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Virtuous Cycle: An Idea of Water Resources Management and Top-Level Planning

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Abstract: Facing the conflict between human activities and the ecological environment, this study proposes a "Virtuous Cycle" concept of water resource management and top-level planning. By analyzing and summarizing typical experiences from both macro-policy and micro-practice, the characteristics and mechanisms of the Virtuous Cycle are discussed. According to the analysis method of "Problem-Attribution-Goal-Task-Measures" (PAGTM), taking the "Five Water Governance" water management project in Zhejiang Province of China as a case study, the specific measures and technical framework of the Virtuous Cycle are explored. This study hopes to provide a reference for the top-level planning and path design of harmonious and sustainable natural-social water resources management.

Keywords: water resources management; virtuous cycle; natural-social water system; mechanisms and measures

Citation: Liu, Z.; Sang, X.; Zheng, Y.; Yan, D.; Zhang, W. Virtuous Cycle: An Idea of Water Resources Management and Top-Level Planning. *Water* **2022**, *14*, 1738. https://doi.org/10.3390/w14111738

Academic Editors: Elias Dimitriou and Athanasios Loukas

Received: 26 March 2022
Accepted: 26 May 2022
Published: 28 May 2022

1. Introduction

Water resource cycle and sustainable utilization are important foundations and components of ecological protection and economic and social systems [1]. However, with the development of society and the enhancement of human activities, the utilization of economic water is constantly crowding out the ecological and environmental water, causing environmental problems, such as ecosystem degradation, forest destruction, river discontinuities, and groundwater funnel [2–4]. On the other hand, the impact is two-way, since environmental problems will also threaten the sustainable development of human society, such as floods, droughts, soil loss, land subsidence, air and water pollution, and biodiversity loss [5–10]. How to coordinate the utilization of water resources and sustainable development, human use, and ecological protection have important scientific significance and practical needs.

Scholars and managers have conducted extensive research on basin-wide water resources management [11–13]. The United States has adopted a whole-basin management model, such as the Tennessee Valley Authority (TVA), and believes that management at the whole-basin scale management and interdisciplinary science in defining environmental flows are the key to the restoration of the entire regional water ecosystem [14]. It pays special attention to upper river basin governance, taking it as the premise and foundation for the protection and restoration of water ecology [15]. At the same time, new management techniques and methods are also proposed, including water rights analysis system, sewage resource utilization system, urban rainwater management system, and water resource decision-making system. For the sustainability of the ecosystem, the Canadian Standards Association (CSA) establishes the Sustainable Forest Management System (SFM) standards [16]. The core is the connection networks of the forest, water, and ecological environment with the socio-economic system [17]. At the same time, the CSA proposes a watershed management model that emphasizes the local decentralization of natural resources within the watershed, and highlights cooperation and the "who invests, who

benefits" approach. Japan adopts natural adaptive river management to restore rivers and wetlands. Due to the high population density, high level of urbanization, and complex terrain, ecological restoration has become a difficult task [18]. In response to changing water security needs, the International Association of Hydrological Sciences (LAHS) put forward the new Scientific Plan for the Decade 2013–2022, which takes the impact of human activities as a key research direction [19]. Studying the synergistic mechanism of human activities and the water resources cycle, and realizing the comprehensive management of water resources, water environment, and water ecology will become major research in the sustainable development of water resources.

The water resources regulations adopted by the above areas or river basins have the following characteristics:

- Take the watershed as the key unit and pay attention to the natural properties of the water when restoring;
- Emphasize the integrity of the water system and the coupling along with other systems;
- Emphasize the "Source-Process-Terminal" comprehensive management of the whole process;
- Minimize disturbance to the natural water cycle.

In China, human–water conflicts are more prominent and complex [20,21]. Three factors jointly constrain social and economic development, and cause water scarcity in China: the complex geographical environment leads to an uneven distribution of water resources; industrialization and urbanization lead to water environment problems; the inefficiency of water utilization leads to waste problems. Uneven spatial distribution, rapid economic development and urbanization, and poor water resource management are three main factors that contribute to China's water scarcity [22]. Since the 1980s, relevant scholars and experts have carried out a lot of research on the optimal allocation of water resources, human activities, and the water cycle [23,24]. Recently, the coordinated development of humans and water, the balance of ecosystems, and integrated water resources management have become research hot spots [25–28].

