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Nature-Based Solutions for Disaster Reduction and Improving Ecosystem Services in the Hutoubi Watershed, Taiwan

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Abstract: The Hutoubi Reservoir and its mainstream, Huyuan Stream, in the southern mountainous region of Taiwan, have experienced riverbed sedimentation and flood disasters for the past 150 years. In addition to climate change, it is necessary to scientifically consider its regulation for the next hundred years. This study adopted a collaborative approach, involving industry, government, and academia, using Nature-based Solutions (NbS) to enhance ecosystem services. The solution layout is constructed by widening the channel and constructing additional farm ponds and wetlands. An hydraulic simulation indicated that flood control was addressed. The restoration project would create diverse aquatic habitats by simulating and evaluating the distribution of ecological biotopes, using porous materials as revetments. It provided urban residents with forest leisure and recreational sites and supported the local agricultural and forestry products. The restoration has propagated local culture and created environmental and professional education. Therefore, ecological services are enhanced regarding regulation, support, provision, and culture. This pilot study, led by researchers, aimed to promote comprehensive management concepts considering all stakeholders and their active participation. We integrated NbS into the watershed and its river system as a pathway for facing the challenges of rapid urbanization and climate change and improving ecosystem services.

Keywords: mountain stream facilities; Nature-based Solutions (NbS); ecosystem services; climate change; disaster reduction; industry-government-academia collaboration

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1. Introduction

The United Nations adopted the "2030 Agenda for Sustainable Development" in 2015, which includes the 15th Sustainable Development Goal (SDG) that urgently calls on all countries in global partnerships to take action on address climate change and strive to protect our terrestrial ecosystems and forest resources while stimulating economic growth. In this context, Nature-based Solutions (NbS) and related concepts are viewed as pathways to achieving the SDGs in various fields. NbS are defined as "*actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits*" [1]. Recently, there has been a noticeable surge in attention directed towards NbS, which are progressively being employed as a viable alternative to conventional engineering methods.

Several cases have been recognized as practical demonstrations of NbS. For instance, the Elwha River Restoration Project in the United States implemented measures like revegetation and removal of dams to restore the river's natural processes and ecosystems [2,3]. The Netherlands's Room for the River program combines traditional measures with NbS, such as creating floodplains and wetlands to manage flood risk [4,5]. These examples illustrate the importance of integrating NbS into river management strategies, promoting sustainable and resilient systems that benefit humans and the environment [6]. NbS offers several advantages, such as enhancing biodiversity, improving water quality, and mitigating the impacts of floods and droughts [1,7]. Additionally, it can provide recreational opportunities and contribute to the local economy through eco-tourism [8,9]. Moreover, NbS typically have lower maintenance costs than traditional engineering methods and can enhance the long-term sustainability of river management [10].

The international trend towards the adoption of NbS is increasingly evident. However, one of the current challenges is translating global policies into national and local policies and legal frameworks to further mainstream and upscale NbS [11]. This challenge is particularly pronounced in Asia where many developing regions are facing environmental degradation due to economic, population, and cultural factors [12]. According to data from the Asian Development Bank, to sustain population and infrastructure development and address climate change, approximately USD 53 billion per year in climate-adjusted water and sanitation infrastructure investments are required in the Asia region from 2016 to 2030 [13]. However, the competition for limited government funding and resources for NbS varies in different countries. This administrative obstacle poses a difficulty in promoting the adoption of NbS [7,9,14,15].

On the other hand, Taiwan's suburban mountain environment has both ecological diversity and environmental sensitivity, as well as diverse characteristics of industry and landscape. However, under the **pressures** of rapid urbanization and climate change, it is facing degradation. In order to maintain the forest's ecological environment and avoid using gray measures, a systematic layout (**action**) of gray-green hybridization and adaptive NbS is necessary to promote an increase in ecosystem services (**response**) but this also poses a technical difficulty for every planning project [10,16].

We aim to share the restoration and regulation project in the Hutoubi watershed and address the existing efforts and future potential of this project from the perspective of ecosystem services. In this context, the actual case experiences serve as valuable learning objectives and are highly important for the mainstreaming and customized design of NbS. The Hutoubi Watershed is a watershed with historical significance, encompassing various historical periods, such as the Dutch colonial period, the Qing Dynasty, the Japanese colonial period, and the post-World War II era. The cultural developments during these periods are closely linked to the history of the Hutoubi Reservoir. However, the watershed and reservoir environment has been gradually deteriorating. Therefore, the watershed in southern Taiwan's mountainous area has undergone watershed management based on the NbS principles. This work has overcome the difficulties as mentioned above and combined the cooperation of the government, industry, and academia, and has also been awarded as a gold engineering example of stream regulation in Taiwan. Therefore, in this study, we exhibit how this project established a consensus, conducted a value analysis, was evaluated using modeling, and designed an NbS systematic layout to implement ecosystem services in the pilot.

2. Materials and Methods

2.1. Case Description

Due to the steep rivers and fragile geology in Taiwan, both streams and reservoirs have problems with sedimentation. The sediment yield from upstream watersheds affects the lifespan of reservoirs, affecting their usage efficiency. The main geological formations in Taiwan's mountainous regions are mudstone and sandstone. Due to their loose geological structure, the soil becomes sticky and slippery after being washed by rainwater for a long time, which can easily flow down slopes and form deep gullies on the mountain surface. Therefore, the deposition ratio of reservoirs in Taiwan is generally high.

The Hutoubi Reservoir is located in southern Taiwan (Figure 1) and was built in 1868, over 150 years ago, primarily to provide irrigation water. The watershed has an average slope of 19.37% and covers an area of approximately 681 hectares. The site is located in a transitional zone of a slope gradient where the phenomenon of sedimentation is explicit [17], with a gentler slope in the west and a steeper slope in the east and elevations ranging from 13 to 154 m above sea level. Natural boundaries form the watershed, and the main source of water in the watershed comes from the Huyuan Stream, which has a total length of approximately 19.1 km.

