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Developing Collaborative Management Strategies for Flood Control and Drainage across Administrative Regions Using Game Theory

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Abstract: There exist conflicts of interest between upstream and downstream regions in flood control and drainage; how to balance these conflicts and achieve collaborative flood management remains an important scientific problem. To explore a balanced governance strategy, this study took the Demonstration Zone of Green and Integrated Ecological Development of the Yangtze River Delta, which consists of three separate administrative regions, as the research domain. Using evolutionary game theory, the study conducts a comparative analysis of the interests between upstream and downstream areas. It introduces external drivers, such as the intervention of higher-level administrative bodies and incentive-constraining policies, along with internal balancing mechanisms like bidirectional compensation. The goal is to explore collaborative strategies and cooperation mechanisms that can balance the conflicts of interest between upstream and downstream areas. Results indicate that: (1) The final collaborative strategy was closely related to factors such as the cost of conflict, the amount of two-way compensation, additional benefits of flood control and drainage, and the intensity of incentive constraints. (2) Incorporating a reasonable two-way compensation and reward and punishment mechanism into the evolutionary game theory model can promote the model to a stable strategy. (3) The external driving mechanisms aim to coordinate the conflicts between upstream and downstream regions through incentive or constraint policies, which help motivate and encourage proactive collaboration in flood control and drainage management. The internal balancing mechanism is responsible for compensating for economic losses caused by imbalances, thereby creating pressure that fosters regional cooperation in flood control and drainage governance. In a word, the collaborated management mechanism helps provide a more balanced strategy across different administrative regions.

Keywords: the demonstration zone of green and integrated ecological development of the Yangtze River delta; flood control and drainage; evolutionary game; cross administrative region; collaboration mechanism

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Citation: Shang, S.; Wang, L.; Guo, W.; Zhang, L.; Wang, Y.; Su, X.; Li, L.; Chen, Y. Developing Collaborative Management Strategies for Flood Control and Drainage across Administrative Regions Using Game Theory. *Water* **2024**, *16*, 2510. https://doi.org/10.3390/w16172510

Academic Editor: Enrico Creaco

Received: 10 July 2024
Revised: 25 August 2024
Accepted: 3 September 2024
Published: 4 September 2024

1. Introduction

A large basin is a complex system with both integrity and correlation [1,2]. In the basin, cities and towns are usually distributed along the river from upstream to downstream; these cities or towns are referred to as administrative regions. The location of these administrative regions determines the order of access to water conservancy project resources; for example, cities in the upstream area usually have priority in storm drainage or pollution discharge, while the cities in the downstream area have to bear the flood pressure or pollution pressure from upstream areas [3,4]. To give a simple example, the carrying capacity of the regional water environment is fixed. Consequently, upstream discharges inevitably impact the downstream water environment, thereby affecting the downstream discharge capabilities [5]. This has led to the development of the concept of pollution discharge rights [6]. However, when the available resources within a watershed are limited and each region strives to maximize its interests, conflicts between administrative regions become inevitable. How to balance the interests and minimize the conflicts is essentially a game question, which remains a challenge for water-related management in a basin [7–9].

As a long-term and complex game process, water security management in the basin involves multiple administrative regions. Within a basin, resources such as water, water environment carrying capacity, and hydraulic engineering facilities are limited [10,11]. These resources fall into the category of common-pool resources, characterized by scarcity, non-excludability, and rivalry [12,13]. Under such resource constraints, administrative entities within the basin may engage in continuous competition for resources, which can easily trigger conflicts of interest and lead to the "Tragedy of the Commons". Scholars have studied this problem based on multi-objective optimization, game theory, and other methods [14,15]. Game theory is a modeling approach that focuses on decision-making subject behavior and decision equilibrium problems from a mathematical perspective; it can better simulate conflicts of interest among different stakeholders and eventually obtain feasible solutions. Therefore, it has been widely used in water pollution control, water resource management, and water rights allocation. Rogers [16] was the first to use non-cooperative game theory to study water resource allocation problems in different regions of the Ganges River Basin. Kucukmehmetoglu [17] proposed a cross-border water resource allocation method based on non-cooperative game theory and Pareto frontier theory to solve the cross-border water resource allocation problem in the Euphrates and Tigris River basins. This method primarily involves using a non-cooperative game theory approach with rational constraints to search for feasible solutions located on the Pareto frontier. The goal is to find the optimal allocation of water resources among different countries within a basin. Wang et al. [18] constructed a cooperative game model for watershed water resource allocation under the premise of reasonable initial water rights allocation for water users and the existence of a water rights trading market and proposed an effective algorithm for an equilibrium solution based on the principle of fairness. Shi et al. [19] applied the concept of cooperative game theory to address transboundary basin water pollution issues. They analyzed the distribution of benefits among the game participants from the perspective of game theory and discussed the stability of cooperative games. Their findings suggest that differences in the marginal cost of pollutant reduction across regions are crucial in determining whether regions can collaborate effectively to prevent transboundary watershed pollution. Lin [20] established an optimization model for cross-border water pollution with upstream and downstream relationships based on Stackelberg's dynamic game theory. This model considered the reduction and transfer of pollutants in various regions to minimize environmental costs and maximize governance benefits. Roy and Bhaumik [21] constructed a matrix game model in a fuzzy environment where the payoff functions of the participants were represented by triangular Type-II intuitionistic fuzzy numbers. They then proposed a ranking function method to effectively solve this model. Finally, using this model, they focused on exploring management mechanisms for fair and equitable access to limited water resources. Both domestic and foreign scholars have studied the issues of initial water rights allocation, water pricing, and water rights trading markets from various perspectives based on game theory. These studies have yielded significant findings. However, due to the limitations of analytical methods, many of these results—particularly those derived from non-cooperative game models—are based on models with highly restrictive assumptions, followed by analyses of the equilibrium outcomes of these game models.

The evolutionary game model is an application of the game model to the evolution of organisms, which combines game analysis with a dynamic evolutionary process [22]. It can reflect the evolution of group size and strategy without requiring participants to have complete information and rationality; such advantages make the evolutionary game model more convenient and effective than the traditional models. As participants in a game can continuously adjust their strategies through learning and imitation, evolutionary game theory focuses on the exploration of equilibrium stability. The concept of an evolutionarily stable strategy (ESS) has thus become foundational. An ESS yields higher payoffs than any other non-stable strategy and is considered the dominant strategy for individuals [23]. In recent years, scholars have applied evolutionary game theory to water resources and ecology. Lu et al. [24] constructed a three-party evolutionary game model of water demand in the upper, middle, and lower reaches of a river basin and systematically explored the game equilibrium state and evolution trend between different regions. Mirzaei-Nodoushan et al. [25] proposed an evolutionary game method to analyze the long-term water resource-sharing strategy of riparian countries in a transboundary river basin over time. Numerical examples were used to illustrate the strategy change process generated by the evolutionary game process, and the impact of factors such as water use, economy, political gains, and socio-economic losses on strategy choices among riparian countries was elaborated in detail. Biancardi et al. [26] explored the evolutionary stability strategy of compliance and non-compliance of enterprises in groundwater exploitation based on the evolutionary game model and emphasized the importance of the government's active crackdown on illegal groundwater exploitation. Guo et al. [27] took the Aral Sea Basin as the research object, studied the multi-objective evolutionary game process and evolutionary stability strategy of water, energy, and food in the upstream and downstream countries, and analyzed the evolutionary stability strategy under the intervention of the basin committee. Shen et al. [28] took the local government and polluting enterprises in the Taihu Basin as the research object, established an evolutionary game model between local governments and polluting enterprises, and simulated the decision-making behavior and influencing factors of basin ecological compensation. Yuan et al. [29] established a dynamic differential game model of cross-basin pollution control composed of upstream and downstream governments and polluting enterprises and analyzed the changes in strategic choices of different stakeholders under cost sharing and non-cost sharing. The results showed that multiple stakeholders had interactive effects on the choice of governance strategies, and the proportion of cost-sharing and incentives affected the changes in the cooperation utility of upstream governments, downstream governments, and polluting enterprises. Satar Mahdevari et al. [30] took the Shahid gravel mine near the Kodan River in Alborz Province, Iran, as the research object and introduced regulatory factors such as government incentives and penalties into the evolutionary game model between the mining party and the government. Finally, a green mining principle implementation model for river sand and gravel resources was proposed.

