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Research on the construction of regional water resources balance sheet based on the dualistic water cycle: A case study of Jiangsu Province

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ABSTRACT

With the emergence of the natural–social dual water cycle model, the compound water crises, including water scarcity, water pollution and aquatic ecological degradation, have become increasingly severe, posing major challenges to traditional water resources management. As an innovative tool connecting water resources management with modern accounting, the compilation of water resources balance sheet (WRBS) provides a systematic framework for enhancing the asset-based management level of water resources accounting entities and achieving sustainable utilization of water resources. Drawing on the natural–social dual water cycle theory and the framework of the System of Environmental-Economic Accounting (SEEA), this paper demonstrates the classification and measurement model of the elements in the WRBS. By constructing the format structure of the WRBS, the WRBS of Jiangsu Province from 2022 to 2024 was complied, and the situation of water resources assets and liabilities in the region was analyzed. The results show that the total amount of water resources assets in Jiangsu Province has been increasing year by year; the net water assets have also exhibited an upward trend, while the water resource liabilities have declined substantially, indicating a continuous improvement in the region's sustainable utilization of water resources.

Keywords: water resources balance sheet (WRBS); dualistic water cycle; measurement model; element classification

1 Introduction

Water resources are a strategic foundation for maintaining ecosystem health and supporting socio-economic development. The sustainable utilization of water resources is directly related to

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national water security and the construction of ecological civilization. However, with the sustained and rapid development of China's economy and the continuous growth of its population, the interference of human activities on the water cycle process has been increasingly intensified. The traditional natural water cycle model has gradually evolved into a complex system of natural-social dualistic collaborative evolution. In this transition, the spatiotemporal distribution, quality status and ecological functions of water resources have been profoundly affected. Multiple pressures such as water scarcity, water pollution and aquatic ecological degradation have intertwined and superimposed, forming a severe compound water crisis that constrains regional sustainable development. To address this challenge, the state has attached great importance to water-resources management and water security. Against this backdrop, scientifically assessing a region's water resource endowment and accurately identifying the overdrafts and liabilities in their development and utilization have become key steps toward achieving refined and asset-based management of water resources.

The WRBS has emerged as an innovative instrument that integrates accounting concepts with water resources management practice. The core idea is to regard water resources as quantifiable assets, while defining the environmental degradation and restoration costs caused by overexploitation, pollutant discharges and other activities as liabilities. Through the accounting identity, the balance sheet systematically reflects the stock, flow, quality and potential risks of regional water resources, providing decision makers with an intuitive and quantitative scientific basis. The compilation of the WRBS not only aligns with institutional requirements of the natural resource asset departure audit for leading cadres, but also constitutes an important practice in the construction of ecological civilization systems. It helps advance the implementation of development concepts that link urban layout, land use, population distribution and production activities to water endowments. Currently, domestic and international scholars have made important progress in water resources asset accounting. In terms of physical quantity accounting, studies have primarily focused on the measurement of total water resources, available water resources, and ecological water demand. In terms of value accounting, methods such as market price method, shadow price method, energy analysis method, and ecosystem service value assessment method have been widely applied. Nevertheless, existing research exhibits notable limitations. Firstly, most studies emphasize the positive valuation of water resources assets, the definition and accounting system for water resources liability remain underdeveloped, lacking the theory and practice to systematically account for assets and liabilities within the same framework. Secondly, different scholars adopt diverse accounting methods and classification standards, which leads to a lack of comparability in accounting results and makes it difficult to form a unified policy reference. Thirdly, existing research remains at the theoretical stage or limited to isolated regional pilots, lacking in-depth analysis of dynamic changes in regional water resources assets and liabilities, as well as comprehensive assessments of the sustainability of net

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water resources assets.

To fill these gaps, this study takes Jiangsu Province as the research object and constructs a WRBS framework based on the natural–social dual water circulation theory. The research aims to: (1) systematically define the accounting scope and classification system of water resources assets, liabilities and net assets; (2) develop measurement models centered on the market price method and the restoration cost method to ensure objectivity and operational feasibility of accounting results; (3) reveal the spatiotemporal evolution characteristics of water resources assets and liabilities in Jiangsu Province by compiling the WRBS, and evaluate the sustainable utilization level of regional water resources. The research is expected to provide theoretical support and a practical example for improving China's asset-based water resources management regime and strengthening water security risk early warning capacity.

2 Literature review

2.1 Water resources asset accounting method

Water resources asset accounting involves the intersection and integration of multidisciplinary knowledge. Its accounting methods can be classified into physical quantity accounting and value quantity accounting. Physical quantity accounting, which assesses resources primarily through physical indicators such as water quantity and quality, serves as the foundation for value quantity accounting. Value quantity accounting employs various methods, including the income method, replacement cost method, shadow price method, target benefit method, market inversion method, and ecosystem service value assessment method (Li et al., 2025). However, due to the lack of a unified measurement standard, scholars have proposed diverse accounting frameworks and methods based on different manifestations of value and accounting objectives.