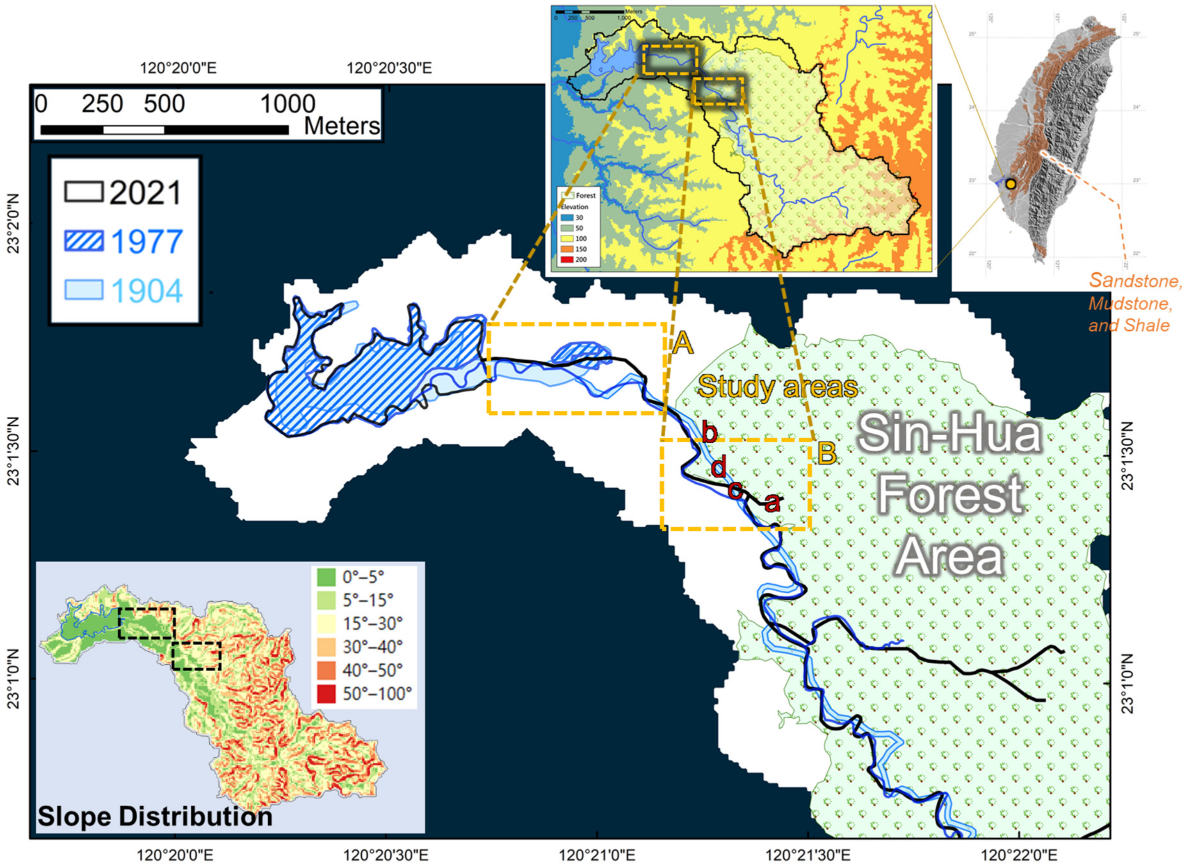


Figure 1. Geographical Location of the Hutoubi Watershed, Sin-Hua Forest, and the study areas. A and B are the study areas. The flood disaster photos of the study, shown in Figure 2, correspond to the locations marked as "a", "b", "c", and "d" in this figure.

The earliest topographic survey of the Hutoubi Watershed can be traced back to 1904, and the range and storage capacity of the Hutoubi Reservoir before that is unclear. Due to the sandstone and mudstone geology of the watershed and no forest cover in the early years, it is highly susceptible to erosion; thereby, it can be inferred that the storage capacity and area at the time of its construction in 1868 was much greater than in 1904. In 1920, National Chung Hsing University established the Sin-Hua Experimental Forest in the Hutoubi Watershed (see Figure 1). In addition to being used for education and training, afforestation was progressively carried out throughout the forest from 1940 onwards to prevent soil erosion. The forest area has reached 503 hectares, accounting for approximately 74% of the watershed (as shown in Table 1). The increase in forest area gradually shows good soil and water conservation function. The Huyuan Stream has become one of the few permanent mountain streams in southern Taiwan. Additionally, the Hutoubi Reservoir is the only reservoir in south Taiwan that can easily survive a century drought [18]. However, although the sedimentation problem has been moderated, the watershed's fine-grained geology still causes the reservoir's tail end to silt up gradually. The volume of the Hutoubi Reservoir has gradually shrunk over the past hundred years, from 1904 to 2021 (Figure 1, study area A), and the tail end of the reservoir has completely silted up.

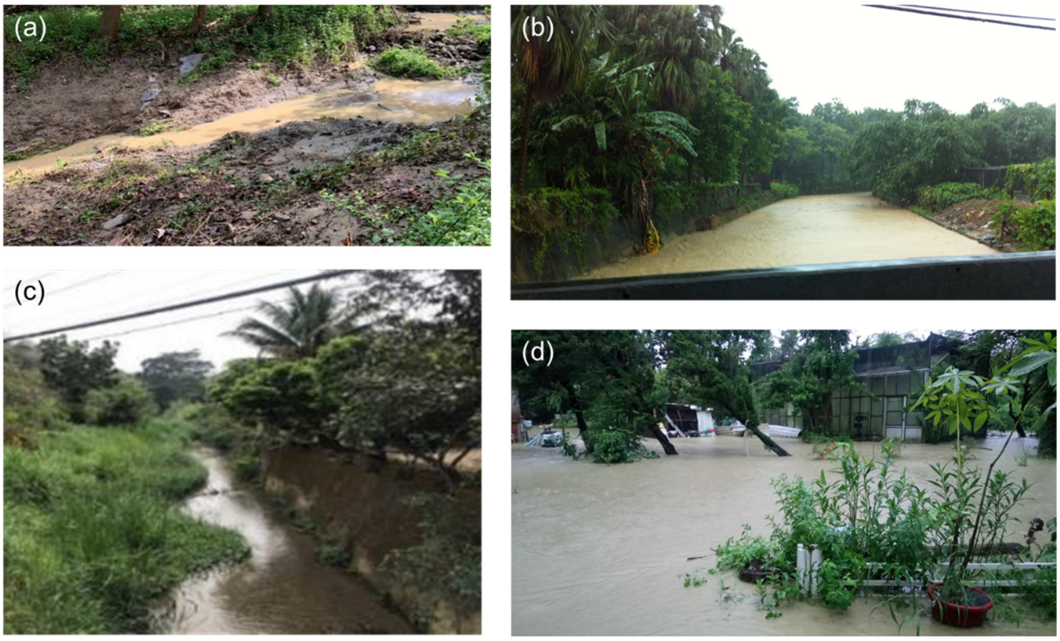


Figure 2. The post-disaster photographs before restoration: (**a**) serious siltation of tributaries with insufficient flood discharge capacity, (**b**) high water level during rainfall, (**c**) the silting channel and concrete embankment, and (**d**) frequent flooding inundating the building area. The locations of a, b, c, and d are marked in Figure 1.

Table 1. The distribution of land cover types in the Hutoubi watershed.

Land Cover	Area Percentage
Forest	73.7%
Cropland	11.3%
Barren land	5.7%
Water bodies	5.3%
Built-up areas	3.7%
Grassland	0.1%

The rainy season in Taiwan usually falls within the monsoon season, which extends from May to October. The major natural disasters in this watershed are caused by typhoons and heavy rains, especially in the downstream section of the Huyuan Stream connecting the reservoir. In a 2 year return period, the 24 h rainfall amount is approximately 260 mm. Intense rainfall resulted in high discharge that exceeded the capacity of the river channel for the given recurrence interval (Table 2). The occurrence of landslides and soil erosion accompanying typhoons leads to a high sediment yield in the watershed and results in channel siltation. Due to the siltation of the channel, the flood discharge capacity is insufficient, and the river bed gradually aggregates, thereby meandering. Among them, study area B in Figure 1 is a severely silted section, which has caused frequent flooding disasters in the past decade (Figure 2), and the aquatic ecosystem has degraded. For example, during the 2016 Typhoon Meranti, the 2017 Typhoon Haitang, and the heavy rain on 23 August 2018 (332 mm/day), the overflowing channel caused severe flooding in the building area. Soil erosion caused stream banks and embankments to collapse, affected the timbers, and resulted in the loss of farmland and road interruption. The riverbank collapse spans a length of 600 m, impacting an area of 11 hectares of forest. Under the influence of adverse environmental factors, the diversity of biological composition in the stream is low. Non-native species, such as *Tilapia* in large numbers, have caused ecological pollution and impacted the habitat environment, resulting in human avoidance of the aquatic environment.

Table 2. The flood discharge of different return periods.

(m^3/s)	$Q_{1.1}$	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}
Hutoubi main stream	51.6	76.8	91.3	102.4	117.0	128.0
tributary	2.5	4.9	5.9	6.5	7.5	8.2

Hutoubi is Taiwan's first reservoir, and the Sin-Hua Forest, with its broad-leaved forest cover, is the closest ecological green space to the Tainan metropolitan area. However, river functions have degraded due to sedimentation and frequent flood disasters, leading to ecological decay. With the gradual exacerbation of climate change in the future, addressing the next stage of watershed management and ecological restoration has become an urgent problem to solve. Therefore, the research team has focused on regulating the A and B study areas to maintain the Hutoubi reservoir and watershed functions.