In this study, two typical watershed management explorations in China, from the perspectives of macro-policy and micro-practice, are introduced. Based on the practice, the concept of "Virtuous Cycle" is put forward, then the characteristics and mechanisms are discussed. Taking the "Five Water Governance" water management project in Zhejiang Province, China as an example, through the "Problem-Attribution-Goal-Task-Measures" (PAGTM) method, the management measures and corresponding results under the Virtuous Cycle are explained. This study hopes to provide a reference for the top-level planning and path design of harmonious and sustainable natural-social water resources management.

2. Practice Experience

This section mainly introduces two cases that inspired the concept of the Virtuous Cycle. The first is to introduce the policies and strategies of the Chinese government from the macro-policy level. The second is to explore the experience of water resources management from the micro-practice level.

2.1. Integrated Water Conservancy Intelligence

In response to the water resources and water environment problems faced by China, the state proposes a National Water Management Strategy called the "Sixteen Chinese-characters", in 2014.

> **"Sixteen Chinese-characters"**: Water-saving Priority, Spatial Equilibrium, System Governance, Two-handed Efforts.
>
> —National Water Manage Strategy of China

(The "Water-saving Priority, Spatial Equilibrium, System Governance, Two-handed Efforts" are translated from the "Sixteen Chinese-characters". "Water-saving Priority": Promote the concept of water-saving, carry out the construction

of water-saving facilities and technologies. Taking water conservation as the primary task of protecting ecology and water resources. "Spatial Equilibrium": The goal is to achieve balanced and sustainable development of social economy and environmental resources. Taking water resources, water ecology, and water environment carrying capacity as constraints of urbanization. "System Governance": Considering the ecosystem as an organic life, when governing the environmental issues, the coordination of water, mountain, forest, land, lake, and grass management should be considered. "Two-handed Efforts": The role of the market and government is integral to water security and water ecology. When addressing the strategy, it is necessary to distinguish what belongs to the government and what depends on market mechanism)

Under this macro-policy guidelines, local governments have issued corresponding strategies for ecologically sustainable development [29–31]. However, in actual operation, the management of economic and social water use belongs to different departments according to the process of water intake, consumption, and drainage; at the same time, different regions have different situations. As a result, there is no complete panorama blueprint for water resources information, hydrological data, and water allocation information; the transformation from decentralized governance to intelligent integrated water management system needs to be strengthened.

The Ministry of Water Resources (MWR) of China has launched a National Intelligence Water Conservancy Initiative (NIWCI) project and has carried out related top-level design and planning works, as well as pilot applications in some regions [32] (see Figure 1) (see http://mwr.gov.cn/ztpd/2020ztbd/zhslxxxszt/) (available online 27 May 2022).

