

Research on the Construction of Regional Water Resources Balance Sheet Based on Dualistic Water Cycle

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ABSTRACT

As a critical material foundation for economic development, compiling a scientific and reasonable water resource balance sheet (WRBS) is a vital measure for advancing national ecological civilization initiatives. Current research on WRBS is still inadequate, facing multifaceted challenges, including a weak theoretical foundation, outdated technical methodologies, and insufficient practical experience, which necessitate systemic innovation and breakthroughs. This study constructs a WRBS framework based on the dualistic water cycle model, organically integrating natural and social water cycles. It further deepens and extends the application of sustainability theory in water resource accounting, providing robust theoretical support and practical pathways for achieving sustainable water utilization and high-quality socio-economic development.

Keywords: water resource balance sheet; dualistic water cycle; regional entities

1. Introduction

In recent years, intensifying global climate change and anthropogenic activities have exacerbated water scarcity, leading to frequent water crises worldwide. In 2022, severe droughts struck multiple regions, notably China's Yangtze River Basin, which experienced its most extreme drought event since 1961, characterized by substantially reduced precipitation and runoff. Concurrently, the exploitation of water resources for economic development has expanded significantly. At the 2024 UN Water Conference, UNESCO and UN-Water jointly released the United Nations World Water Development Report, urging stakeholders to address the intricate linkages between sustainable water management, prosperity, and peace. The report advocated transcending institutional, economic, and political barriers across regions to implement integrated water resource accounting and management. Sustainability theory emphasizes the

need to avoid overexploiting natural resources while pursuing economic growth. As a critical natural resource, sustainable water utilization is fundamental to socio-economic sustainability. Compiling a WRBS comprehensively reflects water resource stocks and flows, reveals utilization patterns, and identifies potential overconsumption or environmental degradation, thereby providing scientific evidence for evaluating sustainable resource development.

The compilation of a WRBS necessitates interdisciplinary integration. During the design of its conceptual framework, fundamental accounting principles provide guidance. The classification of water assets and liabilities depends on hydrological standards. Physical accounting utilizes statistical methods, and valuation requires accounting measurement techniques. This process not only fosters cross-disciplinary validation and collaboration, but also facilitates the convergence of accounting, statistics, and hydrology. However, current research on WRBS primarily focuses on regional entities and is confronted with several limitations: unclear logical frameworks, absence of standardized paradigms and scientific guidelines, insufficient disclosure of water system evolution patterns, weak foundational research, and unresolved technical challenges. To address these gaps, this study develops a WRBS framework based on the dualistic water cycle theory. It aims to establish an accounting methodology that integrates natural-social perspectives for sustainable water management, thereby providing scientific support for the formulation and implementation of water governance policies.

2 Literature Review

2.1 Research on the Dualistic Water Cycle

With the overarching objective of promoting the harmonious development of human activities and natural ecosystems, initial research on the dualistic water cycle primarily focused on exploring the interconnections between them across different phases. The most representative case was the hydro-social cycle model proposed by Stephen (1997), which was developed within the framework of urban water cycle theory. As scholars continuously refined the mechanism and expanded the research scale of the dualistic water cycle, Stephen further developed a resource balance framework for both physical and virtual water within the regional water cycle, which provided foundational insights for the compilation of WRBS (Stephen, 2004). In China, under the leadership of Academician Wang Hao, scholars pioneered the social-natural dualistic water cycle paradigm in 1999. Building on this paradigm, Jia et al. (2005, 2006) established the distributed hydrological model WEP-L and developed a generalized water resources assessment methodology based on the watershed water cycle model. By analyzing the evolution of research on the dualistic water cycle and water resources, Wang et al. (2023) summarized the multidimensional attributes of water resources, enabling a precise characterization of contemporary research frontiers. Given that virtual water circulating through products and trade

channels also has a significant impact on the social water cycle during the water cycle process, Deng et al. (2020) proposed the natural-social-economic ternary water cycle theory.

