

# Synergistic Effects of Nature-based Solutions (NbS) in Watershed Pollution Control and Carbon Sequestration: An Engineering Review of Wetlands, Floodplain Restoration, and Ecological Revetments

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**Abstract.** As global climate change and ecosystem degradation continue to accelerate, nature-based solutions (NbS) have emerged as an important and sustainable approach to improving the health and resilience of watersheds. NbS integrate ecological processes into environmental management, using natural systems such as wetlands, floodplains, and ecological revetments to achieve water purification, habitat restoration, and carbon sequestration. This review systematically analyzes the current progress and application of NbS in the control of watershed pollution and carbon management. It also deals with the synergistic mechanisms between hydrological regulation and biogeochemical cycling. By examining a wide range of research results, it points out how NbS can effectively reduce nutrient and sediment loads, enhance carbon storage through vegetation and soil processes, and contribute to alleviating climate change impacts. However, the practical implementation of NbS still faces several challenges, including limited technology, insufficient economic evaluation, and lack of standardized monitoring and policy. To increase the scale of the application of NbS in watershed management, future research should focus on improving model integration, remote sensing and data-driven monitoring technologies. Also unified evaluation standards should be established. Strengthening collaboration among different fields and standard policy will also be vital to realize the potential of NbS for sustainable watershed governance.

**Keywords:** Nature-based solutions; Watershed Management; Pollution Control; Carbon Sequestration; Ecological Restoration.

## 1. Introduction

Global climate change and ecological degradation, which are serious issues prevalent globally at this time, exert a notable influence on water resource management, the stability of ecosystems, and the long - term development of human society. Under these conditions, Nature - based solutions (NbS), an approach that is both practical and utile, addresses these problems via the protection, restoration, and reconstruction of natural ecosystems. By harnessing natural processes, NbS provides an integrated means for climate change mitigation and adaptation, being in consonance with the aims of carbon peaking and carbon neutrality. The restoration of wetlands, floodplains, and ecological revetments, made possible by NbS, has the potential to enhance the self - cleansing capacity of watersheds, bring about an improvement in water quality, and increase carbon sequestration within plants and soils. These methods not only strengthen ecosystems but also bestow numerous ecological, social, and economic benefits, thereby contributing to the establishment of sustainable watershed and environmental management.

For example, research by Mariana Marchioni et al. shows that when NbS are used together with river restoration in the Seveso River basin in Italy, they clearly lower peak flows, flow rates, flooded areas, and pollution [1]. River restoration makes the ecological quality better, and NbS can remove water pollutants by holding urban runoff and improving drainage chemistry, so they help the management of the Seveso River. Results from the European Commission's (2021) "A Blueprint for Resilience" project show that every €1.19 (£1) spent on NbS can bring €7.98 (£6.70) in net benefits and more than €52 million (£44 million) in possible extra income, such as from carbon sequestration,



biodiversity protection, and flood regulation [2]. The main reason for these good effects is that NbS can offer many kinds of ecosystem services at the same time, for example, carbon storage from wetland restoration, higher ecosystem value, and better biodiversity [3].

This paper studies how Nature-based Solutions (NbS) work together in watershed pollution control and carbon control, with special focus on the engineering use of wetlands, floodplains, and ecological revetments. By reading and sorting related studies, it explains how NbS cut pollutant emissions and increase carbon sequestration by bringing back natural ecosystems, with stress on wetland restoration, floodplain rehabilitation, and ecological revetments. The paper also looks at the main problems and future work for NbS, especially how they can help solve global climate change and ecological degradation. It then gives some suggestions for later policy and practice, mainly in technology cooperation, building standard systems, and doing research across different fields.

## **2. Engineering Types and Hydraulic Characteristics**

### **2.1. Wetland Systems**

Constructed wetlands are environmentally friendly and useful technology for wastewater treatment and ecological restoration. Their treatment works mainly because the substrate, plants, and microorganisms work together. They remove pollutants through physical, chemical, and biological processes. The substrate is the main support and also the place where reactions happen. It usually has many pores and a large surface area. When wastewater flows through the substrate, suspended solids and small particles stay there by settling under gravity. This is an important first step in removing pollutants. At the same time, the chemical properties of the substrate let it adsorb and hold pollutants such as heavy metal ions and phosphorus through simple attraction and ion exchange, so the pollutant level in the outflow becomes lower.