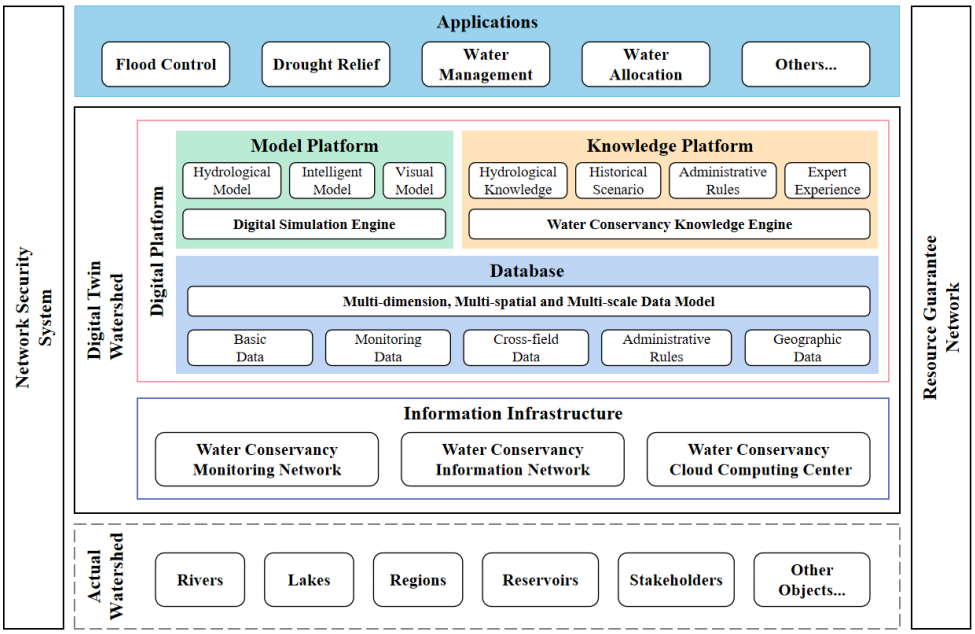

Figure 1. Framework of the National Intelligence Water Conservancy Initiative (NIWCI [32]).

NIWCI makes full use of new-generation information technologies, such as the Internet of Things, Big Data, Cloud Computing, Artificial Intelligence, and Digital Twins, to build a Digital Twin Watershed (DTW) to realize digital scenarios, smart simulations, and smart decision-making. MWR plans to (1) build the system with functions of forecasting, warning, exercise, and planning ("Four Functions"); (2) empower flood and drought disaster prevention, water conservation and utilization, optimal allocation of water resources, ecological protection, and governance; (3) provide strong support for the High-quality Development of Water Conservancy. The Chinese government hopes to use the above-

mentioned intelligent systems to build a unified water resources management network to achieve collaborative management between river basins and regions.

2.2. Constructing "Sponge-Smart River Basins" and Improving Water Carrying Capacity

In the context of the "Sixteen Chinese-characters", scholars have carried out extensive research at the micro-practice level [33–37]. Among them, Yan et al. [38] put forward the "Sponge-Smart River Basins" (SSRB) measures for watershed management and improve the water carrying capacity (see Figure 2).