In domestic research focusing on the quantitative assessment of water quantity and quality, scholars have constructed evaluation indicator systems encompassing water quantity, water quality, population, socio-economic factors, and ecological environment based on fuzzy mathematical evaluation models. Considering the affordability of water users, the water resource asset price is calculated (Jian et al., 2016). Furthermore, the energy analysis method has been extensively applied. Research on the multi-purpose use of water resources employs a unified energy standard for quantitative valuation, achieving integrated accounting of water quantity and quality within a single table. This approach clarifies the credit-debt relationship between the economy and the environment. Energy serves as a benchmark for the unified measurement of ecosystem and environmental resource values, linking the ecosystem with human societal systems (Huang et al., 2020). Based on accounting and statistical principles, scholars have proposed two accounting frameworks for WRBS, subsequently suggesting three types of WRBS

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(Jia et al., 2017). Simultaneously, the research perspective has extended towards the ecological value of water resources. Under the condition of integrating ecological product value accounting methods, the ecological value of water resources is fully considered, introducing water quality weighting coefficients to comprehensively reflect the multi-dimensional value of water resources within ecosystems (Hong et al., 2024). Additionally, the application of methods such as life cycle assessment (LCA) and environmental extended input-output (EEIO) enable the conversion of water consumption impact pathways and their driving factors into measurable indicators, which are further transformed into monetary values to calculate the total economic value, enriching the comprehensive assessment methodologies of water resources value (Xin et al., 2025). Seidl et al. (2020) summarized the most commonly used methods by examining the water resources valuation methods and data sources considered by multiple experts, namely the relative valuation method based on the current market licensing prices and transaction data of water resources. Bagstad et al. (2020) integrated physical and economic data into water resources asset accounts, proposing to track water as a separate product, list its monetary information, and obtain both physical and value data simultaneously.

2.2 Water resources liability accounting method

The accounting method for water resources liability is in the exploratory stage and have not formed a unified standard. Huang et al. (2017) defined water resources liabilities as the gap between the actual water intake, water use efficiency, water quality compliance rate of water functional zone and their corresponding regulatory red line targets, thereby transforming policy implementation deviations into quantifiable liability indicators. Yang et al. (2018) further expanded the accounting dimensions. For issues of different natures such as over-exploitation of water resources, water environment damage, and water ecological degradation, the fuzzy mathematical model for water resource value, virtual governance cost method, shadow engineering method, and market price method are respectively adopted for accounting, reflecting the accounting concept that various types of liabilities need to be treated differently. Jiao et al. (2021) attempted to construct a comprehensive quantitative evaluation model, integrating multi-dimensional factors such as water quality, water quantity, and water use efficiency to advance the integrated accounting of water resource assets and liabilities, indicating the field's progression from single perspective approaches towards systemic evaluation. Zhou (2023) proposed an automated accounting method for water resource liability classification, which utilizes deep clustering algorithms and attention mechanism modules to automatically categorize the water resources liability levels of different regions, achieving comprehensive water resources liability accounting. Although these studies differ in methodology, they collectively contribute to the theoretical development of water resources liability accounting, laying the groundwork for constructing a more systematic and scientific accounting system.

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2.3 Water resources net asset accounting method

Due to the differences in the recognition of water resources liabilities and their recognition criteria, the definition of water resources net assets is also highly contentious. Some scholars argue that the complex interactions between water resources, economy, and environment prevent the direct accounting of water resources net assets. The equity elements can only be represented and measured using the concept of water resources net assets, and cannot be directly presented as water resource owner's equity (Jia & Shen, 2022). The view that water resources net assets represent the residual equity of water resources assets after deducting water resources liabilities is widely recognized. Numerically, it conforms to the identity relationship of “water resources net assets = water resources assets - water resources liabilities”.

2.4 Literature commentary

The research on the theory and methods of water resources asset accounting is constantly deepening, but there is a lack of unified standards for accounting methods, and the comparability between different methods is low. Further breakthroughs are still needed in standardization and comprehensiveness. Concurrently, there are significant difficulties in quantifying the ecological and social value of water resources, and further exploration is needed to establish unified measurement standards and accounting methods. In the accounting of water resources liabilities, the public goods attribute of water resources leads to a lack of market value, making non-use values difficult to quantify. When using restoration cost methods, restoration standards are often inconsistent, and costs vary significantly over time. In practical accounting, the accounting of water resources liabilities tends to focus on water quantity, while neglecting the accounting of water quality and ecological liabilities. The data foundation of water resources liabilities is weak, and the operability is poor. The setting of thresholds and standards are subjective. Due to the lack of effective accountability and repayment mechanisms, the accounting results are difficult to be linked to relevant management systems. The accounting of water resources net assets relies on the accounting results of water resources assets and liabilities. Similar to liabilities, net assets accounting lacks mandatory linkage mechanisms connecting its changes to core management tools such as local government performance evaluation, ecological compensation, and water resource allocation, making the accounting prone to formalism.