Compared with common engineered treatment systems, wetlands as green facilities have lower operation and maintenance costs in their whole life, and they can also improve water purification [4]. Because of these good points, constructed wetlands are now widely used to treat agricultural runoff, industrial wastewater [5], and combined sewer overflows. They also help reduce too many nutrients from farmland, so they can help control eutrophication and make lakes and downstream rivers better [6].

Plants have many important roles in constructing wetlands. For example, reeds and cattails have large root systems. These roots can take in nutrients such as nitrogen and phosphorus, and they also give space for microorganisms to live and attach. Organic substances from plant roots can change the microorganisms around the roots and make good microorganisms grow more.

Microorganisms, in constructed wetlands, are the so - called “decomposition workers”. A group of microorganisms, rich and diverse, is engendered by the contact between the substrate and plant roots. In wastewater, organic matter, nitrogen, phosphorus, and other substances are subject to breakdown and transformation by aerobic, anaerobic, and facultative microorganisms, which operate in distinct locations. Organic matter is decomposed by aerobic microorganisms into carbon dioxide and water, and ammonia nitrogen is converted into nitrate by them. Denitrification is carried out by anaerobic microorganisms, through which nitrate is reverted to nitrogen gas, enabling the removal of nitrogen.

The flow of water within constructed wetlands exerts a substantial influence on their efficacy in water purification. Wetland systems, in a majority of instances, exhibit a low velocity of flow and an extended retention duration. A low flow velocity facilitates prolonged contact among water, substrate, and plants. This extended contact provides adequate time for physical sedimentation, chemical sorption, and biological decomposition, thereby enabling the removal of pollutants and the transformation of carbon. Annually, wetlands are capable of sequestering approximately 2–5 tons of carbon per hectare, a quantity that, as Mitsch et al. assert, is 10–20 times greater than that of a heat sink [7]. Wetland systems, thus, assume crucial significance in the mitigation of climate change and

the control of pollution, especially in relation to the synergistic impacts of pollutant elimination and carbon sequestration.

## **2.2. Floodplain Restoration**

The floodplain plays an important role in the river ecosystem. It is crucial to restore their ecological functions for maintaining the health of the river and for enhancing the local ecological services. The main task of the floodplain restoration work is to let the natural water process return to the areas that were flooded. That means, the river and the floodplain can connect together from side to side and the whole ecological pattern can be established again.

The flood pulse is the main driving force in the floodplain ecosystem. In the natural situation, the pulse would cause the water level to go up and down again and again. Therefore, the floodplain would experience wet and dry periods repeatedly. The special water condition brings many ecological services for the floodplain. The study of McAcreman et al. on the River Cherwell in the UK proved that when the water flow in the floodplain is restored, the flood is better controlled. The peak flow during the flood was reduced by 10–15%, and the peak water level in the floodplain raised 0.5–1.6 meters [8]. It means that when the flood comes, the floodplain can act like a big sponge and can intake and store some floodwater. It can reduce the flood pressure for the places downstream and can protect the people and their properties.

Restoring floodplain can add more carbon into the soil and can maintain the ecological balance of the watershed. When the flood and drying take turns, the change of soil water makes the organic matter break down and change faster. At the same time, the organic matter would be covered by new sediments. They will become the stable carbon in the soil. The river networks are big channels and sediment storage for the carbon from the land. The floodplain in the river system can maintain a large amount of carbon. In the wide valley where the water is slow, the organic material can stay and build up for a long time. It means that the place can store more carbon [9]. When we restore the natural water connection and the natural flow in the floodplain, the flow can be controlled better and can reduce the pollutant at the same time. It can also store carbon for a long time.

## **2.3. Ecological Bank Protection**

Ecological bank protection is a new way to manage the river. It is occupying the place of traditional hard revetments [10]. It is also an important way to build the healthy water ecosystem. It uses a structure made of plants, gabions, and bioengineering. It puts the ecological recovery and improvement before, not only the flood control and bank protection.