2.2 Research on the Water Resources Assets

According to the World Meteorological Organization (WMO) and the United Nations Educational, Scientific and Cultural Organization (UNESCO), water resources refer to water sources that are currently available or have the potential to be available. These sources are not only required to have sufficient quantity and suitable quality, but also need to be capable of meeting demand within a specific time frame. Given that water resources possess the attributes of assets as scarcity, economic value, profitability, well-defined ownership, and the nature of being appropriable, it is essential to include water resources in the scope of asset management. Although characteristics of water resources such as spatial heterogeneity, flow dynamics, and multiple functionalities may influence the specific forms of water resources asset management, they will not change the overall management direction.

Regarding the definition of water resources assets, scholars argue that they represent the portion of water resources that possesses both economic value and usability and can be owned, controlled, or exchanged by entities. For instance, considering the attributes of water rights, water resources exhibit the general characteristics of assets. The allocation of physical water quantities among different regions and users establishes ownership, and corresponding economic benefits are generated during actual utilization (Shen & Lu, 2003). Other scholars define water resources assets by analyzing their relationship with water resources. Dong (2002) utilizes the two-rights theory framework, distinguishes water resources assets from water resources, asserting that water resources assets constitute the economically valuable component of water resources that can be owned or controlled by entities. As research advances, the conceptual understanding of water resources assets continues to evolve and be refined. Wang et al. (2021) categorize China's current water resources institutional framework into stocks and claims based on water resources assets. Stocks include surface water, groundwater, and converted portions, while claims refer to water allocated for production, domestic use, and ecological purposes. Jia & Shen (2022) classifies water resources assets into water rights assets, water economic assets, and water environmental service assets according to their service value and utilization patterns, corresponding to value, economic value, and ecological value, respectively^[10]. Building on this, Zhang & Shen (2024) further analyze multi-dimensional water cycle models, propose that the accounting boundaries for water resources assets can be delineated geographically, by utilization process, by user type, or by physical state. They define the accounting scope of water resources assets as the sum of physical water resources and virtual water resources. Wang et al. (2024) contend that water resources assets include both static water resources assets and assets that generate economic value through economic activities. Their recognition requires meeting two

criteria: the expectation of future economic benefits inflow and reliable measurability. Hong et al. (2024) define water resources assets as the sum of water volumes used for production and ecological services, which consist of controlled utilization volume, medium-based water consumption, and service water volume. Their value is jointly determined by water volume and unit value.

2.3 Research on the Water Resources Liabilities

The debate concerning water resources liabilities centers on whether they conform to the definitional criteria of liabilities in accounting. Scholars such as Geng et al. (2015) have pointed out, based on the System of Environmental-Economic Accounting (SEEA), that the issue of natural resources liabilities, including water resources, cannot be recognized. This is because expenditures associated with natural resource management and environmental protection can be recorded through separate expenditure accounts, and accurately measuring ecological restoration costs remains technically difficult with current methods. Despite the controversies surrounding the recognition of water resources liability, driven by China's need to establish a natural resource departure audit system, most scholars currently advocate recognizing water resources liabilities. The primary basis for this recognition lies in the expected expenditures that economic entities will incur on water governance costs, including the acquisition of external water rights (Jia & Shen, 2022).

The liabilities listed on the WRBS can be regarded as the costs borne by economic entities due to excessive (including unreasonable) use of water resources, as well as the costs necessary for restoring water resource benefits. This relationship can be manifested in the creditor-debtor dynamic between economic entities and the environment, under the premise of water rights allocation. Cao et al. (2019) calculated the water quality liabilities resulting from the disparity between current water quality and target water quality, along with the overdraft deficit resulting from water resource utilization efficiency falling short of expectations. Although many scholars have attempted to calculate water resource liabilities, calculating them solely based on the specific expenditures of economic entities may generate compiled data that fails to accurately reflect the actual situation.

