinjiang, cluster-type for Eastern Xinjiang)
2. Basin-scale comprehensive regulation models
3. Irrigation-zone-scale "Four-in-One" technology systems

[Figure 6: see original paper]

This systematic approach provides scientific guidance for sustainable water resources management in arid regions, balancing economic development with ecological protection. The system has been applied in Xinjiang with positive results, demonstrating its effectiveness in addressing water scarcity challenges.

References

[1] YAN Denghua, WANG Hao, YANG Shuyuan, et al. Some opinions on the eco-hydrological processes simulation and regulation in arid basins[J]. Advances in Earth Science, 2008, 23(7): 773-778.

[2] YOU Junjun, WANG Hao, NIU Cunwen, et al. Conception of high-efficiency water utilization under multi-dimensional regulation[J]. Journal of North China University of Water Resources and Electric Power (Natural Science Edition), 2016, 37(6): 1-6.

[3] GAN Hong, WANG ling, CAO Yanbai, et al. Multi-dimensional overall regulatory modes and threshold values for water cycle of the Haihe River Basin[J].

Chin Sci Bull, 2013, 58(12): 1085-1100.

[4] WANG Xiqin, ZHANG Yuan. The allowable exploitation rate of river water resources of the seven major rivers in China[J]. Journal of Natural Resources, 2008, 23(3): 500-506.

[5] The Chinese Academy of Engineering. Xinjiang sustainable development-water resources strategy research (comprehensive part)[R]. Beijing: The Chinese Academy of Engineering, 2012.

[6] DENG Mingjiang, SHI Quan. Management and regulation pattern of water resources in inland arid regions[J]. Advances in Earth Science, 2014, 29(9): 1046-1054.

[7] WANG Hao, WANG Jianhua, QIN Dayong, et al. The study on water resources assessment and subject system of water resources study on modern times[J]. Advances in Earth Science, 2002, 17(1): 12-17.

[8] QIAN Zhengying, SHEN Guofang, PANG Jiazheng. Water resources allocation for ecological environment construction in the west region and its research on sustainable development strategy[M]. Beijing: Science Press, 2004.

[9] ZHANG Qiang, ZHAO Yingdong, ZHANG Cunjie, et al. Issues about hydrological cycle and water resource in arid region of northwest China[J]. Arid Meteorology, 2008, 26(2): 1-8.

[10] DENG Mingjiang, DONG Xinguang, et al. Water resource and sustainable utilization in Xinjiang Uygur Autonomous Region[M]. Beijing: China Water Power Press, 2005.

[11] Xinjiang Statistics Bureau. Xinjiang statistical yearbook, 2017[M]. Beijing: China Statistics Press, 2017.

[12] DENG Mingjiang, LI Xiangquan, XU Kangning, et al. Water resources projects of settlement for development of animal husbandry and its technical supporting system[J]. Arid Land Geography, 2012, 35(6): 978-987.

[13] LEI Zhidong, HU Heping, YANG Shixiu, et al. Water consumption in Weigan River plain oasis[J]. Journal of Hydraulic Engineering, 2006, 37(12): 1470-1475.

[14] ZHOU Haiying, SHEN Mingxi, CHEN Jie, et al. Trends of natural runoffs in the Tarim River Basin during the last 60 years[J]. Journal of Hydraulic Engineering, 2018, 41(2): 221-229.

[15] WANG Guangyan, WANG Yuanjian, GUI Dongwei. A review on water resources research in Tarim River Basin[J]. Journal of Hydraulic Engineering, 2018, 41(6): 1151-1159.

[16] LEI Zhidong, HUANG Yugang, YANG Shixiu, et al. Water resources consumption in Weigan River plain oasis[J]. Tsinghua University (Sci & Tech), 2004, 44(12): 1664-1667.

[17] WANG Yu, HUANG Qiang, WANG Yimin, et al. Study on combined decomposition model for water dispatching of main stream of the Yellow River[J]. Advances in Water Science, 2004, 15(3): 387-390.

[18] WANG Qianjiu, SHAN Yuyang. Regulation of water and salt for farming soil in arid area[M]. Beijing: Science Press, 2017.

[19] DENG Mingjiang. Kariz wells in arid land and mountain-front depressed ground reservoir[J]. Advances in Water Science, 2010, 21(6): 748-756.

[20] DENG Mingjiang. Prospecting development of South Xinjiang: Water strategy and problem of Tarim River Basin[J]. Arid Land Geography, 2016, 39(1): 1-11.

[21] DENG Mingjiang, YU Haiming, LI Xiangquang. Advances of dam construction techniques in Xinjiang[J]. Chinese Journal of Geotechnical Engineering, 2010, 32(11): 1678-1687.

[22] DENG Mingjiang, HUANG Qiang, ZHANG Yan, et al. Study on ecological scheduling of multi-scale coupling of reservoir group[J]. Journal of Hydraulic Engineering, 2017, 48(12): 1387-1398.

[23] DENG Mingjiang, LI Wenpeng, LI Tao, et al. Investigation of key technologies for underground water storage structures and groundwater reservoirs[J]. Advances in Water Science, 2010, 21(6): 748-756.

[26] DENG Mingjiang, HUANG Qiang, ZHANG Yan, et al. Study on ecological scheduling of multi-scale coupling of reservoir group[J]. Journal of Hydraulic Engineering, 2017, 48(12): 1387-1398.

[28] DENG Mingjiang. Current situation and potential analysis of exploration and utilization of groundwater resources of Xinjiang[J]. Arid Land Geography, 2009, 32(5): 647-654.

Note: Figure translations are in progress. See original paper for figures.