2.2. Study Process

This study process can be broken down into three stages, as shown in Figure 3. Firstly, the issues related to the watershed should be clarified and then focused on crucial river reaches (as described in Section 2.1). During this stage, the consensus among all stakeholders is fostered. Next, various strategies and plans are formulated, and the most suitable option is selected. Numerical models serve as tools in this step to assess flood mitigation capabilities. Then, strategic layout, in conjunction with the geographical environment, is employed to achieve multiple objectives. Finally, an initial evaluation of ecosystem services is conducted. Ecosystem services encompass a wide range of aspects, including provisioning, supporting, regulating, and cultural phases. Flood regulation and habitat diversity within the phases of regulating and supporting are initially quantified using numerical models. On the other hand, the assessments of supplying and cultural phases are more indirect. However, the overall improvement in ecosystem services can be indirectly validated through metrics, such as visitor numbers and forest revenue. Research methods available for estimating the economic value of ecosystem services is not considered in this case as the aim is to present compelling specific facts or visions instead of a virtual price.

2.3. Collaboration Pattern among the Academia, Government, and Forest Management Office

The Sin-Hua Forest management office collaborated with National Chung Hsing University to enhance the ecosystem services. It proposed to the Soil and Water Conservation Bureau (SWCB) to use this case as a pilot for NbS in the Taiwan mountainous watershed and to jointly develop improvement measures. The research team, government, and forest management office represented the roles of guidance, execution, and post-management, respectively (Figure 4). In this project, the research team proposed strategies and professional recommendations for enhancing ecosystem services, and the SWCB funded the contract with the engineering agency. The completed project was then handed over to the forest management office for operation. This collaboration model allows all three parties to benefit. The forest management office directly benefits from improved river health for recreational activities and reducing flood risks; the research team gains a teaching and research field; and the SWCB gains a valuable pilot project for advanced measure and treatment performance. The collaboration of the three parties has overcome the uncertainties of ownership and maintenance responsibilities, as well as institutional, regulatory, and governance barriers that NbS commonly faced [14]. Moreover, the crucial aspect is to promote comprehensive management concepts that consider all stakeholders and encourage their active participation. Given that government water policies do not typically prioritize ecological improvement as a standalone goal, it is essential to leverage the management initiatives of diverse stakeholders [19].

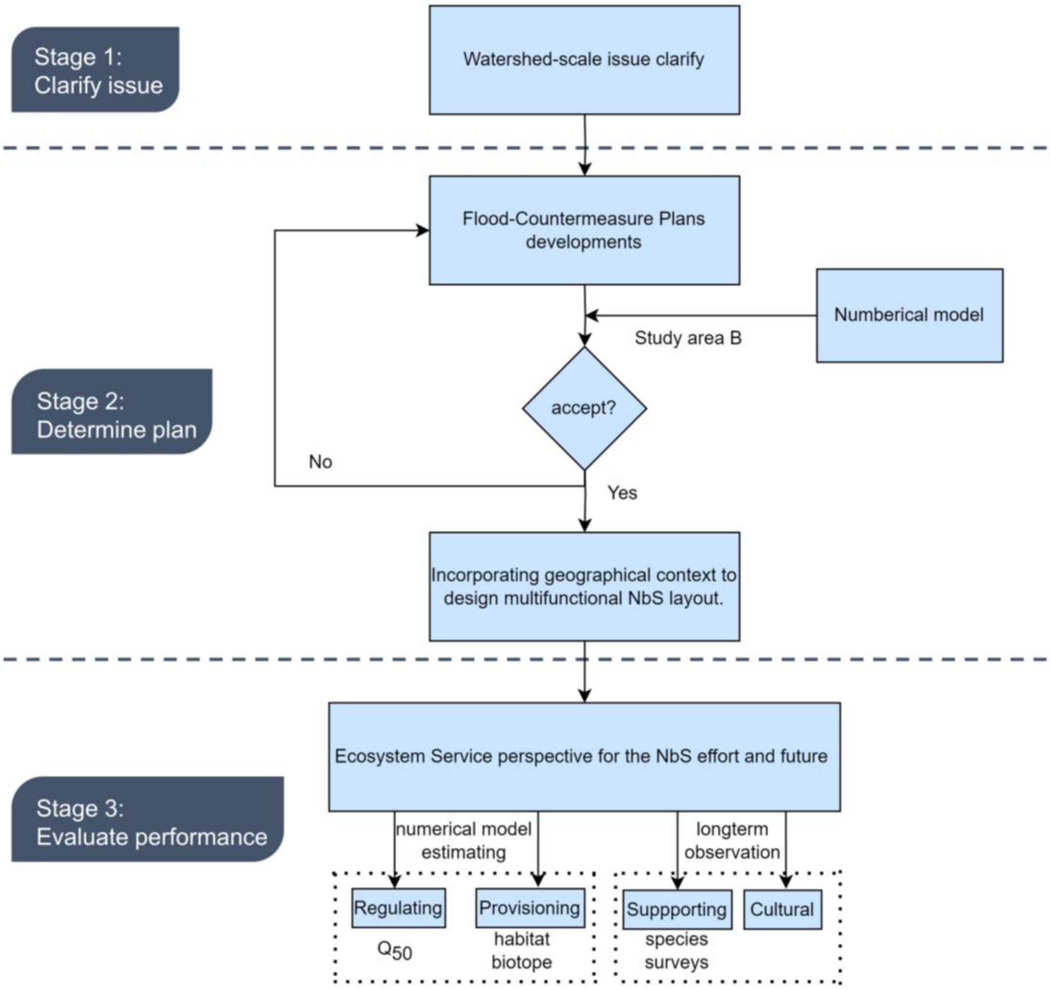


Figure 3. The flowchart of this study.

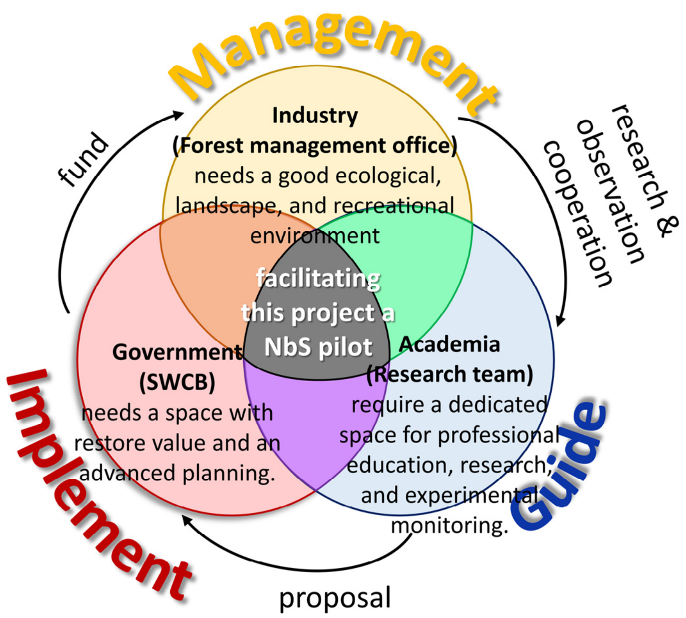


Figure 4. The motivation and interest of stakeholders (management, academia, and government).