2.4 Research on the Compilation of WRBS

Current research on WRBS primarily focuses on the compilation entities, compilation principles, measurement methods, construction of compilation systems, and applications. Regarding the compilation entities for WRBS, foreign studies predominantly regard official water resource management agencies as the compilation entities, whereas domestic studies have placed emphasis on regional-based exploration. In terms of compilation principles, WRBS primarily

draw on accounting and statistical principles, adhering to the accounting equation “Assets = Liabilities +Equity” and core principles such as the accrual basis of accounting and double-entry bookkeeping. Regarding measurement methods, physical measurement is the primary approach, and calculations are carried out using the formula “Water Resource Assets - Water Resource Liabilities = Net Water Resource Assets”. As for compilation methodology, a combined approach integrating physical quantity measurement and value measurement is adopted to comprehensively account for water resources, thereby deriving the net value of water resources assets.

During the compilation process of WRBS, the recognition of water resources assets typically commences from an economic value perspective, meaning that only water resources with economic value can be recognized as water assets. Regarding water resources liabilities, there is substantial disagreement among scholars, primarily divided into two viewpoints: those in favor of recognizing liabilities and those against it. Even within the group of scholars who advocate for liabilities, accurately calculating liabilities presents numerous challenges. Related discussions primarily revolve around three aspects: resource depletion, environmental damage, and ecological destruction. Regarding water resource rights, given that water resources in China are owned by the entire population and allocated by the state, managers and operators enjoy corresponding residual rights. Therefore, when compiling a WRBS, it is often necessary to further subdivide water resource ownership rights. Tang et al. (2021) systematically constructed a framework for WRBS from two dimensions: stock and flow, as well as physical and value, using basic table, auxiliary table, classification table, and summary table. Hong et al. (2024) conducted an in-depth analysis of four methods for calculating the value of water resources assets and discussed their respective advantages and disadvantages. Gao & Li (2022) proposed that WRBS can be applied to multiple fields, including water resource pricing, use control, water rights trading, ecological resource protection, and exit audits.

2.5 Research Review

At present, many scholars have conducted preliminary discussions on the compilation of WRBS. Scholars at home and abroad are showing increasing attention to water resources and have attained certain achievements in the field of water resources accounting, thereby laying a solid foundation for subsequent research. However, the existing results still exhibit certain limitations:

(1) There are significant differences in the processes and mechanisms between the natural water cycle and the social water cycle, rendering it exceedingly complex to integrate them into a unified model. Currently, existing models face difficulties in accurately representing the interaction between the two cycles, and there is considerable uncertainty in parameter values. The dualistic water cycle model encompasses a large number of parameters, such as water use

quotas, sewage treatment rates, and pipe network leakage coefficients in the social water cycle. These parameters are significantly affected by various factors, including regional economic levels, technical conditions, and management measures, resulting in notable differences. Meanwhile, the quality of data acquisition is uneven: data on the natural water cycle (e.g. precipitation) is relatively easy to obtain with high accuracy, whereas data on the social water cycle (e.g. detailed data on domestic water use) is more difficult to acquire.

(2) Water resources accounting demonstrates static features. The current accounting methods employed in WRBS are rather constrained, and the reflected situation tends to be static. Physical inventories and value statements can only reflect the physical quantity and value of water resources, which makes it arduous to conduct a comprehensive analysis of their quality and dynamic characteristics. Consequently, they fail to achieve a balanced emphasis on both quantity and quality. There is a lack of more macro research methods for the mobility, dynamics, and renewability of water resources, which makes it impossible to fully capture the changes in water resources assets from multiple perspectives.

(3) There exist disagreements concerning the recognition of water resources liabilities and their recognition criteria. In the current WRBS, the recognition of water resources liabilities continues to be a contentious issue, and no consensus has been achieved regarding whether and how to measure them. Additionally, there is no definitive definition for the recognition of water liabilities, and the accounting content lacks standardization, resulting in a lack of more in-depth research.

3. Analysis of the Dualistic Water Cycle System

Water resources play an important role in the ecological environment by maintaining structural stability and supplying fundamental products. Meanwhile, they are increasingly becoming deeply integrated into the daily life and value creation processes of human society. With the continuous growth of human demand for water resources, the natural water cycle system and the social water cycle system have gradually become intertwined and interactive, thereby strengthening the connections among water resources, the natural environment, and the economy and society. Therefore, in the process of developing and utilizing water resources, full consideration must be given to the comprehensive impact of the dualistic water cycle system.