Hard revetments in a traditional way commonly use strong and rigid materials to prevent soil washing away. Hard materials do not let water go through, such as concrete or stone blocks. Although they can prevent erosion, their smooth surface cannot give living space for plants and animals. This will affect the growth of plants and animals and make the water ecosystem worse. Hard revetments cannot let water and soil on the bank exchange naturally, and they cannot help the ecosystem to recover either. Ecological revetments use natural or semi-natural materials such as plants, gabions and bioengineering materials. They can make the riverbank more complicated and more diverse. In this way, they can give living space for water plants and animals and increase biodiversity [11].

The water flows around hard and ecological revetments are totally different. Their rough and permeable surface can slow down the water, so the erosion of the shore line around ecological revetments become weaker. Because of this, ecological revetments can not only prevent the soil from being washed away but also hold water during high flows and control water levels, which can weaken the water force on the bank. Plants are very important here. Their roots can fix the soil and prevent the loss of sediment. Hard revetments can stop erosion of the water bank at first. But they are very stiff materials. Under water force for a long time, they will crack, so they need to be repaired more often and the cost is higher.

Ecological revetments can give many ecological services as well. If they are built with plants, turf and gabions, they can help restore the natural ecosystem. They can help treat water, create habitat and protect biodiversity. Plant roots can enhance the soil. Through photosynthesis, plants can take in carbon dioxide from the air, and some carbon will go into the soil through the root system, and become a stable and long-term carbon store. Ecological revetments can play an important role in water management, ecological restoration and climate change mitigation. They can effectively achieve dual benefits of pollution control and carbon storage [12-13].

### **3. Synergies and Trade-offs between Water Quality and Carbon Effects**

Synergies and trade-offs between water quality and carbon effects is a vital issue in NbS. Their complexity and significance directly affect the sustainability and comprehensive benefits of ecological engineering. In this section, we analyse the synergistic mechanism of water quality and carbon effects in ecological engineering, and the trade-offs between water quality and carbon effects, and explore how to apply their benefits.

#### **3.1. Synergistic Mechanisms**

Water quality improvement and carbon effect in NbS could be. They can reduce pollutants and store carbon at the same time. In the wetland, denitrification plays an important role in removing nitrogen from water. Microorganisms change the nitrate into nitrogen gas. Therefore, nitrogen pollution of water will be lower. However, its process also can release some greenhouse gas like nitrous oxide ( $N_2O$ ). Which can reduce some carbon benefits. So, we should choose suitable plants and promote roots growth to reduce the problem. Cattails have a large root system. Because the microorganism has a good place to live, denitrification effect is better and  $N_2O$  emission is also lower.

According to the study of Smith et al. (2020), selecting good plant layout in wetlands can reduce  $N_2O$  emission about 30%. It demonstrates that NbS can provide more than one ecological benefit. By selecting suitable plant species and creating an ideal root structure, wetlands and other NbS projects can store carbon and purify water effectively [14].

#### **3.2. Trade-offs**

Water quality and carbon effect in NbS can be, but there are often trade-offs between different NbS in different ecosystems. Floodplains have shown this [15]. One aspect of the carbon storage in floodplains is that solids (organic matter trapping in soil reduces  $CO_2$  in the air). But in the environment with low oxygen, floodplains also make methane ( $CH_4$ ), a greenhouse gas that reduces the carbon benefit. So, there is a clear trade-off between carbon storage and methane release. There is a trade-off between carbon sequestration and methane emissions.

To balance this carbon–methane relationship, Hydrological measures such as intermittent flooding strategies can effectively reduce methane emissions. When flooding is on and off, the oxygen level is better, and very low-oxygen zones are suppressed, so methane reduces a lot, and carbon storage stays high. Studies proclaim that with good water control, methane can drop by about 40% while keeping high level of carbon storage [16].

Ecological revetments also have trade-offs between water quality and carbon effects. Plants and soil in the structure take in  $CO_2$  and bury carbon in the ground, which is good for climate. But the first building cost is high. Because there are materials, build and maintenance costs. To balance this, we use Life Cycle Assessment (LCA) [17] to choose better design and lower cost. By evaluating the cost and benefits of ecological revetments, it is possible to maximize carbon sequestration capacity and long-term benefits of ecological revetments while controlling investment.