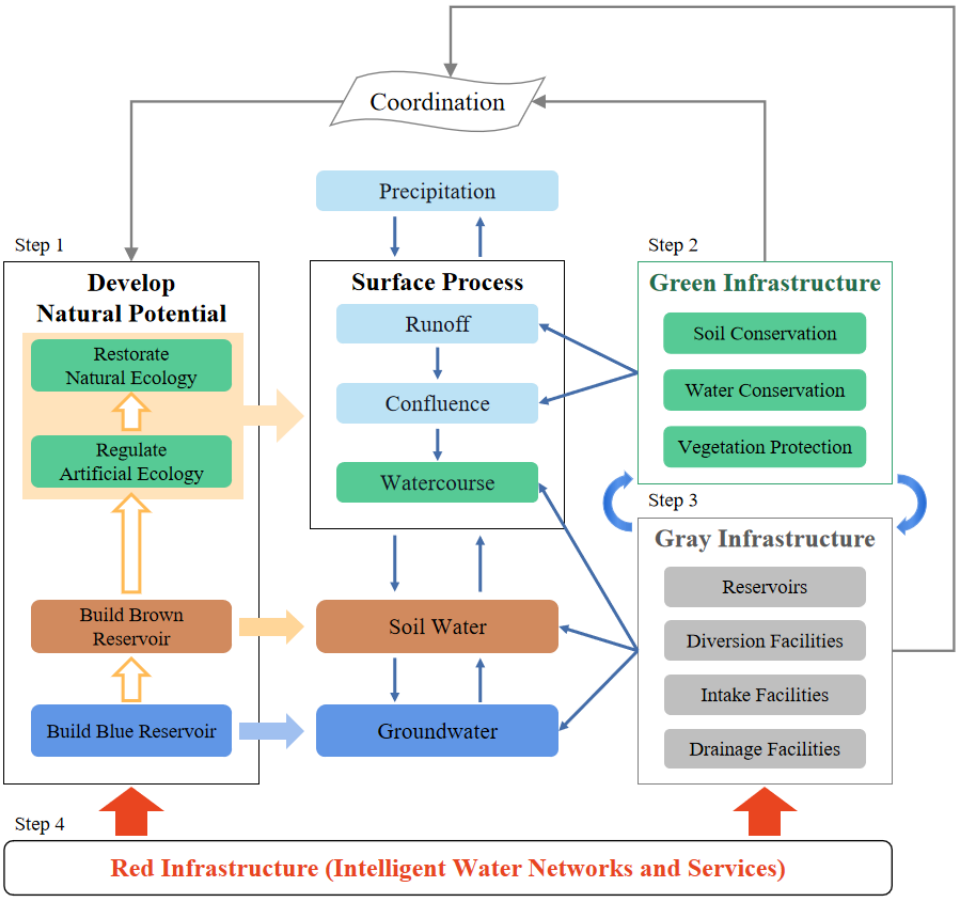

Figure 2. General idea of the Sponge-Smart River Basins (Yan et al. [38]).

The goal of SSRB is to build a healthy natural-social water cycle system in the whole watershed: maximizing the socio-economic and ecological benefits of water resources through social-based integrated management and preventing floods and droughts through the systematic arrangement of engineering and non-engineering measures. It mainly includes three tasks: capacity assessment, regulation system configuration, and regulation capacity building. The specific measures can be summarized as the development of "Four Infrastructures": the Gray Infrastructure (including reservoirs, floodwalls, canals, pumping stations, wells, etc.); the Green Infrastructure (including forest, grassland, wetlands, etc.); the Brown and Blue Reservoirs (representing soil water, groundwater, and other underground aquifers); the Red Infrastructure (intelligent water networks and services). The upper mountainous area is the source of the watershed, with good water quality, rapid elevation changes and fast flow. Therefore, water resource management should respect the natural water cycle and implement a sponge watershed governance model focusing on ecological restoration. Measures include establishing upstream national reserves, banning logging and hunting, and protecting ecological diversity. In the middle reaches of the river, human activities are intensive, and the irrigation systems are widely distributed. Measures

should be adapted to local conditions, implement refined management, strengthen agricultural water-saving construction, and control non-point source pollution. The downstream should pay more attention to the ecological environment, enhance the connectivity of lakes and reservoirs through the construction of water diversion projects, and improve the comprehensive control capacity of runoff. Through the development of "Sponge-Smart River Basins", the extreme hydrological events can be prevented, the comprehensive service capacity of the watershed can be constructed and improved, and the ecological function of the ecosystem can be protected.

3. Virtuous Cycle of Water Resources

3.1. The Concept of Virtuous Cycle

The above research shows that traditional supply and demand management and water conservation measures have been unable to adapt to the new situation, requirements, and challenges. Studying the synergistic mechanism of human activities and the water cycle, and realizing the comprehensive management of water resources, water environment, and water ecology will become major research in the sustainable development of water resources.

Inspired by previous research, we propose the concept of a "Virtuous Cycle" of water resources, which we hope to provide a reference for managers and researchers when conducting water resources management and top-level planning. Virtuous Cycle is a concept of water resources management, and aims to realize the harmonious coexistence of humans and water through integrating and coordinating all aspects of the natural-social water cycle system from the beginning to the end.

The Virtuous Cycle of water resources requires that human activities should be self-restrained to follow the natural laws and maintain the basic characteristics of water ecology and environment. Furthermore, at the same time, through reasonable regulation and utilization, social and economic development can be satisfied. A two-way promotion and restraint mechanism can be built between nature and society to improve the resilience of floods and droughts, and increase the quality of the environment and ecology. Ultimately, the harmony between man and water will be realized (see Figure 3).

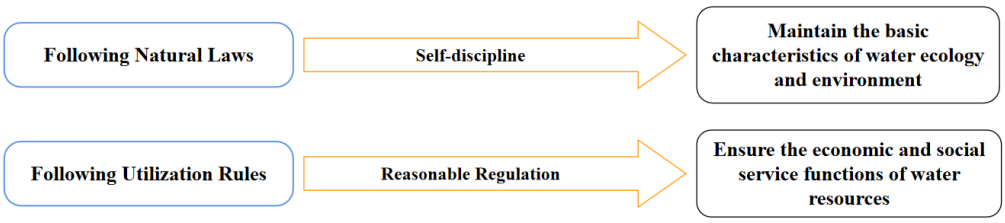

Figure 3. The regulation of the virtuous cycle.