Existing research has utilized stakeholder analysis and evolutionary game theory models to reveal the conflicts and negotiation processes between upstream and downstream entities in the use of public resources. These studies have contributed valuable insights into the development of negotiation mechanisms and improved oversight systems. However, there are notable limitations. First, stakeholder analysis is often insufficiently systematic. The upstream–downstream game involves various aspects, including economic, social, ecological factors, and higher-level administrative management. Current research typically presents these issues in terms of overall utility, lacking attention to regional collaborative mechanisms that influence environmental governance strategies. This approach somewhat detaches from the reality of regional integration and collaboration. Second, evolutionary game models are frequently constructed simplistically and statically, assuming fixed and conflicting interests between upstream and downstream entities. This approach overlooks the deeper connections between administrative regions within a basin. Third, current research mainly focuses on collaborative water environment management, water resource allocation, and water rights integration, with an emphasis on defining stakeholders and constructing governance models. Despite the significance of flood control and drainage issues in a basin, there has been limited in-depth research on the integrated collaborative governance of flood control and drainage involving multiple stakeholders.

Therefore, this study selected the Demonstration Zone of Green and Integrated Ecological Development of the Yangtze River Delta (DZGIED) as the research domain. The DZGIED is composed of three separate administrative regions with complicated flooding conflicts. By analyzing the conflicts of interest among the administrative regions of the DZGIED from economic, social, and management perspectives and considering the dynamic and in-depth connections between upstream and downstream entities, this study develops a watershed strategy evolutionary game model to explore collaborative governance between upstream and downstream areas. This study aims to provide a theoretical basis and decision-making support for achieving balanced governance of flood control and drainage.

2. Study Domain and Conflicts of Interest

2.1. Study Domain

DZGIED is located in the plain river network area of the Yangtze River Delta, in the lower reaches of the Taihu Basin and the upper reaches of the Huangpu River (Figure 1). DZGIED encompasses the Qingpu District of Shanghai City, Wujiang District of Suzhou City, and Jiashan County of Jiaxing City, covering an area of 2413 km^2. The overall terrain of DZGIED is low, with ground elevation generally ranging from 2.5 to 4.0 m. DZGIED has numerous rivers and lakes, a rich water system, and strong hydraulic connections. The Wusong River in the northern part of the region and the Taipu River that runs through DZGIED are important flood discharge channels for Taihu. As a testing ground for China's institutional innovation and a region for sharing public services and infrastructure, DZGIED mainly focuses on planning management, ecological protection, land management, etc., explores effective integrated institutional arrangements, and strives to build a water ecological environment protection and restoration system of joint protection and governance and a comprehensive water management system for joint consultation and management.

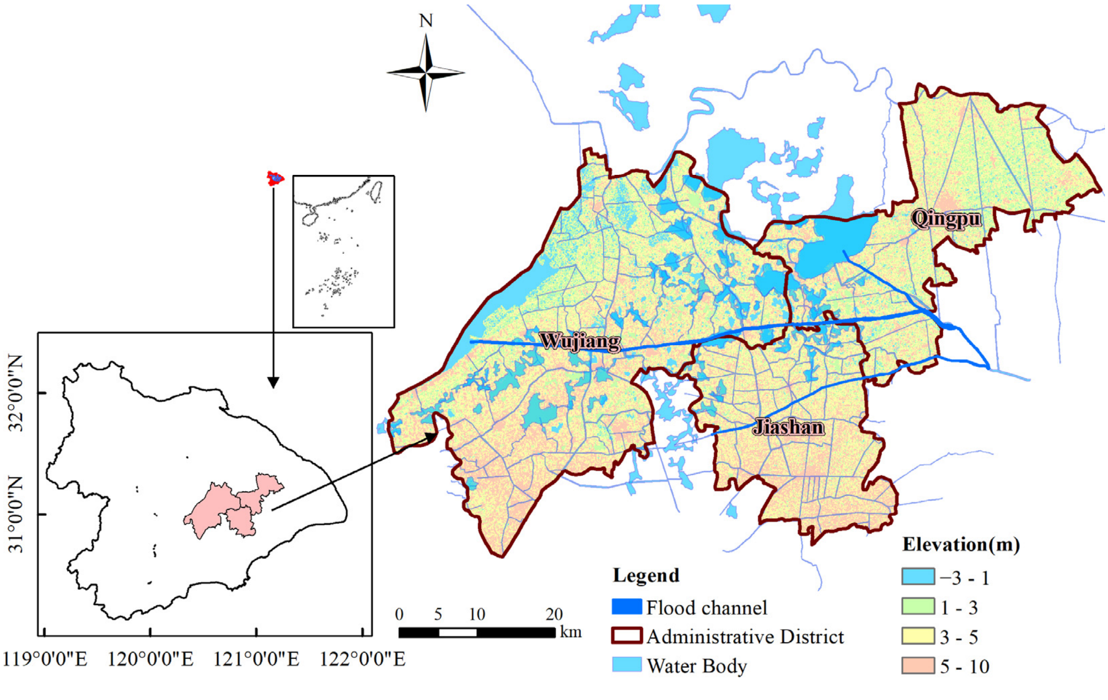

Figure 1. Geographical location, main flood channels, and administrative regions involved in DZGIED.

DZGIED is a plain tidal river network area. The rivers in the area are affected by downstream tides, upstream water, and surface runoff, making DZGIED one of the areas with the greatest flood pressure in the Taihu Basin. The floods in Taihu, as well as waterlogging in the Hangjiahu area and the Dianmao area, must be discharged into the

Huangpu River via the Taihu River, Hongqitang, and Lanlugang. Under the current conditions, the flood control standard in DZGIED is set for a 50-year return period. When cities enhance their drainage standards, this leads to an increase in water levels in the regional backbone rivers, thereby raising flood risks. Significant differences exist between upstream Wujiang District and downstream Jiashan County and Qingpu District in terms of socio-economic development and flood control and drainage standards. Specifically, Wujiang has a drainage standard set for a 20-year return period, Qingpu for 15 years, and Jiashan for approximately 10 years [31]. The overall drainage capacity in the downstream cities is inadequate, resulting in severe waterlogging [32]. As the drainage capacity in the downstream areas increases, it will inevitably heighten flood control pressure across the region, thereby reducing the drainage capacity available to Wujiang [33]. There are urgent conflicts and demands between the upstream and downstream areas due to flood control and drainage, as well as the utilization of water conservancy engineering resources, to alleviate urban flood pressure.

2.2. Conflicts of Interest for Flood Control and Drainage

Most of the flood control and drainage systems in the basin are built with state funding. Therefore, water conservancy projects, such as rivers and reservoirs, are owned by the state. From the perspective of the integrity of water conservancy project resources, water conservancy project resources are the common property of all regional entities in the basin and belong to the category of public pool resources. They are characterized by scarcity, non-exclusivity, and competitiveness [34]. Regional entities (provinces, cities, counties, etc.) upstream and downstream and on the left and right banks of the river can discharge water into the river. Currently, China has a territorial management system, which is manifested in the division of local administration. Local governments at all levels are responsible for local flood management matters [35]. In the basin, various areas are distributed along the river and have a certain geographical order, that is, upstream and downstream areas. The upstream, middle, and downstream areas and tributaries have similar geographical environments and hydraulic characteristics. Different geographical locations mean that the order of water discharge in each area is different. Due to its geographical advantage, the upstream area can discharge its water into the river before the downstream area. Once heavy rainfall is concentrated and the drainage demand of each area is large, each area upstream and downstream, on the left and right banks, and the main and tributary rivers will drain as much water as possible into the main river channels of the basin to reduce its flood pressure out of consideration for its interests. This may lead to the plundering and uncontrolled use of water conservancy project facilities such as rivers, resulting in a competitive drainage situation, causing “Overconsumption” and “Crowding effect”. This will generate negative externalities, which have a negative impact on drainage in other areas. At the same time, due to the large differences in the design methods of flood control and drainage standards between cities, there are also large differences in flood control and drainage capabilities between cities, which further increases the contradiction of drainage between cities.