2.4. Restoration Plans Developments

During the process, the research team had several different tasks at different stages. Firstly, the three parties jointly explored the main and potential benefits and ecosystem services that could be obtained through restoration by conducting multiple field surveys. Subsequently, based on this, the research team proposed professional advice to the engineering agency for design. In this process, other stakeholders (such as environmental NGO/Non-profit) were invited to enhance the communication and friendly measures for ecological maintenance. During the implementation, recording and monitoring were necessary to collect valuable data for analyzing the expected benefits.

The designed plans were led and proposed by the research team. Initially, in study area B where the channel lacked flood capability, the design of an embankment elevation or channel width was determined through numerical modeling, and the required flood capacity (Q_{50}). Once the plans were proposed, they were discussed with stakeholders, and this stage involves diverse perspectives, including considerations of landscape aesthetics, ecology, and more. These opinions were addressed by incorporating multifunctional NbS layouts and evaluating the diversity of hydraulic biotopes. Ultimately, the adoption of a particular plan was decided jointly by the three groups.

2.5. Numerical Model

Riverflow2D hydraulic numerical is one of the most advanced two-dimensional combined hydraulic and hydrologic flexible-mesh models. Its simulation was used to quantitatively analyze the flood control capacity and understand the types of ecological habitats during low water periods. The model calculates shallow water flows using depth-averaged mass and momentum conservation equations with all the associated assumptions [20]. That system of partial differential equations will be formulated here in a conservative form as follows:

$$\frac{\partial U}{\partial t} + \frac{\partial F(U)}{\partial x} + \frac{\partial G(U)}{\partial y} = S(U, x, y) \tag{1a}$$

where $U = \left(h, q_x, q_y\right)^T$ is the vector of the conserved variables with h representing the water depth; $q_x = uh$ and $q_y = vh$ the unit discharges with (u, v) the depth-averaged components of the velocity vector u along the (x, y) coordinates, respectively. The flux vectors are given by:

$$F = \left(q_x, \frac{q_y^2}{h} + \frac{1}{2}gh^2, \frac{q_x q_y}{h}\right)^T \tag{1b}$$

$$G = \left(q_y, \frac{q_x q_y}{h}, \frac{q_y^2}{h} + \frac{1}{2}gh^2\right)^T \tag{1c}$$

where g is the acceleration of gravity. The terms $\frac{1}{2}gh^2$ in the fluxes have been obtained after assuming a hydrostatic pressure distribution in every water column, usually accepted in shallow water models. The source term vector incorporates the effect of pressure force over the bed, and the tangential forces generated by the bed stress:

$$S = \left(0, gh\left(S_{0x} - S_{fx}\right), gh\left(S_{0y} - S_{fy}\right)\right)^T \tag{1d}$$

where the bed slopes of the bottom level z_b. The bed stress contribution is modeled using the Manning friction law.

The advanced finite-volume engine of this model provides exceptional performance, ensuring precise and volume-conserving calculations. It excels in handling even the most challenging flood modeling scenarios, such as simulating dam-break and levee-break situations on initially dry landscapes. Therefore, it can be used to calculate the low-water condition for hydraulic biotope evolution.

The upstream boundary is the steady flow discharge, and the downstream boundary takes the normal depth boundary condition. Manning n is 0.035. In the study, Q_{50} (127 m^3/s, see Table 2) condition is the target flood capacity, we thereby use it as a standard to simulate the condition before regulation and different regulation plans. Additionally, the discharge used as the baseflow to simulate the diversity of hydraulic biotope is 1 m^3/s.

2.6. Hydraulic Biotope

The Froude number (**Fr**) is a reliable hydraulic parameter differentiating the hydraulic ecological units [21–23]. Therefore, this study used hydraulic models to evaluate the distribution and proportion of hydraulic ecological units to ensure the creation of diverse ecological habitats. Allocating different hydraulic parameter ranges to define habitats is a widely accepted assessment method (e.g., [21,22]). At the same time, it can quantify habitat area and diversity, and serve as a basis for quantifying ecological quality, biodiversity, and ecological resilience. This study used a 1 m^3/s baseflow and divided hydraulic biotopes into six categories [21] for simulation and analysis:

$$\mathbf{Fr} = \frac{v}{\sqrt{gh}} \quad (2)$$

These six categories are pool, glide, run, unbroken standing wave, broken standing wave, and chute. They are characterized by different ranges of **Fr**: 0.0–0.04, 0.04–0.15, 0.15–0.24, 0.24–0.49, 0.49–0.70, and 0.70–1.5, respectively [21].

3. Numerical Simulation Results (in Study Area B)

3.1. Condition before Regulation

First, Riverflow 2D was used to realize the flood capacity before regulation. The result is illustrated, which shows that the flood does not remain confined to the channel (red lines in Figure 5). Under Q_{50} conditions, it was observed that the shallow channel cross-section and gentle slope at the confluence caused floods to overflow the embankments and inundate the neighboring terraces and conservation objects in the area. The water depth distribution showed that the flooding inundated the surrounding areas beyond the stream, reaching a height of about 1 to 2 m. The embankments were old and prone to damage during floods, as evidenced by previous events, while the flat slope of the river channel (approximately 0.39% to 1.1%) could lead to silting after floods.