3.2. The Characteristics of Virtuous Cycle

A Virtuous Cycle of water resources should have the following six basic characteristics: Nature and Equilibrium; Comprehensiveness and Hierarchy; Security and Controllability.

Nature and Equilibrium are the basic characteristics of the Virtuous Cycle of water resources. "Nature" is the primary feature of water, which is renewable and resourceful. Rivers and lakes are the basic carrier of the water cycle and the main channel of the Virtuous Cycle of water resources; "Equilibrium" embodies the connection between human-made and nature. Human beings serve themselves by connecting the water network and transforming the environment, but disruption and domestication of the water cycle should also be conditional and appropriate. Only by maintaining a balance between respecting nature and utilizing water resources can harmony between man and water be achieved.

Comprehensiveness and Hierarchy are the properties of the Virtuous Cycle of water resources. "Comprehensive" means that the water cycle is a complex and holistic system, and the river basin represents the whole path of the water cycle. Therefore, the regulation

of the water resources system should focus on the watershed as a whole. The development, management, and protection of water resources from the perspective of the whole basin is an effective way to realize the coordinated development of upstream and downstream, left and right banks. "Hierarchy" refers to the priority and security level of water suppliers and users on the social side. Users in the same sector hold the same priority and security level (such as all domestic water users), while different sectors (such as domestic, industrial, and agricultural users) vary. At the same time, the drainage of upstream users affects the use of downstream users, and there may also be mutual influences and supply chain relationships between water users at different levels. For example, domestic wastewater can be treated to supply industrial and ecological water. Different types and levels of water users constitute a complex water supply system.

Security and Controllability are important goals to ensure the Virtuous Cycle of water resources. "Security" mainly refers to the basic guarantee of human life and industrial production, which stands for the people-oriented purpose of the Virtuous Cycle. "Controllability" means that through infrastructure construction such as reservoirs, the economic and social system can have a certain ability to regulate and control the water cycle, so that the water resource can flow in the direction of achieving the established goals. Through artificial intervention, we can maximize the benefits of the water cycle while meeting ecological and environmental needs.

3.3. The Mechanisms of Virtuous Cycle

"Water Cycle: The water cycle stems from mountains, flows in rivers, connects lakes and reservoirs, supplies cities and villages, breeds farms and fields, and carries cultures and traditions". This sentence is not only a description of the water cycle process but also a generalization of the water resource utilization. The interference of human activities and economic development to the water cycle cannot be ignored. The water cycle in the basin has been transformed into a dual cycle that combines the natural cycle (mainly with precipitation, runoff, and confluence) and the social cycle (mainly based on intake, consumption, and drainage). The natural cycle of water resources obeys the laws of physics and eventually flows into lakes, reservoirs, or the sea, which is a process of convergence; the social cycle of water resources follows the trend of economic development and flows from sources to users, which is a process of consumption.

In actual river governance, even the most environmentally friendly decision makers will first meet flood control needs and water resource utilization, then consider the natural conditions of the river basin to protect the water environment and ecology, and lastly, if necessary, use artificial methods to restore ecological diversity. Therefore, the Virtuous Cycle of water resources management should be based on reality, while respecting the natural laws and utilization rules of the water cycle.

Here, we put forward the mechanism of the Virtuous Cycle include two aspects: "Flatten Flow" and "Balance Utilization" (see Figure 4).

1. **Flatten Flow:** From the perspective of the natural cycle, comprehensively regulate and manage surface water, groundwater, water diversion, rain flood, drainage, and so on. Measures include: proper construction of water conservancy facilities to flatten extreme water flows (floods and droughts) in the basin; water diversion projects to realize the interconnection of rivers and lakes; collection and utilization of rain and flood resources; separation of rainwater and sewage systems, etc. The goal is to flatten the extreme value of the water flow, match water supply and demand, and achieve a proper storage and drainage system and a developed water network.
2. **Balance Utilization:** From the perspective of the social cycle, improve water efficiency through delicacy management and technological progress to achieve sustainable development of water resources, with measures such as water consumption management, water-saving promotion, comprehensive water distribution, water right markets, and so on. Use market orientation and policy support to achieve water consumption equilibrium and benefit optimization in the basin.