Conflicts between upstream and downstream areas. The conflicts of interest between upstream Wujiang and downstream Qingpu and Jiashan of DZGIED can be divided into two situations. Firstly, when the flood control and drainage capabilities of Wujiang, Qingpu, and Jiashan are not coordinated, that is, the flood control and drainage capabilities of the more socio-economically developed areas are higher, while those of the less developed areas are lower. At this point, the interests of the developed areas in terms of flood control and drainage are ensured, while the interests of the underdeveloped areas are undermined, which leads to dissatisfaction among the local governments of the underdeveloped areas whose interests have been compromised, thereby generating hostility towards the developed local governments that have benefited. It will result in conflicts of interest between the developed and underdeveloped governments. Secondly, when the flood control and drainage capabilities of the cities in DZGIED are uniformly planned, that is, when the flood control and drainage capacity of the upstream Wujiang and the downstream Qingpu and Jiashan are coordinated, the three cities will drain as much water as possible into the river to reduce their losses from flood disasters based on their interests. At this point, the upstream areas rely on their geographical advantages; they will discharge regional flood water into the river at will. However, the downstream governments cannot discharge regional flood water into the river due to their geographical disadvantages, thus suffering from flood disasters and greater economic losses. Therefore, conflicts will arise between the upstream and downstream areas.

Interest demands between upstream and downstream areas. As a subsystem of the overall basin system, the upstream and downstream areas of the basin are responsible for local economic development, social stability, and flood control and drainage safety. Governments should not only execute the administrative instructions of the competent authorities of DZGIED but also take into account the social and economic development and flood control and drainage requirements of their respective areas. During the flood season, the interests of the upstream and downstream areas mainly include the following two points. Firstly, for their interests, the upstream and downstream areas will employ every possible means to drain water to alleviate their own flood control and drainage pressure and ensure that regional development is not or is less affected by flood disasters. Simultaneously, governments should implement the unified flood control and drainage standards formulated by the basin's competent authorities to avoid conflicts between regions and penalties from the authorities. Secondly, under the premise of formulating a fair and reasonable drainage rights allocation plan, the upstream and downstream areas should have global strategic thinking, take the overall interests as the starting point, and regulate their drainage behavior. Actively implement the relevant flood control and drainage plans formulated in a coordinated manner and drain water following reasonable drainage capacity under the supervision of the competent authorities of DZGIED. To reduce drainage conflicts between upstream and downstream areas, ensure the balance of basin interests, and promote overall harmonious development.

3. Game Analysis

3.1. Game Model Scenario Assumptions

Flood control and drainage design in cross-regional urban areas involves multiple administrative entities and multi-level departments. To fully account for the interests and relationships among these various entities, this study can draw on the application of evolutionary game theory in areas such as transboundary water pollution, collaborative governance, and multi-administrative water resource allocation [25,27,36]. By introducing a bidirectional compensation mechanism and an administrative reward and penalty mechanism, the basic assumptions for this study are established.

Rule 1: In the basin, cities are ranked according to their geographical locations and can be divided into upstream areas and downstream areas. In this study, Wujiang is located in the upstream area of DZGIED, while Jiashan and Qingpu are located in the downstream area of DZGIED, which is easily affected by the drainage of Wujiang. Therefore, in the game process, Jiashan and Qingpu formed a unified alliance to jointly deal with Wujiang's drainage strategy.

Rule 2: This evolutionary game model includes two types of trading groups, the upstream area Wujiang and the downstream area Jiashan-Qingpu Alliance (JQA). Since the two groups are limited by information and knowledge, they are both limited rational groups. Both groups pursue their interests. Firstly, the drainage plan set by the DZGIED management agency is reasonable. The strategy set by the upstream government is to limit the drainage capacity by bearing the regional flood pressure and to improve the drainage capacity based on the maximization of its interests (Reducing drainage capacity, Increasing drainage capacity). The probability that Wujiang takes the initiative to bear the regional flood pressure and limit the drainage capacity is p $(0 < p < 1)$, and the probability of improving the drainage capacity according to the maximization of its interests is $1 - p$.

As an area that undertakes the flooding in the upstream area, JQA has a strategy set of not requiring Wujiang to limit the drainage capacity and requiring Wujiang to limit the drainage capacity, that is, (Non-conflict, Conflict). The probability that JQA does not require the upstream area to limit the drainage capacity is q $(0 < q < 1)$, and the probability of requiring the drainage capacity of Wujiang to be limited is $1 - q$.

Rule 3: The water capacity of the river is fixed, and the drainage capacity of each region is fair and reasonable. The different levels of socio-economic, environmental, and ecological development in different areas result in different marginal benefits per unit of drainage. Therefore, the marginal benefit per unit of drainage in Wujiang is x, and that in JQA is y.

Rule 4: When Wujiang chooses to reduce its drainage capacity while ensuring its safety, JQA chooses the "Conflict" strategy. To reduce the flood pressure within the region and improve the drainage capacity within JQA, JQA causes a conflict with Wujiang, resulting in a conflict cost. The conflict cost of JQA is F_1. Wujiang reduces its drainage capacity, resulting in a reduction in JQA flood control pressure, so the benefit JQA obtains is M. Assuming that Wujiang accepts the conflict, JQA can increase the drainage power of Q units, and the benefit obtained by JQA is $M + yQ$. Since JQA caused a conflict with Wujiang, it is necessary to compensate Wujiang, and the compensation amount is B. Wujiang suffered a certain loss Qx due to the conflict caused by JQA.

Rule 5: When Wujiang chooses to reduce its drainage capacity while ensuring its safety and JQA chooses the 'Non-conflict' strategy, JQA gains M, and Wujiang gains 0.

Rule 6: When Wujiang chooses to continue to improve its drainage capacity, and JQA chooses the "Non-conflict" strategy, Wujiang can obtain Q more drainage units, and the income obtained is Qx. Due to the increased flood control pressure of Wujiang, JQA has to limit its drainage capacity, and the loss it suffers is Qy. At the same time, Wujiang needs to pay a certain amount of compensation to JQA, which is C.

Rule 7: When Wujiang chooses to continue to improve its drainage capacity, and JQA chooses the "Conflict" strategy, both sides have a 50% chance of winning the conflict caused by Wujiang's increase in drainage capacity and increasing their respective drainage capacities. Therefore, the potential benefit of Wujiang is $\frac{1}{2}Qx$, and the cost of causing conflict with JQA is F_2. The potential benefit of JQA is $\frac{1}{2}Qy$, and the cost of causing conflict with Wujiang is F_1.

Rule 8: Based on the intervention of the DZGIED management agency, a corresponding reward and punishment mechanism is proposed. That is, if any city in DZGIED adopts a cooperative strategy (i.e., the corresponding "Reducing drainage capacity" and "Non-conflict"), the DZGIED management agency will reward it; otherwise, it will be punished, and the amounts of reward and punishment are G and T, respectively.

The specific parameter meanings are shown in Table 1.

Table 1. Description of relevant parameters of the game model.

Parameter	Illustrate
q	The probability that JQA does not require Wujiang to limit its drainage capacity is q $(0 < q < 1)$.
p	The probability that Wujiang will take the initiative to bear the regional flood pressure and limit its drainage capacity is p $(0 < p < 1)$.
F_1	Conflict costs incurred by JQA due to conflicts.
F_2	The conflict costs incurred by the conflict caused by increasing drainage capacity in Wujiang.
M	The flood control benefit obtained by JQA due to Wujiang's reduced drainage capacity is M.
x	Marginal benefits of unit drainage capacity change in Wujiang.
y	Marginal benefits of unit drainage capacity change in JQA.
Q	The drainage power of Wujiang to increase drainage capacity, and the drainage power obtained by JQA causing conflict.

Table 1. *Cont.*

Parameter	Illustrate
B	Compensation to Wujiang when conflicts arise between JQA.
C	Wujiang increases drainage capacity to compensate for JQA.
G	Rewards from management agencies when cities in DZGIED adopt cooperative strategies (i.e., "Reducing drainage capacity" and "Non-conflict").
T	Penalties from management agencies for non-cooperative strategies (i.e., "Increasing drainage capacity" and "Conflict").

According to the above rule design and parameter setting, different profit matrices of Wujiang and JQA under different behavior strategy selections can be obtained, as shown in Table 2.

Table 2. Game profit matrix of flood control and drainage between Wujiang and JQA in DZGIED.