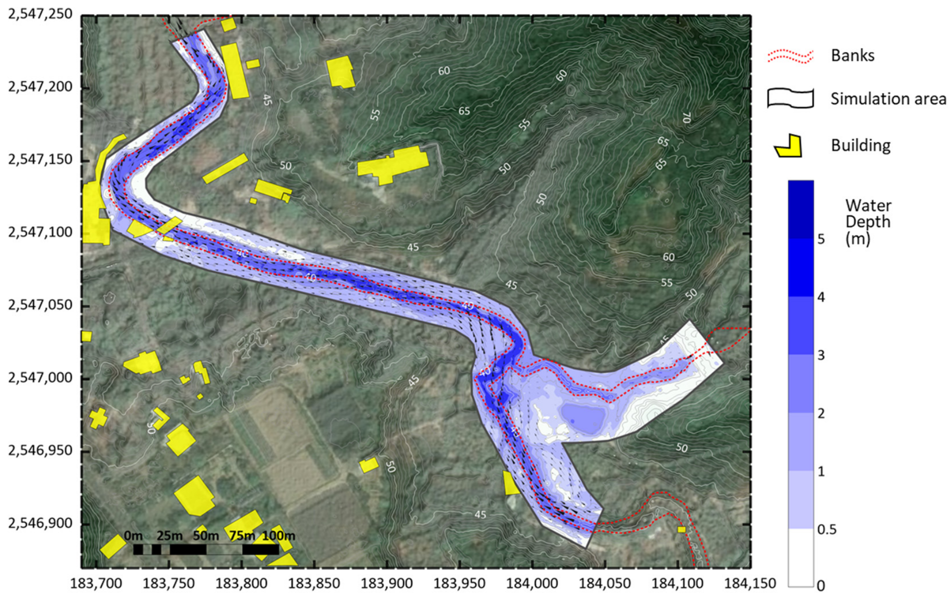
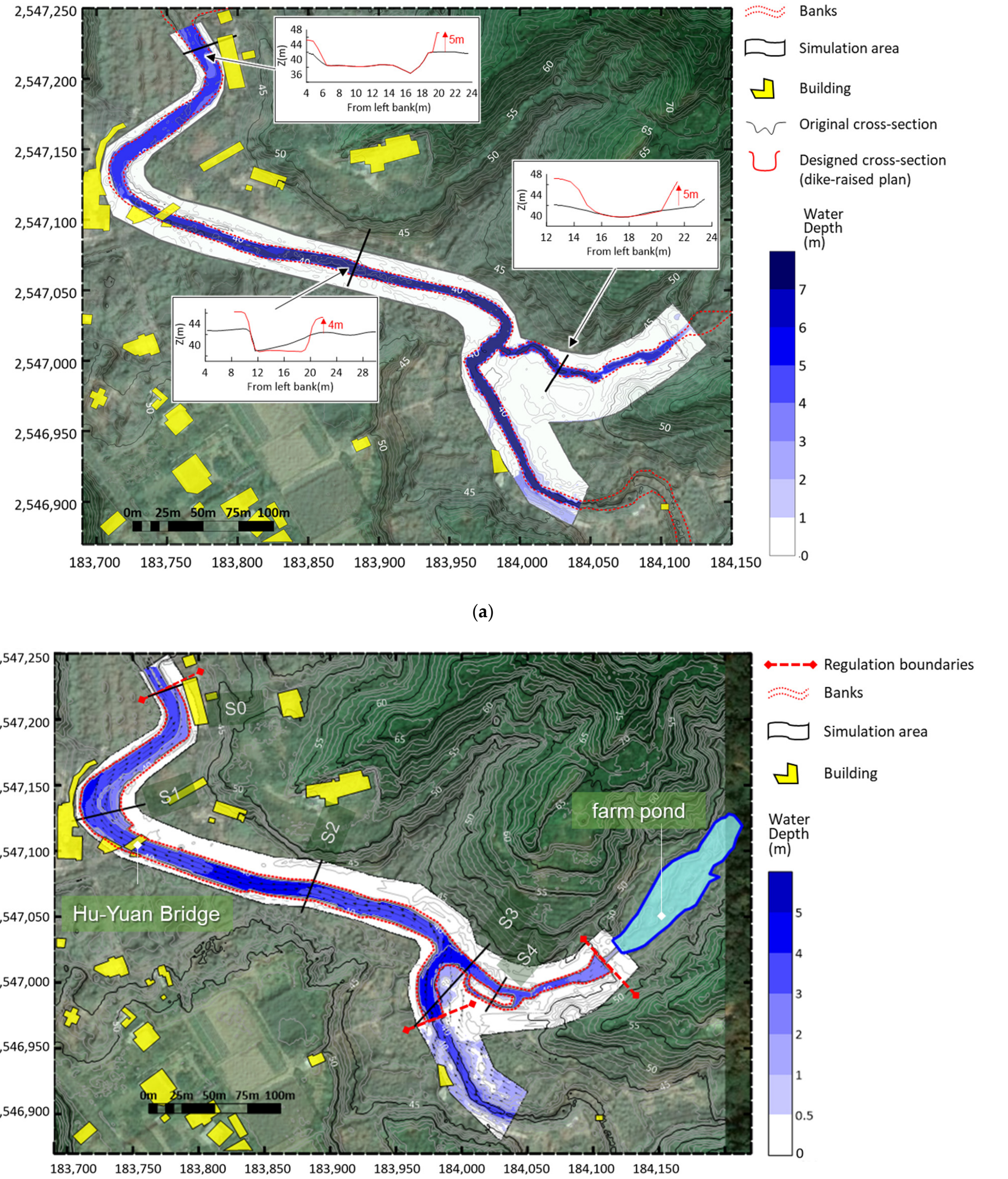


Figure 5. Simulation results of Q_{50} flood before engineering.

3.2. Simulating the Plans for Flood Control and Diversity Habitats

Two flood control plans were developed in response to the problem of insufficient flood control capacity: Plan I, the Raising Dikes Plan and Plan II, the Widening Plan. The engineering details for both plans were evaluated using Riverflow 2D. The results of Plan I are presented in Figure 6a. To meet the 50 year return period flood control standard, the dikes and embankments in the area must be raised by approximately 4–5 m. However, since the river width remains unchanged, the water depth before and after the confluence could reach up to 7 m during the flow peak. Furthermore, damage to the dikes by the high velocity could significantly harm the surrounding areas, indicating that Plan I may have low resilience. The raised dikes may also hinder wildlife passage, interrupt ecological continuity, and harm the landscape.



(a)

(b)

Figure 6. Simulation results of Q_{50} flood for different design plans: (**a**) Plan I: Raising Dikes Plan; (**b**) Plan II: Widening Plan.

The results of Plan II, the Widening Plan, are shown in Figure 6b. Rather than raising the dikes, this plan widens the river to increase the flood control capacity and retention space. The water depth in the widened channel generally ranges from 3 to 4 m, which is lower than the simulation before the engineering scenario (Figure 5). The river widening and channel improvement can significantly improve the flooding situation, and the water flow can be appropriately directed.

Considering the multifunctional aspects of planning and layout, the space above the confluence can be used as a wetland and floodplain to regulate extreme floods. Furthermore, multi-level revetments are planned to be established at the convex bank downstream of the Huyuan Bridge, serving various functions in response to different discharge levels. These revetments address the issue of high velocity and provide an ecological habitat during low-flow periods. After comparing the two plans, the stakeholders agreed that Plan II was more favorable. Furthermore, a farm pond was planned in the northern tributary to address the multiple functions of droughts, sediment retention, and flood control; thereby enhancing the adaptability of the plan to climate change.

The hydraulic biotope diversity simulation (Figure 7) showed that for Plan II, the unbroken standing wave accounted for 36% of the river range, glide accounted for 24%, run accounted for 15%, pool accounted for 10%, broken standing wave accounted for 10%, and chute accounted for 5%. Overall, there is a diverse range of biotope types, and after the disturbance caused by the engineering work stabilizes, there is potential for developing a diverse ecological composition.

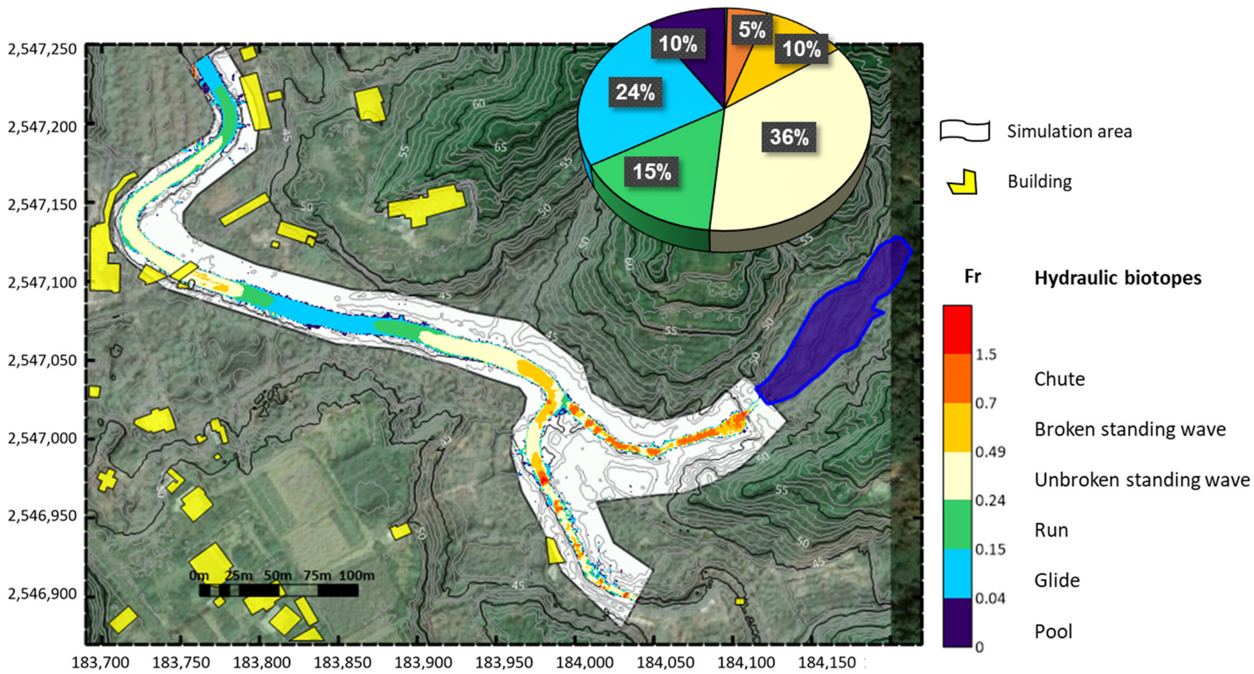


Figure 7. Hydraulic biotopes simulation and the area proportions.