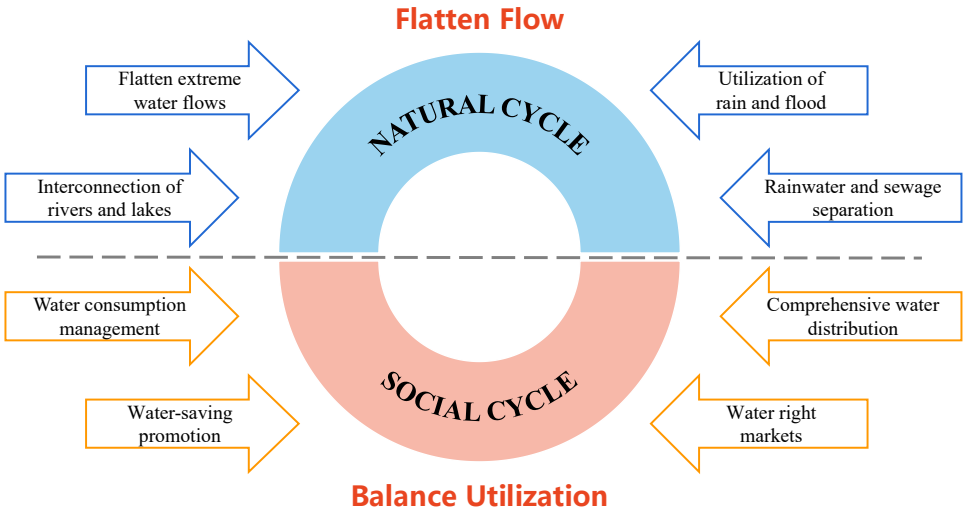

Figure 4. The mechanisms of the Virtuous Cycle.

3.4. The Relationship between the National Strategy and the Virtuous Cycle

The Virtuous Cycle is closely related to the China's "Sixteen Chinese-characters" national strategy, which is a response and complement. "Flatten Flow" embodies the national strategy of "Systematic Governance" and "Spatial Equilibrium", and is the basic carrier for realizing a Virtuous Cycle of natural, comprehensive, and secure water resources. "Balance Utilization" represents the national water management strategy of "Saving Priority", "Spatial Equilibrium", and "Two-Handed Efforts", and is the main driving direction to realize the Virtuous Cycle of balanced, hierarchical, and controllable water resources (see Figure 5).

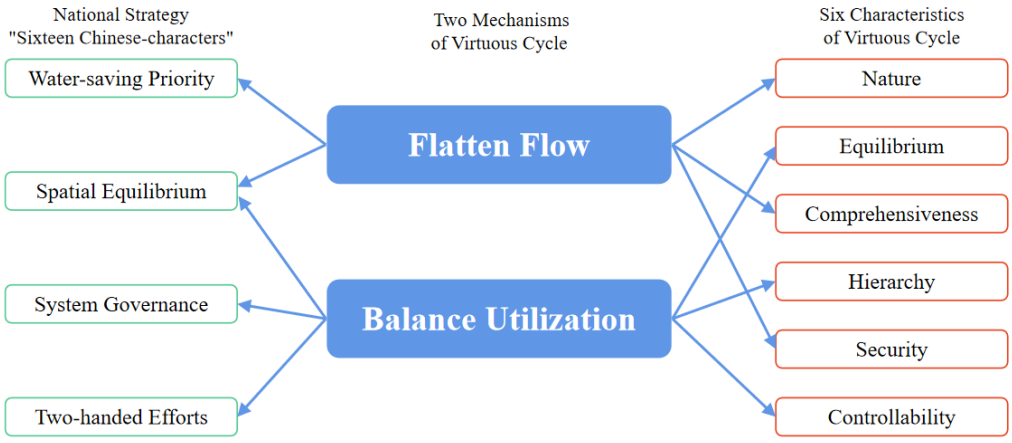

Figure 5. Relationship between the National Strategy and Virtuous Cycle.