	Wujiang Reduces Its Drainage Capacity (p)	**Wujiang Increases Drainage Capacity ($1-p$)**
JQA conflict ($1-q$)	JQA: $Qy+M-F_1-B-T$ Wujiang: $G+B-Qx$	JQA: $\frac{1}{2}Qy-F_1-T$ Wujiang: $\frac{1}{2}Qx-F_2-T$
JQA does not conflict (q)	JQA: $M+G$ Wujiang: G	JQA: $G+C-yQ$ Wujiang: $Qx-C-T$

3.2. Analysis of the Game Stability Strategy

The boundedly rational players will not make the best strategy choice at the beginning of the game, but in the continuous random game, the players will keep on learning the behavior strategies of the higher-yield players and constantly adjust their strategy choices to maximize their benefits. Therefore, the continuous learning and adjustment process is the process of the evolutionary game, and the final strategy choice is the equilibrium strategy of the evolutionary system.

3.2.1. Strategy Stability in JQA

The expected benefits of JQA when choosing the "Non-conflict" and "Conflict" strategies are U_{D1} and U_{D2}, respectively, and the overall average expected benefit is U_D, then:

$$U_{D1}=p(M+G)+(1-p)(G+C-Qy) \tag{1}$$

$$U_{D2}=p(Qy+M-F_1-B-T)+(1-p)(\frac{1}{2}Qy-F_1-T) \tag{2}$$

$$U_D=qU_{D1}+(1-q)U_{D2} \tag{3}$$

The replication dynamic equation of JQA is:

$$\begin{aligned} X(q)=\frac{dq}{dt} &= q(U_{D1}-U_D)=q(1-q)(U_{D1}-U_{D2}) \\ &= q(1-q)(p(\frac{1}{2}Qy+B-C)+G+C+F_1+T-\frac{3}{2}Qy) \end{aligned} \tag{4}$$

The first-order derivative of $X(q)$ can be obtained as:

$$X'(q)=(1-2q)(p(\frac{1}{2}Qy+B-C)+G+C+F_1+T-\frac{3}{2}Qy) \tag{5}$$

Let $X(q)=0$, according to the replication dynamic equation, it can obtain $q^*=0$ and $q^*=1$ are two possible stable state points.

Firstly, when $p = p_0 = \dfrac{\frac{3}{2}Qy - C - F_1 - G - T}{\frac{1}{2}Qy + B - C}$, there exists $0 < \dfrac{\frac{3}{2}Qy - C - F_1 - G - T}{\frac{1}{2}Qy + B - C} < 1$, at this time, for any $q \in [0, 1]$, there is always $X(q) = 0$. That is, any level of q in the range of $[0, 1]$ is a stable state. In this case, when Wujiang chooses the "Reducing drainage capacity" strategy with a probability of $p = p_0 = \dfrac{\frac{3}{2}Qy - C - F_1 - G - T}{\frac{1}{2}Qy + B - C}$, there is no difference in the benefits of JQA choosing the "Conflict" and "Non-conflict" strategies. At this time, all strategy choices are stable states for JQA.

When $p \neq p_0$, $q^* = 0$ and $q^* = 1$ are two possible system equilibrium points. According to the local stability analysis principle of differential equations, when $X(q) = 0$, $X'(q) < 0$, q is the local stable point of the system. There exists:

$$\begin{cases} X'(0) = (\frac{1}{2}p(Qy + B - C) + G + C + F_1 + T - \frac{3}{2}Qy) \\ X'(1) = -(\frac{1}{2}p(Qy + B - C) + G + C + F_1 + T - \frac{3}{2}Qy) \end{cases} \tag{6}$$

Secondly, when $p > p_0 = \dfrac{\frac{3}{2}Qy - C - F_1 - G - T}{\frac{1}{2}Qy + B - C}$, there exists $X'(0) > 0$, $X'(1) < 0$, so $q^* = 1$ is a system evolutionary stable strategy. When Wujiang chooses the strategy of "Reducing drainage capacity" at a level higher than $\dfrac{\frac{3}{2}Qy - C - F_1 - G - T}{\frac{1}{2}Qy + B - C}$, JQA gradually changes from the "Conflict" strategy to the "Non-conflict" strategy. The strategy of not having a drainage conflict with Wujiang is the evolutionarily stable strategy of JQA.

Thirdly, when $p < p_0 = \dfrac{\frac{3}{2}Qy - C - F_1 - G - T}{\frac{1}{2}Qy + B - C}$, there exists $X'(0) < 0$, $X'(1) > 0$, so $q^* = 0$ is the evolutionarily stable strategy of the system. When Wujiang chooses the strategy of "Reducing drainage capacity" at a level lower than $\dfrac{\frac{3}{2}Qy - C - F_1 - G - T}{\frac{1}{2}Qy + B - C}$, JQA gradually changes from the "Non-conflict" strategy to the "Conflict" strategy. The strategy that eventually conflicts with Wujiang in drainage is the evolutionarily stable strategy of JQA.

3.2.2. Strategy Stability in Wujiang

The expected returns of Wujiang when choosing the strategies of "Reducing drainage capacity" and "Increasing drainage capacity" are U_{U1} and U_{U2}, respectively, and the overall average expected return is U_U, then:

$$U_{U1} = q(G) + (1 - q)(G + B - Qx) \tag{7}$$

$$U_{U2} = q(Qx - C - T) + (1 - q)(\frac{1}{2}Qx - F_2 - T) \tag{8}$$

$$U_U = pU_{U1} + (1 - p)U_{U2} \tag{9}$$

The replication dynamic equation of Wujiang is:

$$\begin{aligned} Y(p) = \frac{dp}{dt} &= p(U_{U1} - U_U) = p(1-p)(U_{U1} - U_{U2}) \\ &= p(1-p)[q(\frac{1}{2}Qx + C - B - F_2) + G + B + F_2 + T - \frac{3}{2}Qx] \end{aligned} \tag{10}$$

The first-order derivative of $Y(p)$ can be obtained as:

$$Y'(p) = (1-2p)[q(\frac{1}{2}Qx + C - B - F_2) + G + B + F_2 + T - \frac{3}{2}Qx] \tag{11}$$

Let $Y(p) = 0$, according to the replication dynamic equation, we can obtain $p^* = 0$ and $p^* = 1$ are two possible stable state points.

Firstly, when $q = q_0 = \frac{\frac{3}{2}Qx - B - F_2 - G - T}{\frac{1}{2}Qx + C - B - F_2}$, there exists $0 < \frac{\frac{3}{2}Qx - B - F_2 - G - T}{\frac{1}{2}Qx + C - B - F_2} < 1$, at this time, for any $p \in [0,1]$, there is always $Y(p) = 0$, that is, any level of p in the range of [0, 1] is a stable state. In this case, when JQA chooses the "Non-conflict" strategy with a probability of $q = q_0 = \frac{\frac{3}{2}Qx - B - F_2 - G - T}{\frac{1}{2}Qx + C - B - F_2}$, there is no difference in the benefits of Wujiang choosing the two strategies of "Reducing drainage capacity" and "Increasing drainage capacity". At this time, all strategy choices are stable for Wujiang.

When $q \neq q_0$, $p^* = 0$ and $p^* = 1$ are two possible system equilibrium points. According to the local stability analysis principle of differential equations, when $Y(p) = 0$, $Y'(P) < 0$, p is the local stable point of the system. There exists:

$$\begin{cases} Y'(0) = [q(\frac{1}{2}Qx + C - B - F_2) + G + B + F_2 + T - \frac{3}{2}Qx] \\ Y'(1) = -[q(\frac{1}{2}Qx + C - B - F_2) + G + B + F_2 + T - \frac{3}{2}Qx] \end{cases} \tag{12}$$

Secondly, when $q < q_0 = \frac{\frac{3}{2}Qx - B - F_2 - G - T}{\frac{1}{2}Qx + C - B - F_2}$, there exists $Y'(0) > 0$, $Y'(1) < 0$, so $p^* = 1$ is a stable strategy for the system evolution. When JQA chooses the "Non-conflict" strategy at a level higher than $\frac{\frac{3}{2}Qx - B - F_2 - G - T}{\frac{1}{2}Qx + C - B - F_2}$, Wujiang gradually shifts from the "Increase drainage capacity" strategy to the "Reducing drainage capacity" strategy. Finally, the "Reducing drainage capacity" strategy is the evolutionarily stable strategy of Wujiang.

Thirdly, when $q > q_0 = \frac{\frac{3}{2}Qx - B - F_2 - G - T}{\frac{1}{2}Qx + C - B - F_2}$, there exists $Y'(0) < 0$, $Y'(1) > 0$, so $p^* = 0$ is the evolutionarily stable strategy of the system. When JQA chooses the "Non-conflict" strategy at a level lower than $\frac{\frac{3}{2}Qx - B - F_2 - G - T}{\frac{1}{2}Qx + C - B - F_2}$, Wujiang gradually shifts from the "Reducing drainage capacity" strategy to the "Increasing drainage capacity" strategy. Finally, the "Increasing drainage capacity" strategy is the evolutionarily stable strategy of Wujiang.