4. NbS Strategies

This study considers improving the river environment during both flood and low-flow periods. The former corresponds to flood control and retention, mainly achieved by providing space for the watercourse. To create diverse hydraulic biotopes, the latter corresponds to the water source, habitat conservation, and landscape considerations. This section summarizes the overall NbS strategies adopted in the watershed.

A farm pond is planned to be set up before the confluence of the northern tributary (blue area in Figure 8a), which has excellent potential for providing ecosystem services. During flood periods, it can reduce peak flow and retain sediments, while during low-flow periods, it can provide water storage, supplement irrigation water, replenish groundwater, regulate microclimates, provide recreational opportunities, and activate the landscape.

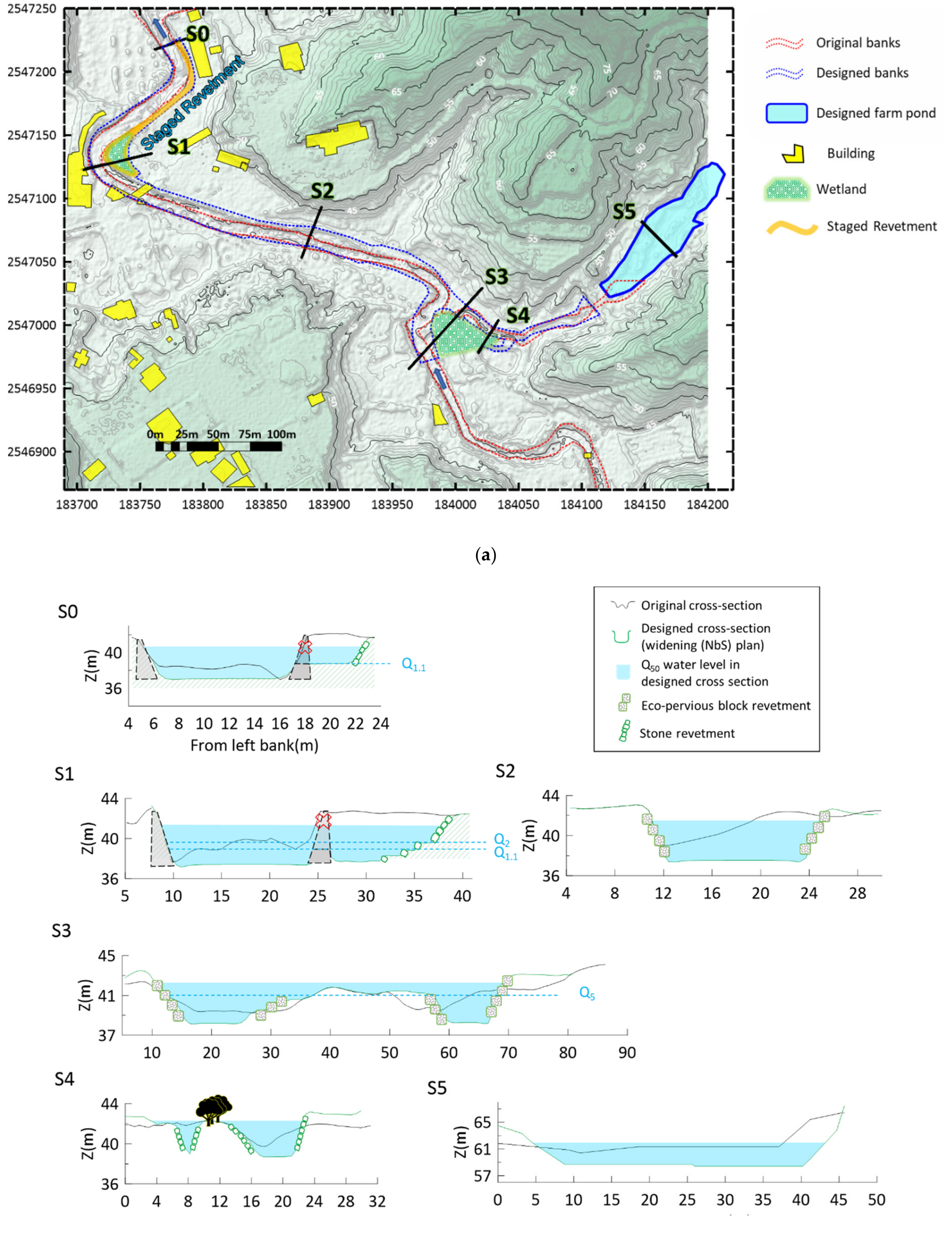


Figure 8. NbS layout of Huyuan Stream in study area B: (**a**) the plan layout, (**b**) the cross-section designs.

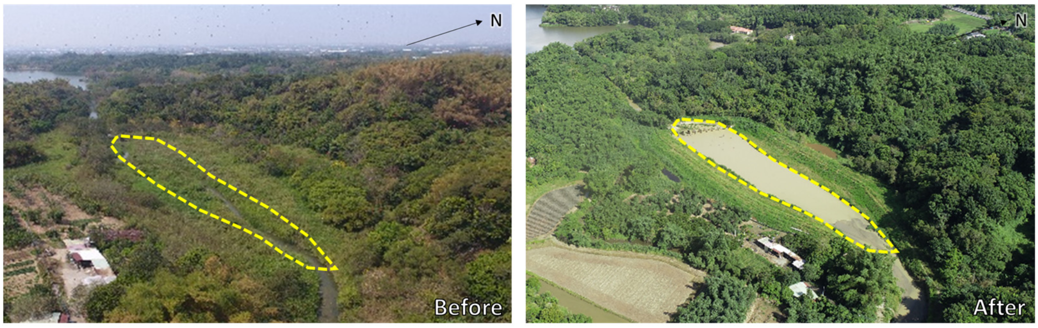
A river islet was set up at the confluence of the main and tributary streams downstream of the farm pond (S4 in Figure 8a) to divert floodwaters. This allows the trees in the center of the river islet to be preserved, and the wetland can serve as a floodplain (S3 in Figure 8a,b) at the confluence where the discharge reaching the maximum. Additionally, this creates an undisturbed ecological habitat where organisms can move between the river and floodplain, helping to spread plant seeds and fragments, nutrients, and carbon and providing opportunities for feeding and reproduction for waterfowl, fish, and amphibians.

Moreover, the flooded space of the river should be significantly increased. Hydraulic modeling planning (Section 3) widened the original mainstream from 6 to 12 m (as in S2 in Figure 8a,b). This design can reduce the flow velocity and lower the risk of scouring the bank and revetment damage. Two types of revetments that belong to ecological methods were used. Stone revetments were used instead of high and vertical concrete dikes, and the pores among the stones facilitate creature habitat and plant growth. In the downstream reach of the confluence, the front yard section of the Sin-Hua Forest, eco-pervious blocks were constructed as another type of ecological revetments. Precast concrete could reduce on-site construction and dust; soil and stones were filled in the hollow parts for planting as integration of gray-green engineering. The river revetments were designed with a mild side slope to enhance the landscape quality.