The dualistic water cycle concept represents a significant notion in modern water cycle theory. In the traditional understanding of the water cycle, the emphasis is primarily placed on the hydrological cycle driven by natural factors, namely, the cyclic processes of precipitation, evaporation, and runoff among land, oceans, and the atmosphere. The dualistic water cycle builds upon this foundation by further incorporating social water cycle factors. The social water

cycle mainly refers to the process through which human society develops and utilizes water resources, encompassing stages such as water intake from water sources, water supply, water consumption, drainage, and the partial reuse of treated sewage. The dualistic water cycle theory reveals the interaction mechanism between the natural and social water cycle, providing a novel scientific perspective for water resources management. Under the dualistic water cycle model, water cycle elements encompass not only three major natural fluxes of precipitation, evaporation, and runoff, as well as the four instantaneous state variables of surface water, soil water, and groundwater, but also incorporate social fluxes such as inter-basin water transfer, over-extraction, water intake, drainage, and pollutant discharge into rivers. The introduction of these social fluxes has blurred the distinguish between purely natural and social water cycles in river basins. An in-depth mutual feedback relationship has developed between the natural and social water cycle. To scientifically depict this mutual feedback relationship, scholars have proposed the watershed dualistic water cycle theory and have called for enhanced coupled research among hydrology, economics, and management to improve the scientific rigor of water resources management.

This study is grounded in the dualistic water cycle theory, with a focus on the nature - society dualistic driving structure. It conducts research from two aspects: the natural subsystem and the social subsystem, dynamically analyzes the development and utilization of water resources in the region and quantifies it through accounting methods. The natural subsystem mainly comprises two aspects: water balance and ecological service functions. During the natural water cycle, surface water is heated and evaporated, moves through the atmosphere in various forms such as rain, fog, snow, ice, and clouds, and forms a cyclical natural process through precipitation, surface runoff, infiltration, underground runoff and other links. In this complex natural water cycle system, the forms of water resources are variable, but the total quantity remains constant, adhering to the principle of water balance. The ecological service function of water resources mainly refers to the conditions and products provided by the water resource ecosystem for human survival and development. It not only encompasses the basic life sustaining function, which directly affects the survival and development of species, but also has ecological and economic functions, providing support for leisure and entertainment, environmental maintenance, and product manufacturing. The social subsystem mainly includes water intake, water use, wastewater reuse and discharge. The social water cycle is involved in multiple links of production and life. After social subjects obtain water resources from nature, they store them directly or after treatment, and retrieve and use them at any time. After entering specific production industries such as agriculture, industry, and handicrafts, or daily life use links, a cycle of "water intake - water delivery - water use - water discharge" is formed.

4. Construction Logic of Regional WRBS

Due to the dualistic attributes of water resources assets, namely economic value and social-

ecological value, two distinct value orientations emerge: the pursuit of economic value and the pursuit of public interests. These two value orientations lead to two different applicable entities and may ultimately result in two differentiated approaches to compiling WRBS. One approach focuses on statistics and auditing, primarily applicable to government departments. The other is more similar to the format of traditional balance sheets and is applicable to enterprises. Given that the objectives of the government and enterprises are not entirely in alignment, enterprises tend to prioritize maximizing their own interests, whereas the government must prioritize protecting public interests. This disparity leads to contradictions in the utilization of water resources. Meanwhile, since enterprises alone cannot be counted on to improve water resource utilization methods, the WRBS specially designed to enhance the management of water resources assets is not initially widely implemented in enterprises. Instead, it is preferentially applied in government management practice.