4. Case Study

This section takes the exploration of the water resource management in Zhejiang Province, China as a case study, where five major water problems are faced. Under the Virtuous Cycle concept, the "Problem-Attribution-Goal-Task-Measures" (PAGTM) analysis method has been launched to find corresponding measures. By managing multiple aspects of the natural-societal water cycle, managers can simultaneously improve water resources, water environment, and water ecology.

4.1. Study Area and Background

Zhejiang Province covers an area of 105,500 km^2, of which 74.63% are mountains and hills, 20.32% are plains, and 5.05% are rivers and lakes. The average annual precipitation is 1600 mm, and the average annual total water resources are 95.5 billion m^3, including

94.4 billion m^3 of surface water resources and 22.1 billion m^3 of groundwater resources (see Figure 6).

Figure 6. Location of Zhejiang Province, China.

However, the distribution of water resources in Zhejiang Province is uneven, the precipitation fluctuates greatly (70% is concentrated in the flood season), and it is often affected by severe weather such as typhoons. At the same time, due to the dense population, the per-capita water resource is only 2110 m^3, and the developed industry further aggravates the contradiction between water supply and demand. The eastern coastal areas of Zhejiang Province, where the population is concentrated and the economy is developed, suffered the most serious water shortage.

4.2. Problem Analysis and Measures

The water problems faced by Zhejiang Province can be categorized into five aspects: water pollution, water scarcity, water waste, water floods, and water-logging. In response to the above problems, the government proposes a water management project of "Five Water Governance", namely: "Sewage Treatment, Flood Control, Water-logging Drainage, Supply Guarantee, and Water Conservation". From 2014 to 2020, a total of more than 200 billion Chinese Yuan (around 30.5 billion U.S. Dollars) has been invested in addressing the water problems.

According to the "Problem-Attribution-Goal-Task-Measure" (PAGTM) analysis method, this study gradually decomposes the problem, conducts attribution analysis, proposes goals according to the principle of Virtuous Cycle, and finally, analyzes the practical tasks and corresponding measures (see Table 1).

At the same time, to ensure the achievement of 5 tasks and 24 specific measures under PAGTM (Table 1), the "Five Water Governance" project coordinated the forces and resources of all parties, scientifically planned and with guaranteed investment, strengthened quality supervision, mobilized social participation, and vigorously promoted environmental protection. Both the natural side and the social side are considered to ensure the implementation of the project.

Table 1. PAGTM of the Virtuous Cycle in Zhejiang Province, China.

PROBLEM	ATTRIBUTION	GOAL "Virtuous Cycle"	TASK "Five Water Governance"	MEASURE
Water Floods	• Extreme Weather • Precipitation Fluctuates	**NATURAL SIDE Flatten Flow**	Flood Control	• Construct Sponge Watershed • Reservoir Construction • Increase Flood Discharge Channels • Reinforce Floodwall
Water Scarcity	• Water Source Degradation		Supply Guarantee	• Protect The Water Source Environment • Ecological River • Connectivity Of Rivers and Lakes • Ecological Water Supplement
Water-logging	• Water Network Obstruction		Water-logging Drainage	• Ecological River • Connectivity Of Rivers and Lakes
Water Scarcity	• Insufficient External Water Diversion • Insufficient Reservoir Regulation and Storage • Water Quality Degradation	**SOCIAL SIDE Balance Utilization**	Supply Guarantee	• External Water Transfer Project • Wastewater Recycling Facilities • Desalination
Water-logging	• Drainage System Drawback		Water-logging Drainage	• Dredge River Channels and Pipe Networks • Artificial Drainage Facilities
Water Waste	• Low Utilization Efficiency • Water Network Leakage • Backward Water-Saving Technology • Inadequate Wastewater Treatment		Water Conservation	• In-Depth Water-Saving Technology • Rainwater Collecting • Improve Water Efficiency • Reduce Pipe Network Leakage
Water Pollution	• Non-Point Source Pollution • Industrial Waste • Domestic Sewage		Sewage Treatment	• Sewage Network Coverage • Centralized Treatment Of Waste • Salvage Sediment Contaminants • Irrigation Intelligence • Limit High-Polluting Industries