On the convex side of the downstream bank, the original vertical dike was downgraded and replaced with a multi-level stone revetment (as in S0 and S1 in Figure 8b). The multi-level revetment can serve as a buffer zone during flood periods and as a waterfront space during low-flow periods to enhance the landscape and recreation quality. The multi-level revetment design can also provide shelter for biodiversity during floods and create another wetland area (as in S1 in Figure 8a) in this research area. Aerial photos and pictures after the completion are shown in Figure 9a. Since the vegetation in this pilot area is dense, the principle of protecting the original forest as much as possible was applied during planning. After completion, the trees and vegetation on the slopes can help stabilize the soil and prevent erosion, thus contributing to the watershed management.

(**a**)

Figure 9. *Cont.*



(**b**)

Figure 9. The results of the NbS engineering: (**a**) study area B, (**b**) study area A.

Additionally, another pond was set in study area A (Figure 9b) at the tail end of the Hutoubi Reservoir to serve as a detention pond for floodwater and sediment. The pond has a capacity for approximately 22,000 m^3. This pond has no grey (concrete) engineering banks, reshapes the natural landscape, and is beneficial for maintaining the reservoir and facilitating regular dredging work. The sedimentation rate in the reservoir can be slowed, and the dredging goals become more clearly defined.

The selected study areas, study area A and B, were originally located in the Hutoubi Reservoir and Sin-Hua Forest Area, respectively. The restoration in these two areas connected the two tourist areas, creating a more cohesive recreational region. Additionally, these efforts integrated the water environment downstream of the watershed, starting from the restorations of local river reaches.

5. The Review of Ecosystem Services in Hutoubi Watershed

The enhancement of the ecosystem services requires long-term maintenance and development, and this restoration project's primary and potential objectives can be seen as parts of the ecosystem services. The pilot showcased the strategy of using stream regulation to enhance ecosystem services. Figure 10 suggests that improving ecosystem services should follow a logical progression from short-term to long-term objectives. The adaptable regulation of flood and drought can be directly addressed by constructing several restoring measures in a systemic layout (regulating aspect). Instead of using traditional gray measures, the planning adopts a gray-green mixed method that meets the principles of NbS. This approach can achieve not only the goals of flood detention and water resource regulation but also maintain habitats during low-flow conditions and help habitats recover faster from disturbances [24–26] (support aspect). As a result, it gradually restores the ecosystem of native species and creates more opportunities to develop characteristic products (providing aspect). The improved aesthetic value of the riparian zones with a friendly environment is expected to enhance the park's tourism quality. The Sin-Hua Forest could create fresh elements, thereby enriching both professional and public education and maintaining local cultures (cultural aspect).

In contrast, if the river function deteriorates, it will directly affect water resources and water safety, as well as the ecological environment and habitats of aquatic organisms, which causes regional ecological degradation. This can affect organisms higher up in the food chain and soil and water conservation, leading to the deterioration of overall ecosystem services. Therefore, stream regulation can be crucial in maintaining ecosystem services by creating a healthy aquatic environment.

5.1. Regulating

Based on the numerical modeling results, the adopted restoration plan will increase the flood control capacity from the current level (approximately Q_2) to Q_{50}. Additionally, the farm pond with a maximum storage capacity of 6000 m^3 can solve the water shortage problem in the nursery during the dry season and have functions, such as irrigation, disaster prevention, and landscape. Additionally, the sediment detention pond (22,000 m^3) can significantly reduce the deposition rate in the reservoir and help maintain its functionality. Furthermore, the enhanced flood and drought adaptation capacity could regulate the microclimate and hydrology. By widening the river and settling the agricultural pond, the humidity of the forest is regulated. In addition to reducing urban heat, the forest remains green even in the dry season.

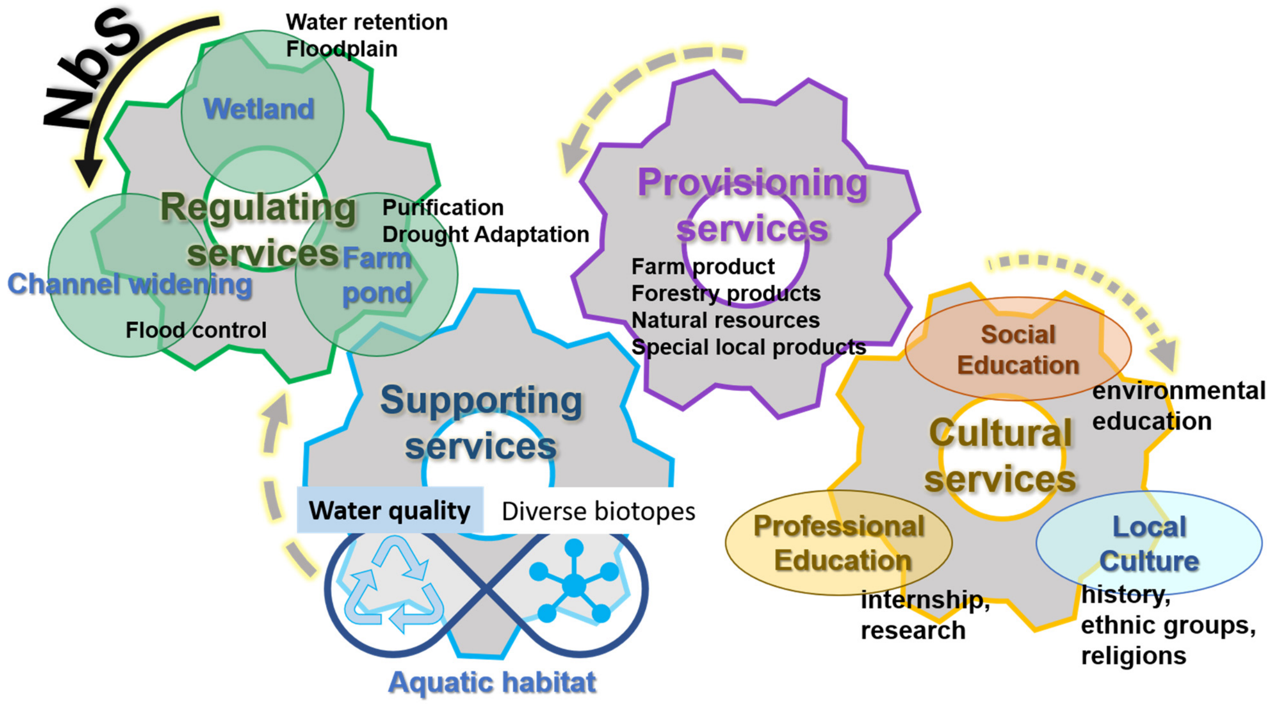


Figure 10. The progression order of improving ecosystem services.

5.2. Supporting

The measures to enhance the supporting services include providing eco-friendly environments and diverse river habitats. Although the diversity of biological species is a providing aspect, it can indirectly indicate the improvement of the habitat status. The results of the species composition of the ecological survey in the adjacent river section show that *Formosan stripe dace*, *Opsariichthys pachycephalus*, *Redspotted goby*, and *Caridina pseudodenticulata* are the dominant species in the other adjacent watersheds. In contrast, in the past ecological surveys conducted in the study area in 2020, these native species were not observed, and instead mainly consisted of invasive species.