The concept of water resource assets can be traced back to early research on the capitalization of natural resources, which aimed to address the contradiction between the supply and demand of natural resources. The peak period of research on this concept is closely related to the implementation of the natural resource asset departure audit system for leading cadres in 2013. Against this background, a series of scholars began to focus on the impact of government financial investment and the efforts of cadres on the management outcomes of natural resources. They explicitly proposed tables for the accounting of natural resources and their values in different forms (stock, flow, and quality), which serves as the prototype of the WRBS. In view of the importance of water resources assets and their unique characteristics compared with other natural resources, such as the continuity of the water cycle, the extensiveness of application and influence, and the role as an crucial basis for the formation of various ecological values, the compilation of the WRBS has become particularly crucial and complex, thus making it a hot research field.

This paper establishes a framework for the WRBS under the dualistic water cycle model, as shown in Table 1. In the WRBS designed for regional entities, water resources assets are classified into two primary categories: current assets and non-current assets. Current assets comprise three sub-accounts: surface water, groundwater, and recycled water. Surface water can be further delineated into lakes, reservoirs, rivers, and other categories based on specific forms. The recycled water in the current assets refer to the wastewater that has been subjected to specific treatment processes to meet the water quality standards for a certain purpose. Reclaimed water not only qualifies as a water resource asset, but also constitutes a significant component in contemporary production and daily life. Non-current assets include one sub-account: water resource reserves. Water resource reserves denote the strategic water resources that a country or region systematically plans, stores, and protects to ensure that the basic water demand can be met

during emergencies caused by sudden water crises or long-term water scarcity.

Water resources liabilities are classified into two primary accounts: current liabilities and non-current liabilities. Current liabilities encompass two sub-accounts: overdraft deficit and water quality liability. The overdraft deficit results from water withdrawals for production and domestic use exceeding the allowable limits, leading to environmental degradation and the subsequent costs required for remediation. Water quality liability arises from the repair costs necessitated by water pollution, the degradation of water body functions, and ecosystem damage caused by pollutant discharges in violation of regulations. Non-current liabilities include two sub-accounts: water resources allocation costs and ecological water demand deficit. Water resources allocation costs primarily originate from large-scale water transfer projects implemented to address the uneven spatial distribution of water resources in China, covering infrastructure construction, operation, and maintenance expenditures. The ecological water demand deficit refers to the gap between the minimum water volume essential for maintaining the health and stability of a specific regional ecosystem and the actual water volume available for ecosystem use within the region. Owing to factors such as excessive water extraction, regulation by water conservancy projects, urbanization, and agricultural reclamation, many regions consistently suffer from ecological water shortages, resulting in persistent ecological water demand deficits.

Water resources net assets are subdivided into three primary accounts: sustainable utilization threshold, risk buffer threshold, and water rights balance. The sustainable utilization threshold of water resources represents the maximum volume of water resources that can be sustainably developed and utilized within a region, reflecting the long-term exploitable potential of water resources. The risk buffer threshold denotes the reserved safety margin of water resources allocated to address unforeseen events, indicating the capacity of water resources to withstand uncertain risks. Under China's water rights system, the ownership of water resources is vested in the state, while natural persons and legal entities acquire water use rights through legal channels. The water rights balance constitutes the legally obtained water withdrawal quota that remains unused, which is acquired either through water rights trading or allocation, thus embodying the residual value of the region's legally recognized water use rights.

Table 1 Framework of the WRBS

Account Code	Assets	Opening balance	Closing balance	Account Code	Liabilities and net assets	Opening balance	Closing balance
1001	Current assets			2001	Current liabilities		
100101	Surface water			200101	Overdraft deficit		
10010101	Lakes			200102	Water quality liability		
10010102	Reservoirs			2002	Non-current liabilities		
10010103	Rivers			200201	Water resources allocation costs		
10010104	Other surface water			200202	Ecological water demand deficit		

100102	Groundwater				Total liabilities		
100103	Recycled water			3001	Sustainable utilization threshold		
1002	Non-current assets			3002	Risk buffer threshold		
100201	Water resource reserves			3003	Water rights balance		
					Total water resources net assets		
	Total Assets				Total liabilities and net assets		