4.3. The Effectiveness of Virtuous Cycle

From 2014 to 2020, the implementation of the "Five Water Governance" project has significantly improved the five major water problems in Zhejiang Province. The project has completed about 2000 km of river ecological comprehensive treatment; about 2000 km of new drainage pipe networks; and 1155 km of floodwalls. Moreover, 987 reservoirs have been reinforced, more than 30 water diversion projects and reservoirs have been constructed, and the list goes on. Through a series of efforts, Zhejiang Province has basically established a virtuous water cycle system on both the social and natural sides; the water efficiency has been significantly improved, and the polluted rivers have disappeared (see Figure 7).

Figure 7. The effectiveness of Virtuous Cycle.

The Virtuous Cycle concept could achieve the maximum economic and social benefits with the minimum ecological disturbance through the two-way coordination between the natural side and the social side. According to the analysis method of PAGTM, the corresponding measures were found to solve the water problem, and finally, a harmonious and sustainable development of humans and water in Zhejiang Province was realized.

In the future, Zhejiang Province will focus on the well-being of residents and further implement the Virtuous Cycle management on the results of the "Five Water Governance" project. At the same time, the digital revolution of water resources management will be carried out under the NIWCI project of MWR. Through the construction of a water conservancy monitoring system, a water conservancy data center, the application of artificial intelligence management, and other new technologies, a new pattern of digital water conservancy development in Zhejiang will be expected.

5. Conclusions

This study proposes a "Virtuous Cycle" concept of water resource management and top-level planning and discusses its characteristics and mechanisms. To better demonstrate the specific measures and technical frameworks, this article uses the "Problem-Attribution-Goal-Task-Measure"(PAGTM) method to analyze the "Five Water Governance" project in Zhejiang Province, China as a case study. By integrating and coordinating all aspects of the natural-society water cycle system, the ecological environment and water security problems of Zhejiang Province have been improved.

In this article, we first reviewed the typical international cases and experiences of the watershed water management and then introduced two typical Chinese watershed management experiences from the perspectives of macro-policy and micro-practice, which have important implications for the "Virtuous Cycle" idea. The "Sixteen Chinese-characters" national water management strategy in China is the macro-policy direction of the idea, and the micro-practice of "Sponge-Smart River Basins" supports the concept system. We put forward the definition of the concept, discussed the characteristics and mechanisms of the Virtuous Cycle, and pointed out their connection to the macro-policy. Finally, we used the "Five Water Governance" project to explain and describe the tasks, management measures, and corresponding results under the Virtuous Cycle through the PAGTM analysis method.

Virtuous Cycle aims to achieve the harmonious coexistence of humans and water by integrating and coordinating all aspects of the natural and social water cycle system. It takes "Flatten Flow" and "Balance Utilization" as the core to build a natural-artificial two-way promotion and constraint mechanism, which includes six main characteristics. It requires self-restraint in human activities and respects the laws of nature to ensure a friendly ecological environment; it meets social and economic development through rational regulation and utilization of water resources while improving the ability to resist floods and droughts. The "Five Water Governance" project, implemented in Zhejiang Province, set up five tasks to solve five water problems, which included 24 specific measures. Under the goal of a Virtuous Cycle, the ecological environment and flood control capacity of the study area has been significantly improved through two-way efforts from the social side and the natural side.

This study hopes to provide a reference for the top-level planning and path design of harmonious and sustainable natural-social water resources management.

Author Contributions: Conceptualization, methodology and design, Z.L. and X.S.; investigation and writing—original draft, Z.L. and Y.Z.; writing—review and editing, Y.Z.; guidance and supervision, X.S. and D.Y.; support and discussion, W.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This study was supported by the China Three Gorges Corporation Research Project (Contract No: 202103044), the National Key Research and Development Program of China (2021YFC3200202), and the Scientific Research Projects of IWHR (01882104, 01882106).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to express their gratitude for the support fundings, three unknown reviewers. The publication of this article is inseparable from their support and help.

Conflicts of Interest: The authors declare no conflict of interest.

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