3 Classification and measurement model of elements in WRBS

3.1 Classification of elements in WRBS

As a fundamental and strategic natural resource that maintains ecosystem stability and supports economic and social development, water resources have significant scarcity, mobility, versatility, and ambiguous property rights. With the deep involvement of human activities, the traditional

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natural water cycle has evolved into a complex system of natural–social dual synergy. The development and utilization of water resources not only involve the spatial and temporal redistribution of water quantity, but also profoundly affects water quality safety and ecological health. Against this backdrop, asset-based management of water resources has become an inevitable trend to improve governance efficiency. However, due to the complex attributes of water resources and the diversity of accounting objectives, different scholars have significant differences in the classification of elements in the balance sheet. Some studies focus on the physical form and economic value of water resources, simply classifying them as surface water, groundwater, etc. Other studies attempt to integrate ecological value and environmental costs to construct a more comprehensive accounting framework. These differences highlight the necessity of establishing a unified classification system that reflects both the natural attributes of water resources and their socio-economic functions and environmental responsibilities.

3.1.1 Classification of water resources asset elements

This study draws on the principle of classifying assets by liquidity in accounting, and combines the usage purpose and value realization of water resources assets to divide water resources assets into two categories of primary accounts: current water assets and non-current water assets, as shown in Table 1.

Current water assets mainly reflect water resources assets that can be moved or changed in form within a relatively short period of time and participate in economic activities to generate economic benefits. Their value is usually realized through direct use or sale in the short term, and they are characterized by high liquidity and flexible use. Based on the source of water resources and their natural attributes, current water assets can be divided into three secondary categories: surface water assets, groundwater assets, and reclaimed water assets. Surface water assets mainly come from lakes, rivers, and reservoirs, which are the most accessible and utilizable part of water resources in nature. Their quantity and quality are affected by multiple factors such as precipitation, topography, and intensity of human activities. Groundwater assets are characterized by their wide distribution, relatively stable water quality, and resistance to pollution, making them crucial for ensuring the livelihoods of residents and the production of industry and agriculture in arid and semi-arid regions. Reclaimed water assets are water resources that have been treated through specific processes to meet water quality standards required for a certain purpose, thus enabling them to be reused.

Non-current water assets are primarily designed to meet long-term, stable water resource demands, and their value realization process is complex and time-consuming. A secondary category, water reserves, is established under non-current water assets. Water reserves refer to the water resources that a country or region reserves through systematic planning, storage, and

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protection measures to ensure the guarantee of basic water demand in emergency situations in response to sudden water crises or long-term water shortages. Water reserves are mainly reflected in the strategic planning and storage of different types of water resources to form a stable supply source. Based on the form and location of water resources, water reserves can be divided into two categories: surface water reserves and groundwater reserves. Surface water reserves rely on natural or artificial surface water bodies such as rivers, lakes, and reservoirs, and are stored through scientific planning and engineering measures. They can be allocated and utilized to deal with peak water consumption or sudden water shortages. Groundwater reserves utilize the water storage capacity of underground aquifers and are stored through reasonable extraction control and artificial recharge, providing a solid guarantee for long-term stable water supply and being relatively less affected by external interference.

3.1.2 Classification of water resources liability elements

Water resources liabilities reflect present obligations of economic entities arising from past water resource development and utilization activities, the fulfillment of which is expected to result in an outflow of economic benefits. Based on the principle of prudence in recognizing environmental responsibility and the theory of liability maturity structure, water resources liabilities are divided into two categories: current water liabilities and non-current water liabilities, as shown in Table 1. Furthermore, the current water liabilities can be divided into two secondary categories: overdraft deficit and water quality deficit. The overdraft deficit quantifies the losses caused by excessive water resources extraction, and the water quality deficit quantifies the short-term environmental remediation costs caused by pollutant discharge. Non-current water liabilities include two secondary categories, namely water resource allocation and ecological water deficit. The former accounts for the long-term economic burden brought about by engineering measures such as inter-regional water transfer, while the latter assesses the ecological risks caused by the difference between the minimum water quantity required to maintain ecosystem health and the actual water volume.

3.1.3 Classification of water resources net asset elements

Net water assets reflect the equity of water resource owners. They are the residual equity of water resources assets after deducting water resource liabilities, and embody the true value and sustainable utilization capacity of water resources. This study establishes three categories: sustainable utilization threshold, water rights balance, and risk buffer threshold, corresponding to the long-term utilization potential of regional water resources, the legally obtained remaining water rights, and the ability to cope with uncertain risks, respectively. This category system not only reflects the property rights characteristics of water resources as a public resource but also provides key indicators for risk warning and sustainability assessment in water resource

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management.