### 3.3. Summary

The ways that water quality and carbon effects work together or conflict with each other are very important in NbS design and use. By choosing the right plants, managing water in a good way, and using life cycle assessment, NbS can clean water and store carbon at the same time and make bad effects smaller. In real projects, methods need to change based on different ecosystems and local conditions so that water and carbon can work together more and conflict less.

## 4. Indicator System and Evaluation Methods

Evaluating the effectiveness of Nature-based Solutions (NbS) requires a specific sound indicator system. These indicators not only measure NbS impacts on water quality and carbon effects but also provide suggestions on optimizing designs and refining measures. The following content will follow a logical sequence of "evaluation objectives—key indicators—evaluation methods—technical tools" to detail evaluation approaches for water quality and carbon effects along with their associated technical tools.

### 4.1. Evaluation Objectives and Key Indicators

The water quality indicator is the tool to check how well the key pollutants are removed from water. According to USEPA(2021), the indicators often used are Total Nitrogen (TN), Total Phosphorus (TP), Chemical Oxygen Demand (COD). TN and TP are the main cause of eutrophication. When there is too much TN and TP, the algae grow too fast and the balance of the water is destroyed. COD indicates how many organic pollutants in the water. The greater the COD, the more polluted the water. If we observe how these values change, we will know clearly if NbS make the water cleaner. This also gives an numerical way to judge the ecological benefit.

And the carbon indicator serves to check how well NbS help slow down the climate change. The indicators include carbon sink capacity (tons/hectare/year), carbon density (tons/hectare), greenhouse gas emission intensity (CO<sub>2</sub> equivalent). The carbon sink capacity is to see how well NbS can lower greenhouse gases in the air by fixing CO<sub>2</sub>. Carbon density means how much carbon in 1 unit area, so it can help us understand the carbon storage of NbS. The greenhouse gas emission intensity takes a look at the different kinds of greenhouse gases that may come out during the use of NbS and during different management scenarios. It will change all of them into CO<sub>2</sub> equivalents, so we can see the total influence on climate change.

### 4.2. Evaluation Methods and Technical Tools

In order to evaluate the effectiveness of natural solutions in water quality and carbon management, multiple assessment methods can be used. These methods include model calculation, remote sensing monitoring and field measurement based on remote sensing data.

The model calculation is based on mathematical method, and the characteristics and operating conditions of different NBS measures can be considered at the same time. For example, the "water quality carbon benefit calculation tool" developed by the U.S. Environmental Protection Agency in 2021 (see document [18]) realizes the fusion assessment of water quality and carbon indicators. By establishing a mathematical model, the comprehensive impact of various NBS measures can be quantified. In many NBS scenarios, this method is helpful to verify the ecological benefits, and its advantages include: (1) get results quickly; (2) Multiple factors can be considered at the same time; (3) It is applicable to different environment and management schemes. However, the model method needs high-quality input data support, and accurate environmental data and model parameters are indispensable, otherwise the results will be distorted.

Remote sensing technology is widely used in NBS assessment. Through satellite or UAV, remote sensing can efficiently collect a wide range of regional information, covering wetlands, forest areas and vegetation growth. This technology is particularly important when the study area or watershed is

too large to be fully covered by the field survey. Remote sensing technology can realize rapid monitoring of a large area, and can provide time series data to support cross month and cross year change observation. However, its effectiveness is limited by image resolution and time interval. In small-scale areas or areas with complex land structure, data accuracy is often insufficient.

As another method, ground-based measurement can provide direct and highly reliable information and data. The method is characterized by the use of field investigation of soil, plants and water. For example, when estimating forest carbon storage, DBH and tree height can be measured, and soil samples can be collected for carbon content testing. The data obtained from such field work are detailed and reliable, which is conducive to the assessment of ecosystem solutions at a local scale. However, this method requires a lot of manpower, time and money, and its scope of application is limited, which is only applicable to small areas. For a wide area, it is difficult to meet the demand only by relying on field data, which usually needs to be combined with remote sensing technology.