An ecological species survey was conducted in 2022 after the completion of the engineering works (as shown in Table 3 and Table S1). As the project had just been completed, the ecological recovery of the study area still required time. However, compared to the records in 2020, it was found that there were more native species. For example, in terms of fish, the survey found the presence of the indigenous species *Opsariichthys pachycephalus* (endemic species), which prefers the environment of pools or shallow zones. The survey also found the presence of *Rhinogobius rubromaculatus* (*Redspotted goby*, endemic species), which prefers the environment of glides, and *Pseudorasbora parva*, which prefers muddy and sandy still waters. The survey indicated that hydraulic biotopes (Figure 7) provide diverse habitat environments for aquatic fish species. As for crustaceans and mollusks, two endemic species were found, including *Neocaridina saccam* and the *Geothelphusa olea*. Furthermore, the presence of the *Tarebia granifera* indicates that the river's organic matter has been chiefly decomposed, maintaining high dissolved oxygen levels and rich aquatic insects. *Neocaridina denticulate* and *Neocaridina saccam* prefer clean environments with flowing and oxygenated water, indicating that the aquatic habitats have gradually improved and recovered. In addition, there are also firefly populations in the restored wetlands. *Fireflies* require a clean and unpolluted environment and are considered indicator species of environmental health.

Table 3. The comparison of the species number statistics.

	Total Number of Species		Number of Endemic Species	
	2020	**2022**	**2020**	**2022**
Crustaceans	2	9	0	2
Fishes	5	12	1	2
Amphibians	8	8	1	1
Reptiles	6	8	1	2

However, as the state of the stream is still unstable and the riparian vegetation has not fully recovered, it has also affected the composition of the aquatic organisms. Long-term monitoring is recommended to observe changes in the biological community and to continue investigating and tracking during the different seasons of high and low flows, and to understand the influence of the restoration on the local ecology.

5.3. Provisioning

An increase in native and conservation species has been observed through ecological surveys, as described in Section 5.2 and shown in Table 3 and detailed in Table S1. The ecological species surveys focused on aquatic species (including fish and crustaceans) and amphibians and reptiles, considering their sensitivity to improvements in the aquatic environment. The statistics results are in Table 3. While the changes observed in amphibians and reptiles were relatively small, there was a notable increase in the number of fishes and crustaceans species recorded in 2022 compared to 2020. This indicates an enhancement in species diversity and richness in these groups. The diverse biological environment and the activities, such as the restoration of fireflies, the revenue from local timber, agricultural products, and surrounding goods in the Hutoubi Watershed has also increased. The *Honduras Mahogany* from the forest is also used for building wooden houses. The water resources of the Hutoubi Reservoir and ponds also supply the needs of people's livelihoods and agriculture.

5.4. Cultural

The Hutoubi Reservoir is the first reservoir in Taiwan and has cultural remains from different regimes periods, including those of indigenous peoples, the Qing Dynasty, the Japanese colonial era, and the post-World War II period. Maintaining the aesthetic value is not only to preserve the aesthetic value of the riparian zone, but also the historical and cultural significance of the waterway. The cohesive restoration of study areas A and B has also enhanced the connectivity and richness of the tourist area. Furthermore, given the success of the cooperative mode used in the Hutoubi Watershed restoration project, similar experimental NbS studies are ongoing. The Sin-Hua Forest has become more diverse in its functions, including serving as a soil and water conservation classroom and an outdoor laboratory for NbS experiments. For example, due to the geological characteristics of the mudstone and sandstone in the Huyuan Stream, there are often gullies caused by heavy rainfall on the slopes. The research team is currently studying innovative methods to use the tree roots left in the gullies and the sediment from the farm ponds to conduct NbS erosion control studies. In the past, traditional gray infrastructure was difficult to replace because it was easy for engineers to control but NbS implementation urgently needs outdoor laboratories as mechanisms for observation and case data verification to overcome obstacles. This restoration project's solutions, strategies, and experiences have also attracted attention from the domestic ecology and soil and water conservation fields, impacting these subcultures. Figure 11 shows that during the phased construction period from 2020 to 2022, the number of tourists increased significantly (despite the impact of the COVID-19 epidemic). The number of tourists is used to evaluate its function as a recreational environment.

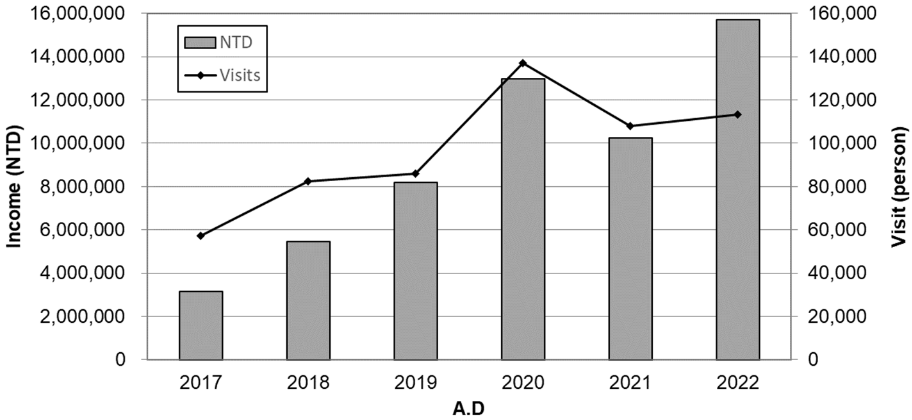


Figure 11. Visitor numbers and revenue statistics for the forest recreation area.

6. Conclusions

This study focused on the Hutoubi Watershed to preserve the reservoir's functions and improve flood and drought adaptations through two study areas, A and B, while improving the overall ecological services by rehabilitating the hostile water environment. Firstly, historic documents were used to trace the changes in the reservoir and river system over the past century to understand the watershed's river path evolution process. Different functions are expected for the basin during dry and flood seasons, so corresponding measures should be taken.

Study area A, originally located at the tail of the reservoir based on historical maps from over a century ago, had been lost due to prolonged sedimentation. A sedimentation pond was established in this area to restore the original state and maintain the reservoir's functionality. In study area B, flood control standards were considered. Regarding flood prevention, two contrasting plans were proposed and compared through numerical simulations to highlight the differences in flood control, landscape, and ecological continuity. The results indicated that to meet the Q_{50} flood control standard, Plan I required raising the embankment by 4–5 m, which would significantly impact the landscape and ecology. Plan II, which involved widening the mainstream channel from 6 to 12 m to provide additional flood space, was ultimately adopted. In addition, the distribution of hydraulic biotopes evaluated using the Froude number was simulated under low water conditions to create diverse ecological habitats. Based on the numerical simulation results, NbS layouts that are sustainable and resilient to extreme weather conditions were designed, with farm ponds and wetlands, and ecological-friendly porous materials were used for bank protection. The data from ecological species surveys and tourist statistics indicated an increase in species richness and higher returns in the park area after the completion of the project.

This case study demonstrates a strategy of using river regulation to continuously improve ecosystem services by chain reaction, adopting gray-green hybrid planning that meets the NbS criteria to address flood and weather issues (regulating) directly. The management of diverse biotopes is operated to maintain the ecological habitats (supporting), make the forest an environmentally friendly environment, and enhance the quality of landscape and agricultural products (provisioning). The Sin-Hua Forest, originally a teaching and experimental area, could maintain the function and local cultures and also create new possibilities (cultural). The Hutoubi Watershed pilot project has established a model with active involvement from all stakeholders, including the forest management office, researchers, and the government, promoting cooperation among them. A customized solution for the watershed can be developed, and long-term research and management projects can be conducted. The restoration of the Hutoubi Watershed is a response to the

15th SDG and represents a resilient approach to addressing climate change impacts. It achieves flood control objectives and enhances biodiversity habitats, species, and benefits to the tourist area. The strategies implemented in this pilot case can serve as guidance for the restoration of other watersheds facing functional degradation due to climate change. However, the importance of subsequent management should not be overlooked.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w15142527/s1, Table S1: The species survey in Hutoubi Watershed.

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