3.2.3. Strategy Stability in Wujiang and JQA

In the dynamic evolutionary game between Wujiang and JQA, $\left(\dfrac{\frac{3}{2}Qx - B - F_2 - G - T}{\frac{1}{2}Qx + C - B - F_2}, \dfrac{\frac{3}{2}Qy - B - F_1 - G - T}{\frac{1}{2}Qy + B - C}\right)$ is a threshold for the change of structural evolution characteristics. When the strategies of both parties in the game are close to this threshold, any slight change in the strategy of either party will cause the strategy of the other party to change.

Formula (1) and Formula (7) constitute a dynamic replication system of the evolutionary game between the JQA and Wujiang. The local equilibrium point stability of this system has five possible evolutionary stable equilibrium points: (0,0), (0,1), (1,0), (1,1), and (q_0, p_0). The Jacobian matrix of this system is:

$$J = \begin{pmatrix} \dfrac{\partial X(q)}{\partial q} & \dfrac{\partial X(q)}{\partial p} \\ \dfrac{\partial Y(p)}{\partial q} & \dfrac{\partial Y(p)}{\partial p} \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix}$$
$$= \begin{pmatrix} (1-2q)(p(\frac{1}{2}Qy + B - C) + G + C + F_1 + T - \frac{3}{2}Qy) & q(1-q)(\frac{1}{2}Qy + B - C) \\ p(1-p)(\frac{1}{2}Qx + C - B - F_2) & (1-2p)[q(\frac{1}{2}Qx + C - B - F_2) + G + B + F_2 + T - \frac{3}{2}Qx] \end{pmatrix} \tag{13}$$

The determinant and trace of the matrix are:

$$\begin{cases} \det.J = a_{11}a_{22} - a_{12}a_{21} = \dfrac{\partial X(q)}{\partial q}\dfrac{\partial Y(p)}{\partial p} - \dfrac{\partial X(q)}{\partial p}\dfrac{\partial Y(p)}{\partial q} \\ \text{tr}.J = a_{11} + a_{22} = \dfrac{\partial X(q)}{\partial q} + \dfrac{\partial Y(p)}{\partial p} \end{cases} \tag{14}$$

Since the five possible local equilibrium points of the replicated dynamic equation are not necessarily the stable equilibrium points of the system, the local stability of the Jacobian matrix should be analyzed to determine whether the possible local equilibrium point is the stable equilibrium point of the system. When there is a game strategy combination that satisfies: $\det.J > 0$ and $\text{tr}.J < 0$, the game strategy combination is a stable strategy for the evolutionary game. Table 3 shows the values of $\det.J > 0$ and $\text{tr}.J < 0$ at possible equilibrium points in the game between the Wujiang and JQA. It can be seen from Table 3 that at point (q_0, p_0), $\text{tr}.J = 0$. So (q_0, p_0) did not meet the stable strategy conditions, so the possible local equilibrium point (q_0, p_0) is not the system's evolutionary stable strategy.

Table 3. The values of $\det.J$ and $\text{tr}.J$ in the game between Wujiang and JQA at possible equilibrium points.

Balance Point	det.*J*	tr.*J*
O (0,0)	$(G + C + F_1 + T - \frac{3}{2}Qy)(G + B + F_2 + T - \frac{3}{2}Qx)$	$(G + C + F_1 + T - \frac{3}{2}Qy) + (G + B + F_2 + T - \frac{3}{2}Qx)$
A (1,0)	$\left[-(G + C + F_1 + T - \frac{3}{2}Qy)\right](G + C + T - Qx)$	$\left[-(G + C + F_1 + T - \frac{3}{2}Qy)\right] + (G + C + T - Qx)$
B (1,1)	$[-(G + B + F_1 + T - Qy)] \cdot$ $[-(G + C + T - Qx)]$	$[-(G + B + F_1 + T - Qy)] +$ $[-(G + C + T - Qx)]$
C (0,1)	$(G + B + F_1 + T - Qy) \cdot$ $\left[-(G + B + F_2 + T - \frac{3}{2}Qx)\right]$	$(G + B + F_1 + T - Qy) +$ $\left[-(G + B + F_2 + T - \frac{3}{2}Qx)\right]$
$D(q_0, p_0)$	$(1 - 2q_0)(p_0(\frac{1}{2}Qy + B - C) + G + C + F_1 + T - \frac{3}{2}Qy) \cdot$ $(1 - 2p_0)[q_0(\frac{1}{2}Qx + C - B - F_2) + G + B + F_2 + T - \frac{3}{2}Qx]$	0

3.3. Simulation Analysis of the Strategy Evolution

The specific determination results of the system stability points of the evolutionary game are shown in Table 4. As can be seen from Table 4, there are merely four system stability points in the evolutionary game, indicating that there are four situations in which the flood control and drainage strategies of the Wujiang and JQA can be coordinated with each other. According to the stability analysis and judgment of the evolutionary game, the evolutionary simulation is carried out using Matlab R2019b software to explore the mutual changes between the strategy choices of the upstream and downstream areas based on the stability results. The results are shown in Figure 2.

Table 4. Analysis of system stability points in the game between Wujiang and JQA.

Balance Point	Scene	det.*J* Symbol	tr.*J* Symbol	In Conclusion
(0,0)	$G + C + F_1 + T - \frac{3}{2}Qy < 0,$ $G + B + F_2 + T - \frac{3}{2}Qx < 0$	+	−	*ESS*
	$G + C + F_1 + T - \frac{3}{2}Qy > 0,$ $G + B + F_2 + T - \frac{3}{2}Qx > 0$	+	+	Unstable
	$G + C + F_1 + T - \frac{3}{2}Qy > 0,$ $G + B + F_2 + T - \frac{3}{2}Qx < 0$	−	±	Saddle Point
	$G + C + F_1 + T - \frac{3}{2}Qy < 0,$ $G + B + F_2 + T - \frac{3}{2}Qx > 0$	−	±	Saddle Point
(0,1)	$G + B + F_1 + T - Qy < 0,$ $-(G + B + F_2 + T - \frac{3}{2}Qx) < 0$	+	−	*ESS*
	$G + B + F_1 + T - Qy > 0,$ $-(G + B + F_2 + T - \frac{3}{2}Qx) > 0$	+	+	Unstable
	$G + B + F_1 + T - Qy > 0,$ $-(G + B + F_2 + T - \frac{3}{2}Qx) < 0$	−	±	Saddle Point
	$G + B + F_1 + T - Qy < 0,$ $-(G + B + F_2 + T - \frac{3}{2}Qx) > 0$	−	±	Saddle Point
(1,0)	$-(G + C + F_1 + T - \frac{3}{2}Qy) < 0,$ $G + C + T - Qx < 0$	+	−	*ESS*
	$-(G + C + F_1 + T - \frac{3}{2}Qy) > 0,$ $G + C + T - Qx > 0$	+	+	Unstable
	$-(G + C + F_1 + T - \frac{3}{2}Qy) > 0,$ $G + C + T - Qx < 0$	−	±	Saddle Point
	$-(G + C + F_1 + T - \frac{3}{2}Qy) < 0,$ $G + C + T - Qx > 0$	−	±	Saddle Point
(1,1)	$-(G + B + F_1 + T - Qy) < 0,$ $-(G + C + T - Qx) < 0$	+	−	*ESS*
	$-(G + B + F_1 + T - Qy) > 0,$ $-(G + C + T - Qx) > 0$	+	+	Unstable
	$-(G + B + F_1 + T - Qy) > 0,$ $-(G + C + T - Qx) < 0$	−	±	Saddle Point
	$-(G + B + F_1 + T - Qy) < 0,$ $-(G + C + T - Qx) > 0$	−	±	Saddle Point
(q_0, p_0)	none	+	0	Center