Table 1 Classification accounting subjects for water resources assets and liabilities

Subject code	Level	Subject name	Subject description
1001	1	Current water assets	Calculate the various types of water resources that meet the region's immediate water demand
100101	2	Surface water assets	Calculate water resources stored on the surface used within the region
10010101	3	Lakes	Calculate water resources sourced from lakes used within the region
10010102	3	Rivers	Calculate water resources sourced from rivers used within the region
10010103	3	Reservoirs	Calculate water resources sourced from reservoirs used within the region
100102	2	Groundwater assets	Calculate water resources stored in underground aquifers used within the region
100103	2	Reclaimed water assets	Calculate water resources used within the region that meet standards after treatment
1002	1	Non-current water assets	Calculate the types of water resources meeting the region's long-term water demand
100201	2	Water reserves	Calculate various water resources in the region
10020101	3	Surface water reserves	Calculate water resources stored in surface water bodies in the region
10020102	3	Groundwater reserves	Calculate water resources stored in underground aquifers in the region
2001	1	Current water liabilities	Calculate actual obligations arising from the development and utilization of water resources
200101	2	Overdraft deficit	Calculate water deficit caused by over-exploitation in the region
200102	2	Water quality deficit	Calculate the discharge of pollutants into water bodies exceeds their self-purification capacity
2002	1	Non-current water liabilities	Calculate long-term practical obligations
200201	2	Water resource allocation	Calculate cross regional water transfer through engineering measures
200202	2	Ecological water deficit	Calculate the difference between actual water demand and available water
3001	1	Sustainable utilization threshold	Calculate maximum exploitable water quantity in the region
3002	1	Water rights balance	Calculate the remaining unused water intake in the region
3003	1	Risk buffer threshold	Calculate the safe water reserved to cope with risks in the region

3.2 Water resources asset accounting model

Water resources are economic resources defined by scarcity and utility. The value of water resources is reflected most directly in the market price users are willing to pay. This study uses the market price method to account for the value of water resources assets. For directly tradable water resources, market transaction prices are used for accounting. For water resources without an active market but with government pricing, shadow prices are used to calculate the value of

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water resource assets. This method reflects the true economic value of water resources, aligning with the definition of an asset as expected to generate inflows of economic benefits. Moreover, water price data is easy to obtain, making the accounting work more reproducible and generalizable.

3.2.1 Surface water assets

Surface water assets refer to the water resources provided by lakes, rivers, reservoirs, etc., used by regional accounting entities to meet immediate water demand. The physical quantity of surface water assets can be obtained from statistics on the water resource usage from lakes, rivers, reservoirs, etc. The value accounting can be measured using the market price method. The calculation formulas are as follows:

$$Q_{\text{surface water assets}} = Q_{\text{lakes}} + Q_{\text{rivers}} + Q_{\text{reservoirs}} \quad (1)$$

$$V_{\text{surface water assets}} = Q_{\text{surface water assets}} \times P_{\text{market price}} \quad (2)$$

Where $Q_{\text{surface water assets}}$ represents the physical quantity of surface water assets in the region. Q_{lakes}, Q_{rivers}, and $Q_{\text{reservoirs}}$ respectively represent the physical quantities of water resource assets for lakes, rivers, and reservoirs used in the region. $V_{\text{surface water assets}}$ represents the value of surface water assets in the region. $P_{\text{market price}}$ is the market price of water resources in the region, which is calculated by comprehensively considering the water prices for residents, industries, and agriculture in the region.

3.2.2 Groundwater assets

Groundwater assets are water resources stored in underground aquifers. Regional accounting entities use these resources to meet immediate water demand. The physical quantities of groundwater assets come from groundwater usage statistics. The value of groundwater assets is measured using the market price method.

$$V_{\text{groundwater assets}} = Q_{\text{groundwater assets}} \times P_{\text{market price}} \quad (3)$$

Where $V_{\text{groundwater assets}}$ represents the value of groundwater assets in the region, $Q_{\text{groundwater assets}}$ is the physical quantity of groundwater assets in the region.

3.2.3 Reclaimed water assets

Reclaimed water assets are water resources that have been treated through specific processes and reused to meet immediate water demand. The physical quantity of reclaimed water assets can be

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obtained from statistics on recycled water usage. The value can be measured using the market price method.

$$V_{\text{reclaimed water assets}} = Q_{\text{reclaimed water assets}} \times P_{\text{market price}} \quad (4)$$

Where $V_{\text{reclaimed water assets}}$ is the value of recycled water assets in the region, $Q_{\text{reclaimed water assets}}$ is the physical quantity of recycled water assets in the region.

3.2.4 Water reserves

Water reserves are water resources stored through scientific planning and engineering measures in natural or artificial surface water bodies such as rivers, lakes, and reservoirs, which can be allocated to cope with peak water demand or sudden water shortage. The calculation formulas are as follows:

$$Q_{\text{water reserves}} = Q_{\text{surface water reserve}} + Q_{\text{groundwater reserve}} \quad (5)$$

$$Q_{\text{surface water reserve}} = Q_{\text{lake storage}} + Q_{\text{reservoir storage}} \quad (6)$$

$$Q_{\text{groundwater reserve}} = Q_{\text{groundwater resource}} - Q_{\text{groundwater extraction}} \quad (7)$$

$$V_{\text{water reserves}} = Q_{\text{water reserves}} \times P_{\text{market price}} \quad (8)$$

Where $Q_{\text{water reserves}}$ is the quantity of water resources reserves in the region. $Q_{\text{surface water reserve}}$ and $Q_{\text{groundwater reserve}}$ are the physical quantities of water resources reserved in surface water bodies and groundwater bodies in the region. $Q_{\text{lake storage}}$ and $Q_{\text{reservoir storage}}$ are the lake storage capacity and reservoir storage capacity at the end of the year in the region. $Q_{\text{groundwater reserve}}$ is the quantity of groundwater resources in the region. $Q_{\text{groundwater extraction}}$ is the quantity of groundwater extraction in the region. $V_{\text{water reserves}}$ is the value of water resources reserves in the region.