### **4.3. Cost and Land Use Analysis**

Cost and land use analysis is an important part of evaluating the feasibility and effectiveness of natural solutions. By comprehensively evaluating the cost-effectiveness, we can clearly grasp the economic impact and ecological effect of the solution.

Cost analysis includes construction cost, operation and maintenance cost and opportunity cost. The construction cost covers the cost of materials, equipment and labor, and its composition varies according to the type of project - for example, wetland restoration requires a large number of aquatic plants, while ecological revetment projects require specific rock materials. The cost of operation and maintenance involves daily maintenance, monitoring and plant care. Continuous investment is essential to maintain the function of the ecosystem. Opportunity cost refers to the loss caused by abandoning a specific opportunity. For example, the income loss caused by the conversion of farmland or commercial land to other uses.

Land use analysis focuses on the ecological space occupied by the NBS project. High intensity land occupation may affect local habitat and species reproduction. The ecological and social impacts can be assessed by investigating the land use changes (such as farmland to wetland) before and after the implementation of NBS. At the same time, by investigating the landscape connectivity, we can evaluate how the natural infrastructure changes the regional ecological network. If connectivity is strong, species migration is more convenient, and key ecological processes can continue to operate.

## **5. Planning and Operation & Maintenance Recommendations**

It is suggested that scientific planning and operation and maintenance strategies are crucial to the successful implementation of nature based solutions (NBS). The phased construction strategy and scientifically designed monitoring system are of great significance to ensure the effective implementation of NBS, achieve the maximum ecological benefits and maintain long-term operation.

### **5.1. Phased Construction Strategy**

The phased construction strategy attempts to gain the most ecological benefits by doing the project in steps and making sure each step reaches its goal. In this way, it can achieve the two goals of pollution control and carbon sequestration.

In the first phase, the work should be focused on pollution hotspots and places with high carbon sequestration potential. Pollution hotspots are the places where the most amount of pollutants are discharged. If we fix the places with the most pollutant discharge first, water quality can improve quickly and the pollution won't spread to other water bodies. Areas with high carbon sequestration potential can absorb and store large amounts of carbon. If priority is given to the development of these areas, carbon absorption and storage can be rapidly increased, thus helping to cope with climate change. Putting resources into these areas first will lay a good foundation for the subsequent stage.

The work in the medium-term phase should be extended from a single site to the whole basin. After the results of the first stage are good, the basin level construction can be planned and implemented to maintain the integrity and connectivity of the ecosystem. All parts of the basin are interrelated. Carrying out work at this scale can simultaneously consider water resources, water environment and aquatic ecosystem, promote the ecological balance between the upstream and downstream and both banks, and realize the overall healthy development of the basin.

In the later phase, the work should focus on better monitoring and more flexible management. A good monitoring system can monitor NbS projects in real time and see how the ecological benefits change. Then the managers can change their measures in time so that the projects can fit the new natural and social situation. A stronger monitoring system can also make support for managers in time.

California's "Floodplain–Wetland Connectivity Project" used this three-phase model. The first phase fixed some key areas. The middle phase was all watershed. And the later phase used long-term monitoring and more flexible management to maintain good results in pollution control and carbon sequestration [19-21]. This successful experience shows good support for the phased construction strategy in NbS implementation.

## **5.2. Design of Monitoring System**

When we use NbS to implement, we should establish a scientific, complete and efficient monitoring system. This system is used to evaluate how well the project works. And this system can give us information to guide later management. A combined "sky–air–ground" monitoring system can do observation at many scales and for a long time. And this system can give strong data support so the NbS project can run in a stable way. And this system can help manager to improve plan in time.

The "sky" means use satellite remote sensing [22]. For example, we can use Landsat series. Satellite can see large area. And satellite can watch for many years. And by looking at the remote sensing image in many years, we can see the land use, vegetation cover, and ecosystem status before and after we use NbS. This large scale information can help we know how well NbS can work. But because the satellite image can't always have very high spatial resolution. So the satellite can't see the small change very clearly. And the small pollution problem can't be seen very clearly.