5 Conclusions

The compilation of the WRBS under the dualistic water cycle model represents not only an innovative breakthrough in traditional water resources accounting methods, but also a critical pathway for addressing contemporary water challenges and crises. Building on the dualistic water cycle framework, this study integrates the natural and societal water cycles to construct a WRBS framework. This approach further promotes the application of sustainable development theory in water resources accounting and provides comprehensive and systematic informational support for integrated water resources management. By systematically examining the fundamental elements, structural framework, and tabular design of the WRBS based on the essential characteristics of the dualistic water cycle model, this study inherently addresses the core requirements of water resources governance. Concurrently, it establishes a robust foundation for achieving sustainable water resources utilization and advancing the progress of ecological civilization.

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References

- [1] Stephen Merrett. 1997. Introduction to the economics of water resources: An international perspective. London: University College London Press.
- [2] Stephen Merrett. 2004. Integrated water resources management and the hydro social balance. *Water International*, 29(2):148-157.
- [3] Jia Yangwen, Wang Hao, Wang Jianhua, et al. 2005. Development and verification of a distributed hydrologic model for the Yellow River Basin. *Journal of Natural Resources*, 20(2):300-308.
- [4] Jia Yangwen, Wang Hao, Qiu Yaqin, et al. 2006. Generalized water resources assessment based on watershed hydrologic cycle model. *Assessment Approach. Journal of Hydraulic Engineering*, 37(9):1051-1055.

- [5] Wang Hao, Niu Cunwen, Zhao Yong. 2023. Natural-artificial dualistic water cycle in river basins and water resources research. *Acta Geographica Sinica*, 78(7):1599-1607.
- [6] Deng Mingjiang, Long Aihua, Li Jiang, et al. 2020. Theoretical analysis of “natural-social-trading” ternary water cycle mode in the inland river basin of Northwest China. *Acta Geographica Sinica*, 75(7):1333-1345.
- [7] Shen Juqin, Lu Qingchun. 2003. Preliminary discussion on water rights market and water resources assets. *China Water Resources*, 8:10-11.
- [8] Dong Wenhui. 2002. Implementation status and revision proposals for financial and accounting systems in water management entities. *China Water Resources*, 2:47-49.
- [9] Wang Ran, Zhuo Xin, Cheng Jinhua, et al. 2021. Framework development for basin-scale water resources balance sheets: A Qingjiang Basin case study. *Friends of Accounting*, 21:68–73.
- [10] Jia Yizhen, Shen Juqin. 2022. Construction and compiling practice of water resources balance sheet system. *Statistics and Decision*, 38(15): 5-9.
- [11] Zhang Dandan, Shen Juqin. 2024. Regional water resources assets accounting based on cyclic coupling perspective. *Journal of Natural Resources*, 39(1): 153-169.
- [12] Wang Ran, Zhuo Xin, Zhang Yuanyuan. 2024. Development and application of water resources balance sheets with pro forma statements: A Qingjiang Basin case study. *Communications in Finance and Accounting*, 15:89–96.
- [13] Hong Minghai, Liu Hui, Yan Tao, et al. 2024. Study on the accounting method of water resource asset value based on ecological value. *Water Resources and Hydropower Engineering*, 55(12): 148–158.
- [14] Geng Jianxin, Hu Tianyu, Liu Zhujun. 2015. The research on preparation and application of China’s national balance sheet and natural resources balance sheet——An analysis based on SNA 2008 and SEEA 2012. *Accounting Research*, 1: 15-24.
- [15] Cao Shengle, Liu Chuntong, Li Fuzhen, et al. 2019. Research on water resource assets and liabilities in Jinan city based on social and economic development level. *China Population, Resources and Environment*, 29(5): 88-97.
- [16] Tang Yang, Han Jie, Wang Jiarui. 2021. Research on the Compilation of Water Resources Balance Sheet——Taking Hunan Province water resources as an example. *Journal of University of South China (Social Science Edition)*, 22(5): 60-66.

- [17] Gao Shaofu, Li Liwu. 2022. Research status and application prospects of China's water resources balance sheet. *Friends of Accounting*, 24:10-15.