3.3 Water resources liability accounting model

Based on the comprehensive consideration of the economic attributes of water resources, the operability of accounting, and the inherent consistency with management system requirements, this study adopts the restoration cost method to account for water resources liabilities. The restoration cost method focuses on the total cost required to restore the water resource system to its intended state before the damage or over-exploitation, such as calculating the cost required to recharge over-extracted groundwater to the original water level or the sewage treatment costs required to restore polluted water bodies to target water quality standards. This method reveals

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the essence of water resources liabilities as a form of environmental debt, adheres to the accounting principle of prudence, which is conducive to warning risks. For regional government managers, understanding the amount of funds required to repair environmental problems is far more valuable for decision-making than knowing the abstract extent of loss, which perfectly aligns with the practical needs of the natural resource asset departure audit for leading cadres. Simultaneously, this method avoids the difficulty of directly valuing ecological damage itself, and indirectly characterizes the scale of liabilities by using engineering costs, making the accounting results more robust.

3.3.1 Overdraft deficit

The overdraft deficit accounts for the water resource deficit caused by excessive extraction of water resources, expressed as the excess of the sustainable utilization threshold over the total water supply. The calculation formulas are as follows:

$$Q_{\text{overdraft deficit}} = \max(Q_{\text{sustainable use threshold}} - Q_{\text{total water supply}}, 0) \quad (9)$$

$$V_{\text{overdraft deficit}} = Q_{\text{overdraft deficit}} \times P_{\text{market price}} \quad (10)$$

Where $Q_{\text{overdraft deficit}}$ is the quantity of over-extracted water resources in the region. $Q_{\text{sustainable use threshold}}$ is the annual dual-control target for total water consumption intensity in the region. $Q_{\text{total water supply}}$ is the total water supply in the region. $V_{\text{overdraft deficit}}$ is the value of the over-extracted water resources in the region.

3.3.2 Water quality deficit

The water quality deficit accounts for the short-term environmental treatment costs caused by pollutant discharge. The calculation formula is as follows:

$$V_{\text{water quality deficit}} = Q_{\text{water quality deficit}} \times P_{\text{sewage treatment price}} \quad (11)$$

Where $V_{\text{water quality deficit}}$ is the cost incurred to treat water pollution caused by sewage discharge. $Q_{\text{water quality deficit}}$ is the quantity of sewage discharge in the region. $P_{\text{sewage treatment price}}$ is the average price for sewage treatment.

3.3.3 Water resource allocation

The water resource allocation accounts for the long-term economic burden generated by engineering measures such as inter-regional water transfer. The calculation formula is as follows:

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$$V_{\text{water resource allocation}} = Q_{\text{water resource allocation}} \times P_{\text{water transfer project price}} \quad (12)$$

Where $V_{\text{water resource allocation}}$ is the value of water transferred out of the province. $Q_{\text{water resource allocation}}$ is the total quantity of water transferred out of the province. $P_{\text{water transfer project price}}$ is the average water price for each section of the water diversion project.

3.3.4 Ecological water deficit

The ecological water deficit accounts for the difference between the minimum water quantity required to maintain ecosystem health and the actual water quantity. The calculation formulas are as follows:

$$Q_{\text{ecological water deficit}} = Q_{\text{ecological water demand}} - Q_{\text{ecological environment water use}} \quad (13)$$

$$Q_{\text{ecological water demand}} = Q_{\text{urban ecological demand}} + Q_{\text{river lake ecological supplement}} \quad (14)$$

$$V_{\text{ecological water deficit}} = Q_{\text{ecological water deficit}} \times P_{\text{market price}} \quad (15)$$

Where $Q_{\text{ecological water deficit}}$ is the ecological water demand gap in the region. $Q_{\text{ecological water demand}}$is the minimum water quantity required to maintain healthy and stable ecosystems in the region. $Q_{\text{ecological environment water use}}$ is the artificially supplied water for ecological environments. $Q_{\text{urban ecological demand}}$ is the water demand for urban greening management. $Q_{\text{river lake ecological supplement}}$ is the difference between surface evaporation and precipitation in river and lake areas. $V_{\text{ecological water deficit}}$ is the total value of the ecological water demand gap in the region.

3.4 Water resources net asset accounting model

The accounting of water resources net assets strictly follows the accounting identity of "water resources net assets = water resources assets - water resources liabilities". The calculated net asset index is the key to measuring the regional water security situation. If the net assets are positive, it indicates that the regional water resources are in a healthy and sustainable state. If the net assets are negative, it is a strong risk signal indicating that the development and utilization of water resources have been seriously overdrawn, and there is a risk of unsustainability.