The "air" means use drone (UAV). Drone can help we make up the weakness of satellite. Because drone can fly low and have high spatial resolution. And drone can go to the place that is hard to go. For example, we can use it to observe wetland and the edge of river. And drone can take the clear picture. We can see the health of plant. We can see the surface water. We can see where is the pollutant. This fine information can help we find the small problem and help we do the target management. But the drone can not fly for very long time. And the drone can't cover very large area in one time. So the drone is good to cover a small area.

The "ground" means use monitor tool in the land. Also, we should use the local people to help us observe. The ground tool, such as the sensor to measure water quality and the station to measure carbon flux. This tool can keep measure the total nitrogen, total phosphorus, and COD in many years. And these are the real time information. And these information can help we know clearly how well NbS remove the pollution and store the carbon. And at the same time, if we can use the local resident to join in the monitor. The resident can record the small change that the machine can't see. And if the local resident have some simple tool. They can report the local environment problem in time.

The integrated "sky–air–ground" monitoring system used in Seveso River [22-23] showed that this multi-level monitoring system can work. And by linking the information from remote sensing, UAV, and ground based data. The system helps adjust the management strategy in real time. So this system can ensure the continuous optimization and long-term sustainability of NbS projects. And this system can maximize the ecological and social benefits of NbS projects.

## 6. Conclusions

In the current campaign to control water pollution and carbon sequestration, nature based solutions (NBS) show great potential. The integration of ecological restoration and hydrological regulation enables NBS to provide a wide range of ecological and social benefits. In the practical project application of NBS, it is necessary to carefully weigh multiple trade-offs, including the balance between water quality and carbon storage, the trade-off between cost-benefit and benefit, and the coordination of ecological and social impacts. The restoration of natural ecosystems such as wetlands and floodplains enables NBS to control pollution and store carbon dioxide, making it an ideal solution for watershed management and environmental remediation. The CO<sub>2</sub> absorption capacity of vegetation and the long-term carbon storage characteristics of soil make the nature based solutions not only purify water, but also participate in climate change mitigation.

However, challenges and uncertainties remain. The linkage between water treatment and carbon sequestration may lead to unexpected consequences such as methane emissions or rising construction costs in the early stage, highlighting the need to optimize the design and management of natural solutions. Future work can focus on optimizing hydrological regulation, accurately selecting plant species and improving matrix design. Through these means, nature based solutions can remove pollutants more efficiently while reducing greenhouse gas emissions. Integrating ecological, hydrological and economic considerations to ensure the efficiency and cost-effectiveness of the NBS project is crucial, which will achieve synergy between environmental and economic objectives.

In view of the increasing support in policy and market areas, the possibility of accelerating the development of natural solutions does exist. The expansion of the global carbon market and the increasing importance of China's initiatives such as "realizing the value of ecological products" make it possible for nature based solutions to become an important link between carbon sequestration and water quality management.