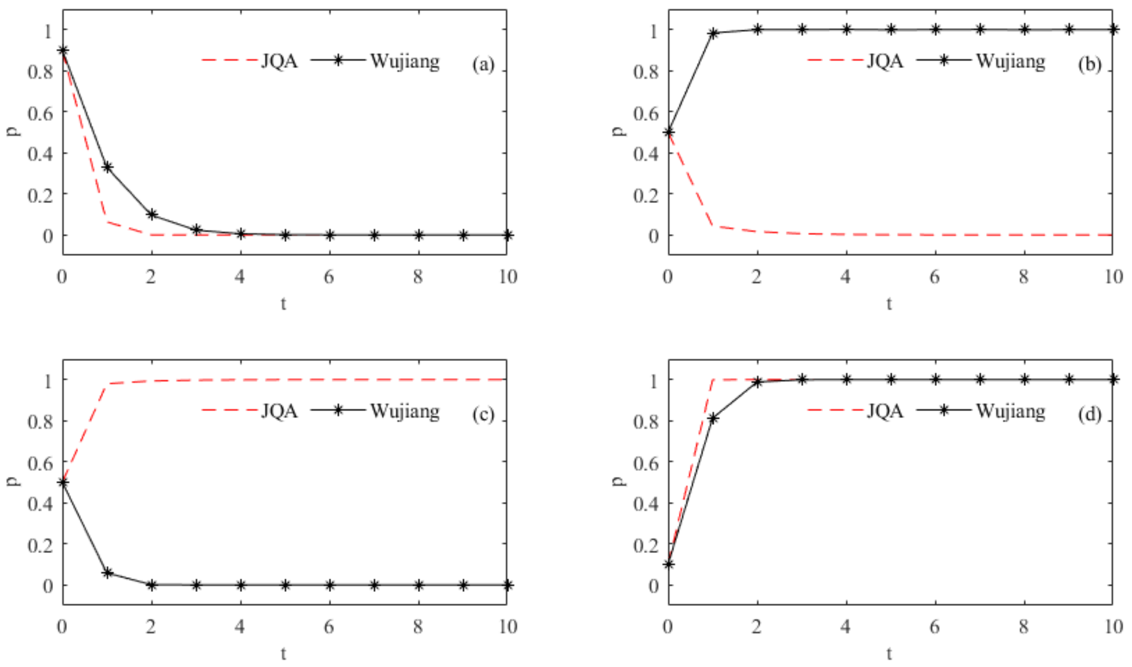

Figure 2. Evolution results of the four system stability strategies in Wujiang and JQA. (**a**). result of the equilibrium point *O* (0,0); (**b**). result of the equilibrium point *A* (0,1); (**c**). result of the equilibrium point *B* (1,0); (**d**). result of the equilibrium point *C* (1,1).

Case 1: At the equilibrium point *O* (0,0), when $G + C + F_1 + T - \frac{3}{2}Qy < 0$, $G + B + F_2 + T - \frac{3}{2}Qx < 0$, the system is in an evolving stable state. When Wujiang chooses the strategy of "Increasing drainage capacity", JQA's flood risk increases due to the increase in Wujiang's drainage capacity. Since the compensation from Wujiang to JQA, the cost of JQA's conflict choice, and the sum of rewards and penalties from the management agency are less than the benefits obtained by JQA for opposing Wujiang's increase in drainage capacity, JQA tends to choose the strategy of "Conflict" with Wujiang. However, when JQA chooses the "Conflict" strategy with Wujiang, the sum of the conflict compensation for Wujiang caused by JQA, the cost of the conflict caused by JQA due to the increase in its drainage capacity, and the rewards and penalties from the management agency are less than the benefits obtained by Wujiang from increasing its drainage capacity, so Wujiang tends to choose the "Increase drainage capacity" strategy.

In this state, to pursue its interests and to reduce its own flood control and drainage pressure, Wujiang continuously increased its drainage capacity, causing the water level of the backbone river to rise and the flood pressure of JQA to increase. To ensure its flood control safety, JQA had to restrict its drainage. JQA was unwilling to be outdone and launched a resistance and clashed with Wujiang, demanding that Wujiang assume regional flood control responsibilities and limit drainage. At this time, since the beneficiary's compensation to the injured party was very small, it was insufficient to make up for the economic and environmental losses in the disaster-stricken areas. Moreover, the cost of increasing drainage capacity and conflicts caused by JQA in Wujiang is very low. At the same time, the benefits of Wujiang increasing its drainage capacity and causing conflicts with JQA were significant. Under such conditions, both parties would choose extreme ways to obtain benefits. In this situation, the regional flood control and drainage effectiveness is the worst. For the entire basin, the drainage conflicts between cities are intensifying, affecting the coordinated management of flood control and drainage between cities across regions.

Scenario 2: At the equilibrium point *A* (0,1), when $G + B + F_1 + T - Qy < 0$, $-(G + B + F_2 + T - \frac{3}{2}Qx) < 0$, the system is in an evolving stable state. When Wujiang chooses the strategy of "Reducing drainage capacity", the flood risk of JQA decreases due to the reduction in Wujiang's drainage capacity. At this time, since the sum of the rewards and punishments of the management agency to JQA, the compensation of JQA to Wujiang, and the cost of choosing to conflict is less than the benefits obtained by JQA continuing to require Wujiang to reduce its drainage capacity, JQA tends to choose the "Conflict" strategy. When JQA chooses the "Conflict" strategy with Wujiang, the sum of the rewards and punishments obtained by Wujiang from the management agency, the compensation caused by the "Conflict" caused by JQA, and the cost of the conflict caused by the increase in its drainage capacity is greater than the benefits obtained by Wujiang to increase its drainage capacity, Wujiang tends to choose the "Reducing drainage capacity" strategy. At this time, the stable point of the system is (0,1)

In this state, after JQA triggers a conflict, the flood pressure on JQA is reduced, thereby obtaining huge flood control benefits and thus causing conflicts with Wujiang. At this time, the cost of the conflict caused by JQA and the compensation to the Wujiang area are both low, which further prompts JQA to continuously demand that Wujiang reduce its drainage capacity. After the conflict initiated by JQA, Wujiang has a high cost of confronting JQA and can obtain certain compensation from JQA, which is enough to make up for the flood losses caused by the reduction in drainage capacity. At the same time, Wujiang will gain little benefit by increasing its drainage capacity. Therefore, Wujiang will not confront JQA, and choose the strategy of "Reducing drainage capacity". However, in this state, JQA will unrestrictedly require Wujiang to reduce its drainage capacity. For the entire basin, it will cause a serious imbalance in drainage capacity between cities, affecting the integrated and coordinated development of regional flood control and drainage.

Scenario 3: At the equilibrium point B (1,0), when $-(G + C + F_1 + T - \frac{3}{2}Qy) < 0$, $G + C + T - Qx < 0$, the system is in an evolving stable state. When Wujiang chooses the strategy of "Increasing drainage capacity", JQA will face an increased flood risk due to the increase in Wujiang's drainage capacity. Since the sum of the management agency's rewards and punishments on JQA, Wujiang's compensation to JQA, and the cost of JQA's choice of conflict is greater than the benefits obtained by JQA from opposing Wujiang's increase in drainage capacity, JQA tends to choose the "Non-conflict" strategy. When JQA chooses the "Non-conflict" strategy with Wujiang, the sum of Wujiang's compensation to JQA due to its increase in drainage capacity and the management agency's rewards and punishments on Wujiang is less than the benefits obtained by Wujiang's increase in drainage capacity, so Wujiang tends to choose the "Increase drainage capacity" strategy. At this time, the stable point of the system is (1,0).

Under this state, to alleviate its own flood control and drainage pressure, Wujiang continuously increased its drainage capacity, causing the water level of the backbone river to rise, and obtained greater flood control and drainage benefits. The cost of JQA causing conflicts with Wujiang is high, which hinders the motivation of JQA to conflict with Wujiang. At the same time, after Wujiang increases its drainage capacity, considering the regional flood disaster losses, out of social responsibility, Wujiang will give JQA considerable economic compensation to make up for the economic and environmental losses suffered by JQA. Therefore, JQA tends not to fight back against Wujiang's behavior of increasing drainage capacity. At this time, the effect of regional flood control and drainage coordinated governance is poor. Because Wujiang unscrupulously increases its drainage capacity, it affects the flood safety of JQA while obtaining greater benefits, while JQA relies solely on the compensation of Wujiang to make up for the huge losses caused by flood disasters. For the entire basin, it will cause a serious imbalance in flood control and drainage capacity among cities, affecting the integrated and coordinated development of regional flood control and drainage.