3.4.1 Sustainable utilization threshold

The sustainable utilization threshold accounts for the long-term usable potential of water resources. Its calculation formula is as follows:

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$$V_{\text{sustainable utilization threshold}} = Q_{\text{sustainable utilization threshold}} \times P_{market\ price} \quad (16)$$

Where $V_{\text{sustainable utilization threshold}}$ is the value of water resources that can be developed and utilized in the region; $Q_{\text{sustainable utilization threshold}}$ is the quantity of water resources that can be developed and utilized in the region, namely the dual-control target of total annual water use intensity.

3.4.2 Water right balance

The water right balance accounts for the remaining water intake right obtained in accordance with the law. Its calculation formula is as follows:

$$Q_{\text{water right balance}} = \max(Q_{\text{sustainable utilization threshold}} - Q_{\text{total water supply}} - Q_{\text{water trabsfer}}, 0) \quad (17)$$

$$V_{\text{water right balance}} = Q_{\text{water right balance}} \times P_{\text{market price}} \quad (18)$$

Where $Q_{\text{water right balance}}$ is the annual remaining water right in the region; $V_{\text{water right balance}}$ is the value of the annual remaining water right in the region.

3.4.3 Risk buffer threshold

The risk buffer threshold accounts for the ability of regional accounting subjects to cope with uncertain risks. Its calculation formula is as follows:

$$Q_{\text{risk buffer threshold}} = Q_{\text{water resource asset}} - Q_{\text{water resource liability}} - Q_{\text{sustainable utilization threshold}} - Q_{\text{water right balance}} \quad (19)$$

$$V_{\text{risk buffer threshold}} = V_{\text{water resource asset}} - V_{\text{water resource liability}} - V_{\text{sustainable utilization threshold}} - V_{\text{water right balance}} \quad (20)$$

Where $Q_{\text{risk buffer threshold}}$ is the reserved water resource surplus to cope with emergencies; $Q_{\text{water resource asset}}$ and $Q_{water\ resource\ liability}$ are the physical quantities of water resources assets and water resources liabilities respectively; $V_{\text{risk buffer threshold}}$ is the value of reserved water resources for emergency response; $V_{\text{water resource asset}}$ and $V_{water\ resource\ liability}$ are the value of water resources assets and water resources liabilities respectively.

4 Construction of WRBS

4.1 Structure of WRBS

Based on the natural-social dualistic water cycle model, this study divides the water resources

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system into natural subsystem and social subsystem, and systematically reflects the assets, liabilities and net assets status of regional water resources through accounting methods. The basic format of the constructed WRBS is shown in Table 2. The left side of the statement lists water resources assets, and the right side lists water resources liabilities and net assets, with opening balance and closing balance shown respectively.

According to the liquidity of water resources assets, water resources assets are divided into two categories: current water resources assets and non-current water resources assets. Current water resources assets include three accounting subjects: surface water assets, groundwater assets and reclaimed water assets, while non-current water resources assets include the subject of water reserve. Water resources liabilities are divided into two categories: current water resources liabilities and non-current water resources liabilities. Current water resources liabilities include accounts for overdraft deficit and water quality deficit, while non-current water resources liabilities include accounts for water resource allocation and ecological water deficit. The water resources net assets are divided into three categories of accounting subjects, namely sustainable utilization threshold, water rights balance, and risk buffer threshold. By compiling the regional WRBS, the current situation, change trend and potential risks of water resources are comprehensively evaluated, providing a solid theoretical basis and data support for the formulation of water resources policies.

Table 2 Structure of WRBS

Subject code	Assets	Beginning balance	Closing balance	Subject code	Liabilities and net assets	Beginning balance	Closing balance
1001	Current water assets			2001	Current water liabilities		
100101	Surface water assets			200101	Overdraft deficit		
10010101	Lakes			200102	Water quality deficit		
10010102	Rivers			2002	Non-current water liabilities		
10010103	Reservoirs			200201	Water resource allocation		
100102	Groundwater assets			200202	Ecological water deficit		
100103	Reclaimed water assets				Total liabilities		
1002	Non-current water assets			3001	Sustainable utilization threshold		
100201	Water reserves			3002	Water rights balance		
10020101	Surface water reserves			3003	Risk buffer threshold		
10020102	Groundwater reserves				Total net assets		
	Total assets				Total liabilities and net assets		

According to the elements classification and structure of WRBS, the changes in the value quantity of water resources assets and net assets are mainly affected by physical quantity and market price. As for water resources liabilities, the influencing factors of the value of different subjects are different. Overdraft deficit is affected by exploitable quantity and restoration cost,

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water quality deficit is affected by sewage discharge quantity and sewage treatment charge price, the value of water resource allocation is determined by government fiscal expenditure, and the ecological water deficit is determined by physical quantity and market price. The combination of these methods can theoretically reveal the economic and environmental attributes of water resources in the dualistic water cycle, and has the advantages of data availability, simple operation, intuitive results and serving management in practice, making the WRBS a powerful policy tool for government water resources management and risk warning.