## References

- [1] Mariana Marchioni, Franco Raimondi, Gianfranco Becciu, Claudia Dresti, et al. Nature-based solutions for watershed management: An investigation on water-related ecosystem services delivery at multiple spatial scales. *Ecosystem Services*, 2025, 73: 101718. <https://doi.org/10.1016/j.ecoser.2025.101718>
- [2] European Commission. A Blueprint for Resilience: Nature-Based Solutions for Europe. Publications Office of the European Union, 2021.
- [3] Sadat-Noori M., Andersen M. S., Rutledge H., Glamore W. Coastal Wetland Restoration Effects on Carbon Dynamics: A Groundwater Perspective. *Reviews of Geophysics*, 2025, 63(3). <https://doi.org/10.1029/2025rg000895>
- [4] Irwin N. B., Irwin E. G., Martin J. F., Aracena P. Constructed wetlands for water quality improvements: Benefit transfer analysis from Ohio. *Journal of Environmental Management*, 2018, 206: 1063–1071.
- [5] Dimuro J L , Guertin F M , Helling R K ,et al.A Financial and Environmental Analysis of Constructed Wetlands for Industrial Wastewater Treatment[J].*Journal of Industrial Ecology*, 2015, 18(5):631-640.DOI:10.1111/jiec.12129.
- [6] Bechmann M. E., Berge D., Eggestad H. O., Vandsemb S. M. Phosphorus transfer from agricultural areas and its impact on the eutrophication of lakes—two long-term integrated studies from Norway. *Journal of Hydrology*, 2005, 304(1–4): 238–250. <https://doi.org/10.1016/j.jhydrol.2004.07.032>
- [7] Mitsch W. J., Bernal B., Nahlik A. M., et al. Wetlands, carbon, and climate change. *Landscape Ecology*, 2013, 28: 583–597. <https://doi.org/10.1007/s10980-012-9758-8>
- [8] Acreman M. C., Riddington R., Booker D. D. J. Hydrological impacts of floodplain restoration: a case study of the River Cherwell, UK. *Hydrol. Earth Syst. Sci.*, 2003, 7: 75–85. <https://doi.org/10.5194/hess-7-75-2003>
- [9] Sutfin N. A., Wohl E. E., Dwire K. A. Banking carbon: A review of organic carbon storage and physical factors influencing retention in floodplains and riparian ecosystems. *Earth Surface Processes and Landforms*, 2016, 41: 38–60.
- [10] EcoShape. Creating rich revetments. EcoShape, 2024.
- [11] Sanitwong-Na-Ayuthaya S., Saengsupavanich C., Ariffin E. H., Ratnayake A. S., Yun L. S. Environmental impacts of shore revetment. *Heliyon*, 2023, 9(9): e19646. <https://doi.org/10.1016/j.heliyon.2023.e19646>
- [12] Chong L. Hydraulic Characteristics of Emerged Rigid and Submerged Flexible Vegetations in the Riparian Zone[J]. *Water*, 2021, 13.DOI:10.3390/w13081057.

- [13] Smith J., et al. The role of vegetation in mitigating nitrous oxide emissions in wetland ecosystems. *Environmental Science & Technology*, 2020, 54(12): 7521–7532.
- [14] Cui S., Liu P., Guo H., et al. Wetland hydrological dynamics and methane emissions. *Commun Earth Environ*, 2024, 5: 470. <https://doi.org/10.1038/s43247-024-01635-w>
- [15] Liu W., Sun F., Sun S., Guo L., Wang H., Cui H. Multi-scale assessment of eco-hydrological resilience to drought in China over the last three decades. *Science of The Total Environment*, 2019, 672: 201–211. <https://doi.org/10.1016/j.scitotenv.2019.03.408>
- [16] Jiangbo X., Xiong W., Wei Q., Shaowei W., Sheng S., Danni Z., Xinyu C. Life cycle carbon emission assessment for ecological protection slopes: Focus on construction and maintenance phases. *Journal of Cleaner Production*, 2025, 497: 145174. <https://doi.org/10.1016/j.jclepro.2025.145174>
- [17] USEPA. Benefit Accounting of Nature-Based Solutions for Watersheds: A Guide. Environmental Protection Agency, 2021.
- [18] Fujian Provincial Government. Bamboo Forest Carbon Sink Project: A Case Study in Sanming City. Policy Brief, 2022.
- [19] Liu L. Y., et al. Satellite Remote Sensing Monitoring Methods, Progress, and Challenges for the Global Carbon Inventory. *Journal of Remote Sensing*, 2022, 26(2): 253–267.
- [20] California Department of Water Resources. Floodplain-Wetland Connectivity Project. 2020.
- [21] Reddy K. R., et al. Denitrification in Wetlands: Processes, Kinetics, and Greenhouse Gas Implications. *Critical Reviews in Environmental Science and Technology*, 2019, 49(12): 1021–1068.
- [22] Wulder M. A., Roy D. P., Radeloff V. C., Loveland T. R., Anderson M. C., Johnson D. M., et al. Fifty years of Landsat science and impacts. *Remote Sensing of Environment*, 2022, 280: 113195. <https://doi.org/10.1016/j.rse.2022.113195>
- [23] Gruppo CAP, BrianzAcque, Como Acqua. Seveso Stream: A new project to preserve local river ecosystem using drones. *Aqua Publica Europea*, 2021.