Scenario 4: At the equilibrium point C (1,1), when $-(G + B + F_1 + T - Qy) < 0$, $-(G + C + T - Qx) < 0$, the system is in an evolving stable state. When Wujiang chooses the strategy of "Reducing drainage capacity", the flood risk of JQA decreases due to the reduction in Wujiang's drainage capacity. At this time, since the sum of the costs of the downstream alliance's compensation to Wujiang, the conflict caused by JQA's choice, and the management agency's rewards and punishments on JQA is greater than the benefits obtained by JQA continuing to require Wujiang to reduce its drainage capacity, JQA tends to choose a "Non-conflict" strategy. When JQA chooses the "Non-conflict" strategy, the sum of the cost of Wujiang's compensation to JQA due to increased drainage capacity and the cost of the management agency's reward and punishment of Wujiang is greater than the benefit obtained by Wujiang's increased drainage capacity, Wujiang tends to choose the "Reducing drainage capacity" strategy. At this time, the stable point of the system is (1,1).

In this state, the cost of causing conflict for JQA is huge, and causing conflict requires huge compensation to Wujiang, so JQA will not cause conflict with Wujiang. At this time, the compensation given to JQA by Wujiang for increasing drainage capacity is huge, and the benefits are also small, so Wujiang also tends to choose the strategy of "Reducing drainage capacity". In this state, the overall flood control and drainage effect of the region is the best because Wujiang actively assumes the responsibility of regional flood control and drainage. From the perspective of the whole region, Wujiang reduces its drainage capacity and reduces the flood pressure of JQA. At the same time, JQA also actively assumes the responsibility of regional flood control and drainage, which will not cause regional flood control and drainage conflicts. This strategy promotes integrated and coordinated management of regional flood control and drainage.

4. Collaborative Governance Strategy

The above analysis reveals that the marginal benefits of flood control and drainage for both parties, the costs of conflict (F_1 and F_2), the compensation (B and C) provided by the party causing the conflict, the additional flood control and drainage benefits gained by the conflicting parties, and the rewards (G) and penalties (T) imposed by DZGIED's management on the choices of both parties (such as "Reducing drainage capacity" versus "Non-conflict" or "Increasing drainage capacity" versus "Conflict") are the main factors influencing the strategic behavior of the upstream Wujiang and the downstream JQA. This is similar to the findings of Shi Guangming et al. [19,28,29], who identified that differences in marginal pollutant reduction costs and conflict compensation costs are key factors in determining whether regions can collaborate to prevent transboundary watershed pollution. Therefore, the collaborative governance of urban flood control and drainage in the Demonstration Zone can be approached from the following perspectives:

(1) Unified planning and management of DZGIED, along with the coordinated integration of urban flood control and drainage planning within DZGIED

Firstly, the intervention by the DZGIED management agency can facilitate overall management, coordination, and guidance. Additionally, it can provide a negotiation platform to foster coordinated cooperation between the upstream Wujiang and the downstream Jiashan and Qingpu. Secondly, the DZGIED management agency and the Taihu Basin Authority of Ministry of Water Resources should fully leverage their roles in basin flood control and drainage management. Establishing a consultation system and promoting equitable dialogue between upstream and downstream areas will facilitate effective communication and collaboration. Overall coordination of flood control and drainage planning between upstream and downstream can effectively coordinate the contradiction of inconsistent flood control and drainage needs in Wujiang, Jiashan, and Qingpu. At the same time, it is necessary to further rationally adjust the layout of flood control and drainage projects in Wujiang, Jiashan, and Qingpu, clarify the flood control and drainage capabilities and needs of each region under the current conditions, and make unified and coordinated planning for the layout and capabilities of flood control and drainage projects in upstream and downstream areas.

(2) Enhance the reward and punishment mechanism to incentivize the cities in DZGIED to cooperate.

As an external driving force, the incentive and constraint policy form a policy mechanism with well-defined rewards and punishments, which fully mobilizes the enthusiasm and initiative of Wujiang, Jiashan, and Qingpu to enhance cooperation and protection in flood control and drainage across the regions. Based on the results of the game analysis, the intensity of incentives and constraints can be adjusted to balance the flood disaster losses caused by the reduction in drainage capacity in Wujiang and reduce the pressure of compensation payment for the increase in drainage capacity in Jiashan and Qingpu to Wujiang. Therefore, the DZGIED management agency actively explores the implementation of the reward and punishment mechanisms of "Rewarding positive compensation" and "Punishing negative compensation". Under the reward mechanism, on the one hand, Wujiang is rewarded for actively assuming the regional flood control and drainage responsibilities and sharing the regional flood pressure. This can alleviate the losses caused by flood disasters in Wujiang due to bearing regional flood pressure and ensure the enthusiasm and stability of Wujiang to actively bear flood pressure. On the other hand, Jiashan and Qingpu are rewarded for actively participating in the work of regional flood control and drainage integrated management. This can reduce the flood pressure caused by the current insufficient drainage capacity in Jiashan and Qingpu. Under the penalty mechanism, if the upstream Wujiang fails to actively assume the responsibility of regional integrated flood control and drainage management and chooses to continue to increase its drainage capacity, thereby increasing the flood control pressure on JQA and even the entire DZGIED. Or if the downstream Jiashan and Qingpu fail to actively follow the DZGIED management department to reasonably set up the local flood control and drainage capabilities, resulting in unbalanced development of upstream and downstream flood control and drainage capabilities. The DZGIED management agency shall impose penalties on the upstream and downstream areas. The funds obtained shall be used for the construction of flood control and drainage projects in DZGIED.

(3) Introducing an internal equilibrium mechanism and a two-way compensation mechanism between cities.

As an internal coordination mechanism for upstream and downstream cooperation, the compensation mechanism can effectively make up for the economic losses caused by the reduction in drainage capacity in Wujiang and the flood losses caused by Wujiang drainage in JQA. It is beneficial for resolving the conflicts of interest between upstream and downstream areas. Therefore, the DZGIED management agency, based on the principle of "Who benefits, Who pays", determines a reasonable compensation subject through consultation among the cities in DZGIED. It determines the compensation basis based on the layout of flood control and drainage projects in DZGIED and the current socio-economic conditions. Taking into account the cost of flood losses in the upstream Wujiang and the downstream Jiashan and Qingpu to calculate scientifically reasonable compensation standards. In terms of compensation methods, provide diversified compensation methods such as technical compensation and physical compensation in addition to economic compensation.

5. Conclusions

By analyzing the interests of the upstream Wujiang and the downstream Jiashan and Qingpu, an evolutionary game model of flood control and drainage between upstream and downstream areas was constructed to explore the factors that affect the behavioral strategies of areas in the process of allocating flood control and drainage capacity. The main conclusions are as follows:

(1) Based on the game stability analysis, the strategy of the two parties in the game changes according to the strategy of the other. Five elements, namely the cost of conflict, the compensation of one party to the other, the additional benefits obtained by the two parties, the reward for the choices, and the punishment for the choices, are the main factors affecting the behavioral strategy of Wujiang and JQA.

(2) The strategies of both parties will evolve towards those that are beneficial to themselves, thereby maximizing each party's interest. To promote the game model towards a stable strategy (Reducing drainage capacity, Non-conflict), a reasonable two-way compensation mechanism and reward and punishment mechanism should be established. It can share the losses caused by the assumption of flood pressure upstream and alleviate the compensation pressure downstream.

(3) The collaborative management strategy for flood control and drainage is proposed: for the external part, the agency of DZGIED is responsible for coordinating the conflicts; for the downstream and upstream, it should implement incentive and constraint policies with clear rewards and punishments; for the internal part, a two-way compensation mechanism should be established to compensate for the economic losses caused by the imbalanced capabilities of both parties.

Author Contributions: Conceptualization, S.S. and L.W.; methodology, S.S.; software, S.S.; validation, S.S., L.W. and Y.W.; formal analysis, S.S.; investigation, S.S.; resources, L.W., L.L. and X.S.; data curation, Y.W.; writing—original draft preparation, S.S.; writing—review and editing, L.W., W.G. and L.Z.; visualization, Y.C. and L.Z.; supervision, L.W., X.S. and W.G.; project administration, L.W.; funding acquisition, L.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Key R&D Program of China, grant number 2021YFC3000101-02.

Data Availability Statement: Data is contained within the article.

Conflicts of Interest: Weijian Guo and Leilei Zhang were employed by the company PowerChina Huadong Engineering Corporation Limited. Author Yuan Chen was employed by the company Nanjing Taosan Intelligent Technology Co., Ltd. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflicts of interest.