4.2 Practices of compiling WRBS

Jiangsu Province is situated in the eastern coast of China, downstream of the Yangtze River, Huai River, and Yi-Shu-Si River basins. The water area of the province accounts for 16.9% of its total area, featuring numerous lakes, a dense river network, and proximity to the sea, giving it superior geographical conditions. It is a key area for regional water resource regulation and ecological protection. Since 2013, Jiangsu has continuously explored directions and pathways for water resource management, and its water resources asset and liability status has significant research value. The basic data of water resources involved in this study are sourced from the Jiangsu Water Resources Bulletin (2022–2024), Jiangsu Statistical Yearbook, Urban and Rural Development Statistical Yearbook, China Hydrological Yearbook, China Water Situation Annual Report, Jiangsu Ecological and Environmental Status Bulletin, as well as government information disclosed on central and local government websites.

Water resources assets in Jiangsu Province reflect the scale and value of utilizable water resources in the region, as detailed in Table 3 and Table 4. The physical quantity of current assets decreased from 61.18 billion m^3 in 2022 to 57.14 billion m^3 in 2023, before recovering to 57.87 billion m^3 in 2024. The primary reasons are the overall declining trends in surface water and groundwater. River water resources decreased by 12.08%, while storage in lakes and reservoirs increased by 33.31% and 49.75%, respectively, indicating enhanced storage capacity. However, as its contribution to surface water is far less than that of rivers, the surface water decreased by 5.78%. Groundwater extraction decreased from 0.28 billion m^3 to 0.21 billion m^3, a reduction of 25%, ensuring the safeguard groundwater quality and sustainable development. Reclaimed water increased from 1.40 billion m^3 to 1.60 billion m^3, a rise of 14.29%, with its proportion in current assets increasing from 2.29% to 2.76%, indicating continuous improvement in water resource utilization efficiency in Jiangsu Province. Based on the accounting results for non-current assets, water reserves have grown steadily, with the physical quantity increasing from 18.02 billion m^3 to 23.72 billion m^3 and the value increasing from 38.02 billion CNY to 54.78 billion CNY, a growth of 31.61%. Among these, the groundwater reserves increased by 44.57%, reflecting significant achievements in groundwater management in recent years and good recovery conditions, providing more stable support for regional water supply. From the total assets, the scale of water resources assets in Jiangsu Province generally showed a steady upward trend from 2022 to 2024, increasing from 79.20 billion m³ to 81.59 billion m³, a growth of 3.01%, with an identical increase in value. This indicates enhanced core water supply capacity and a significant improvement in the overall utilizable scale and value of regional water resources.

According to the accounting results of current liabilities, the total water supply in 2022 was relatively high, and it was a drought year, resulting in an overdraft deficit of 4.93 billion m³. In 2023 and 2024, the overdraft deficit was zero. The water quality deficit remained consistently high, with a slight increase in 2024. This shows that the issue of water resource over-extraction in Jiangsu has been properly addressed, but water quality problems persist. Based on the accounting results for non-current liabilities, the physical quantity of non-current liabilities decreased from 5.67 billion m³ to 1.46 billion m³, and the value decreased from 11.55 billion CNY to 1.64 billion CNY, indicating a significant decline in long-term water resource pressure and ecological costs. In 2022, non-current liabilities remained high because the average annual precipitation was lower than the multi-year average surface evaporation in Jiangsu, resulting in insufficient ecological water replenishment for rivers and lakes. Additionally, water for production and domestic use encroached on ecological base flow, leading to an ecological water deficit of 5.25 billion m³. From 2023 to 2024, precipitation increased significantly, resulting in no ecological water deficit. The physical quantity of water resource allocation increased from 0.42 billion m³ to 1.46 billion m³, and the value increased from 0.47 billion CNY to 1.64 billion CNY, with annual water transfers from outside the province reaching new highs. Overall, the physical quantity of water resources liabilities decreased from 17.37 billion m³ in 2022 to 7.95 billion m³ in 2023, then rose to 8.39 billion m³ in 2024. The corresponding value decreased from 32.65 billion CNY to 12.02 billion CNY, then increased to 12.58 billion CNY. This indicates an overall alleviation of pressure from regional water resource overuse, allocation costs, and ecological damage.

Water resource net assets reflect the net equity of water resources. The sustainable utilization threshold in physical terms is the dual-control target value of annual total water use intensity in Jiangsu Province. Both the physical quantity and value of water rights balances were zero in 2022 and 2023. In 2024, the physical quantity of the water rights balance was 0.75 billion m³, with a value of 1.74 billion CNY. This indicates improved water-saving technology, optimized water resource allocation, enhanced water resource security capacity, and a surplus in water rights that provides a foundation for expanded reproduction. The risk buffer threshold, serving as reserved water resources for crisis response, increased from 5.58 billion m³ to 12.36 billion m³, and in value increased from 14.46 billion CNY to 33.20 billion CNY, demonstrating Jiangsu's enhanced capacity to respond to water resource risks. Overall, the water resources net assets have continued to grow, with the physical quantity increasing from 61.83 billion m³ to 73.20 billion

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m³ and the value increasing from 133.15 billion CNY to 173.73 billion CNY. This signifies improved long-term sustainability of water resource utilization in Jiangsu Province and the notable effectiveness of a series of water resource management measures.

Table 3 WRBS of Jiangsu Province (Physical quantity, billion m³)

Subject code	Assets	2022	2023	2024	Subject code	Liabilities and net assets	2022	2023	2024
1001	Current water assets	61.18	57.14	57.87	2001	Current water liabilities	11.70	6.77	6.93
100101	Surface water assets	59.50	55.39	56.06	200101	Overdraft deficit	4.93	0.00	0.00
10010101	Lakes	7.42	10.05	9.89	200102	Water quality deficit	6.77	6.77	6.93
10010102	Rivers	51.46	44.62	45.24	2002	Non-current water liabilities	5.67	1.18	1.46
10010103	Reservoirs	0.62	0.71	0.93	200201	Water resource allocation	0.42	1.18	1.46
100102	Groundwater assets	0.28	0.25	0.21	200202	Ecological water deficit	5.25	0.00	0.00
100103	Reclaimed water assets	1.40	1.50	1.60		Total liabilities	17.37	7.95	8.39
1002	Non-current water assets	18.02	22.82	23.72	3001	Sustainable utilization threshold	56.25	58.17	60.08
100201	Water reserves	18.02	22.82	23.72	3002	Water rights balance	0.00	0.00	0.75
10020101	Surface water reserves	10.22	12.56	12.44	3003	Risk buffer threshold	5.58	13.85	12.36
10020102	Groundwater reserves	7.80	10.26	11.28		Total net assets	61.83	72.01	73.20
	Total assets	79.20	79.96	81.59		Total liabilities and net assets	79.20	79.96	81.59

Table 4 WRBS of Jiangsu Province (Value, billion CNY)

Subject code	Assets	2022	2023	2024	Subject code	Liabilities and net assets	2022	2023	2024
1001	Current water assets	127.78	130.35	131.53	2001	Current water liabilities	21.10	10.70	10.95
100101	Surface water assets	124.23	126.31	127.35	200101	Overdraft deficit	10.40	0.00	0.00
10010101	Lakes	15.65	23.22	22.84	200102	Water quality deficit	10.70	10.70	10.95
10010102	Rivers	108.59	103.08	104.51	2002	Non-current water liabilities	11.55	1.32	1.64
10010103	Reservoirs	1.31	1.64	2.15	200201	Water resource allocation	0.47	1.32	1.64
100102	Groundwater assets	0.59	0.58	0.49	200202	Ecological water deficit	11.09	0.00	0.00
100103	Reclaimed water assets	2.95	3.47	3.70		Total liabilities	32.65	12.02	12.58
1002	Non-current water assets	38.02	52.73	54.78	3001	Sustainable utilization threshold	118.69	134.36	138.79
100201	Water reserves	38.02	52.73	54.78	3002	Water rights balance	0.00	0.00	1.74
10020101	Surface water reserves	21.56	29.01	28.74	3003	Risk buffer threshold	14.46	36.69	33.20
10020102	Groundwater reserves	16.46	23.71	26.05		Total net assets	133.15	171.06	173.73
	Total assets	165.80	183.08	186.31		Total liabilities and net assets	165.80	183.08	186.31

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5. Conclusions

The compilation of WRBS is a requirement under environmental governance and the system for auditing outgoing leading officials. Based on the SEEA and existing research, this study proposes the classification of elements, accounting methods, and reporting framework for WRBS from the perspective of dual water cycle theory, , and applies them in practice. The main conclusions of this study are as follows:

(1) In accordance with the basic principles of environmental accounting and the dual water cycle theory, this study clarifies that the WRBS should encompass three major elements: water resources assets, water resources liabilities, and water resources net assets. By combining the characteristics of natural water resources and the processes of the social water cycle, the elements of the statement are classified to ensure they conform to the logic of accounting element recognition.

(2) By systematically reviewing accounting methods in existing research, this study adopts methods such as market price method and restoration cost method to account for the value of water resources assets, liabilities, and net assets. These methods not only align with the definitions of each element, but also meet the requirements of authenticity and prudence, while possessing high feasibility.

(3) The setting of report subjects balances clarity and relevance, and the prepared WRBS can reflect the stock and usage of water resources clearly. In the practical compilation of the WRBS in Jiangsu Province, the water resources status can be intuitively presented, providing a practical basis for the formulation of water resources management policies.

Due to limitations such as insufficient geographic information technology, inconsistent statistical standards for water use in social production and daily life, and inadequate availability of data, quantification methods involve subjectivity. Therefore, the practical application of WRBS compilation still requires consideration and improvement from multiple aspects. As the statistical work on basic data gradually strengthens, future research could expand to compiling WRBS for entities at different levels, comprehensively monitoring the dynamic changes in water resources assets and liabilities. By establishing asset liability accounting model at the basin-city scale, conducting joint research across regions and basins, and expanding accounting coverage, the widespread application of research findings can be ensured. Additionally, by promoting the deep integration of water resources quantitative assessment with the Environmental, Social, and Governance (ESG) system, unified standards for quantifying water ecological service value and implicit costs can be developed, fostering further development of interdisciplinary collaboration.

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