References

1. Luo, Z.; Zuo, Q. Evaluating the coordinated development of social economy, water, and ecology in a heavily disturbed basin based on the distributed hydrology model and the harmony theory. *J. Hydrol.* **2019**, *574*, 226–241. [CrossRef]
2. Jia, K.; Yuan, R. The impact of basin horizontal ecological compensation policies on carbon emissions: A case study of the Yangtze River economic Belt. *Heliyon* **2024**, *10*, e28858. [CrossRef] [PubMed]
3. Wheeler, K.G.; Robinson, C.J.; Bark, R.H. Modelling to bridge many boundaries: The Colorado and Murray-Darling River basins. *Reg. Environ. Chang.* **2018**, *18*, 1607–1619. [CrossRef]
4. Zhang, K. Study on Allocation Method of Flood Drainage Rights Based on Game Analysis. Ph.D. Thesis, Hohai University, Nanjing, China, 2020.
5. Chen, S.; He, Y.; Tan, Q.; Hu, K.; Zhang, T.; Zhang, S. Comprehensive assessment of water environmental carrying capacity for sustainable watershed development. *J. Environ. Manag.* **2022**, *303*, 114065. [CrossRef]
6. Huang, X.; Chen, X.; Huang, P. Research on Fuzzy Cooperative Game Model of Allocation of Pollution Discharge Rights. *Water* **2018**, *10*, 662. [CrossRef]
7. Gorgoglione, A.; Crisci, M.; Kayser, R.H.; Chreties, C.; Collischonn, W. A New Scenario-Based Framework for Conflict Resolution in Water Allocation in Transboundary Watersheds. *Water* **2019**, *11*, 1174. [CrossRef]
8. Bernauer, T.; Böhmelt, T. International conflict and cooperation over freshwater resources. *Nat. Sustain.* **2020**, *3*, 350–356. [CrossRef]
9. Liu, Y.; Chen, L.; Huang, C. A Tripartite Evolutionary Game and Simulation Analysis of Transportation Carbon Emission Reduction across Regions under Government Reward and Punishment Mechanism. *Sustainability* **2022**, *14*, 10562. [CrossRef]
10. Kicsiny, R.; Varga, Z. Differential game model with discretized solution for the use of limited water resources. *J. Hydrol.* **2019**, *569*, 637–646. [CrossRef]
11. Zhou, X.Y.; Zheng, B.; Khu, S.T. Validation of the hypothesis on carrying capacity limits using the water environment carrying capacity. *Sci. Total Environ.* **2019**, *665*, 774–784. [CrossRef]
12. Tucker, C.M.; Hribar, M.Š.; Urbanc, M.; Bogataj, N.; Gunya, A.; Rodela, R.; Sigura, M.; Piani, L. Governance of interdependent ecosystem services and common-pool resources. *Land Use Policy* **2023**, *127*, 106575. [CrossRef]
13. Wang, Y.; Liu, J.; Feng, Z.; Li, S.; Cai, Y. Theoretical Framework for Sus-tainable Governance of Common-Pool Resource. *J. Nat. Resour.* **2012**, *27*, 1797–1807.
14. Feng, J. Optimal allocation of regional water resources based on multi-objective dynamic equilibrium strategy. *Appl. Math. Model* **2021**, *90*, 1183–1203. [CrossRef]

15. Fu, J.; Zhong, P.-A.; Xu, B.; Zhu, F.; Chen, J.; Li, J. Comparison of Transboundary Water Resources Allocation Models Based on Game Theory and Multi-Objective Optimization. *Water* **2021**, *13*, 1421. [CrossRef]
16. Rogers, P. A Game Theory Approach to the Problems of International River Basins. *Water Resour. Res.* **2010**, *5*, 749–760. [CrossRef]
17. Kucukmehmetoglu, M. An integrative case study approach between game theory and Pareto frontier concepts for the transboundary water resources allocations. *J. Hydrol.* **2012**, *450–451*, 308–319. [CrossRef]
18. Wang, L.; Fang, L.; Hipel, K.W. Basin-wide cooperative water resources allocation. *Eur. J. Oper. Res.* **2008**, *190*, 798–817. [CrossRef]
19. Shi, G.; Wang, J.; Dong, Z.; Zhang, Y. Pollution Prevention for Transboundary Watershed: Perspective from Cooperative Game Theory. *J. Nat. Resour.* **2015**, *30*, 549–559.
20. Lin, N. Study on the Coordination Mechanism and Damage Assessment System of Domestic Transboundary Water Pollution Accidents. Ph.D. Thesis, Harbin Institute of Technology, Harbin, China, 2014.
21. Roy, S.K.; Bhaumik, A. Intelligent Water Management:A triangular Type-2 Intuitionistic Fuzzy Matrix Games Approach. *Water Resour. Manag.* **2018**, *32*, 949–968. [CrossRef]
22. Madani, K. Game theory and water resources. *J. Hydrol.* **2010**, *381*, 225–238. [CrossRef]
23. Wang, J.; Zhou, Z.; Botterud, A. An evolutionary game approach to an-alyzing bidding strategies in electricity markets with elastic demand. *Energy* **2011**, *36*, 3459–3467. [CrossRef]
24. Lu, S.; Lian, Z.; Sun, H.; Wu, X.; Bai, X.; Wang, C. Simulating transboundary watershed water resources conflict. *Resour. Policy* **2021**, *73*, 102139. [CrossRef]
25. Mirzaei-Nodoushan, F.; Bozorg-Haddad, O.; Singh, V.P.; Loaiciga, H.A. Analysis of long-term strategies of riparian countries in transboundary river basins. *Sci. Rep.* **2021**, *11*, 20199. [CrossRef]
26. Biancardi, M.; Iannucci, G.; Villani, G. An evolutionary game on compliant and non-compliant firms in groundwater exploitation. *Ann. Oper. Res.* **2021**, *318*, 831–847. [CrossRef]
27. Guo, L.; Wu, Y.; Huang, F.; Jing, P.; Huang, Y. An approach to complex transboundary water management in Central Asia: Evolutionary cooperation in transboundary basins under the water-energy-food-ecosystem nexus. *J. Environ. Manag.* **2024**, *351*, 119940. [CrossRef]
28. Shen, J.; Gao, X.; He, W.; Sun, F.; Zhang, Z.; Kong, Y.; Wan, Z.; Zhang, X.; Li, Z.; Wang, J.; et al. Prospect theory in an evolutionary game: Construction of watershed ecological compensation system in Taihu Lake Basin. *J. Clean Prod.* **2021**, *291*, 125929. [CrossRef]
29. Yuan, L.; Qi, Y.; He, W.; Wu, X.; Kong, Y.; Ramsey, T.S.; Degefu, D.M. A differential game of water pollution management in the trans-jurisdictional river basin. *J. Clean Prod.* **2024**, *438*, 140823. [CrossRef]
30. Mahdevari, S.; Fazli Allah Abadi, A. A model based on the evolutionary game theory for implementing green mining principles in riverine sand and gravel resources. *J. Clean. Prod.* **2023**, *428*, 139501. [CrossRef]
31. Liu, K.; He, S. Review and consideration of flood control and management practice in Taihu Lake Basin. *Yangtze River* **2024**, *55*, 9–17.
32. Ma, K. Study on the Disaster Effects of Heavy Rain and Waterlogging Caused by Land Use/Cover Change: A Case Study of the Yangtze River Delta Eco-Green Integrated Development Demonstration Zone. Master's Thesis, Shanghai Normal University Master of Science, Shanghai, China, 2021.
33. Zhong, G.; Liu, S.; Hu, Z.; Zhang, X. Analysis of influence on region flood control due to polder waterlogging drainage in Yangcheng and Dianmao area. *Yangtze River* **2017**, *48*, 9–14.
34. Zhang, K.; Shen, J. Research on China's Drainage Rights Trading Management under the Quasi Market: Based on the Perspective of Evolutionary Game. *J. Henan Univ. (Soc. Sci.)* **2019**, *59*, 21–29.
35. Hu, R. Analyse of the absurdity of the administration division and the river basin water pollution mending. *Environ. Prot.* **2006**, *6*, 65–68.
36. Peng, K.; Dong, C.; Mi, J. Dynamic Research on the Collaborative Governance in Urban and Rural Black-Odorous Water: A Tripartite Stochastic Evolutionary Game Perspective. *Systems* **2024**, *12*, 307. [CrossRef]