Research on Theoretical Framework and Implementation Path of Green Maintenance of Inland Waterway

Zhaoxing Han[1,2,3], Chaohui Zheng[1,3], Wenxi Jiang[1,3], Jinxiang Cheng[1,3(✉)], and Liguo Zhang[1,3]

[1] Transport Planning and Research Institute, Ministry of Transport, Beijing 100028, China
chengjx@tpri.org.cn
[2] Tsinghua University, Beijing 100084, China
[3] Ministry of Transport, Laboratory of Transport Pollution Control and Monitoring Technology, Transport Planning and Research Institute, Beijing 100028, China

Abstract. Inland waterway maintenance could guarantee channel dimension and maintain navigation conditions. With the continuous increase of channel mileage, inland waterway maintenance gradually became more frequent and scale-up, as well. The maintenance activities would inevitably cause adverse environment impacts on waters, and disturb the ecosystem. Therefore, it was necessary to implement the green maintenance to reduce the negative impacts in the maintenance process. However, the research on green maintenance of inland waterway was not systematic and impeccable. This paper proposed a solution for the problem above. Firstly identified the environmental impacts of maintenance based on the analysis of maintenance process. Secondly the notion and principles of green maintenance are put forward, according to the concept of green transportation and green channel. Thirdly, the study constructed the technical framework of green maintenance and summarized the major measures for green maintenance. An last, implementation path of green maintenance was addressed including standard-setting, establishing system management, technology research and development, etc.

Keywords: Inland waterway · Green maintenance · Environment impact · Theoretical framework · Implementation path

1 Introduction

Inland navigation shipping has the comparative advantages of large traffic volume, low freight rate, low energy consumption, less land occupation and light pollution (Yuan Yuan et al. 2017). It is an important part of the comprehensive national transport network (the comprehensive national transport network planning, 2021) and the main path for the transportation industry to achieve carbon peak (carbon peak action plan before 2030, 2021). Inland waterway is the main support for the development of inland navigation. Since the 13th five year plan, the construction of inland water transport

Y. Li et al. (Eds.): PIANC 2022, LNCE 264, pp. 155–168, 2023.
https://doi.org/10.1007/978-981-19-6138-0_14

infrastructure has been strengthened. And an inland waterway network including the Yangtze River main line, Xijiang River shipping trunk line, Beijing Hangzhou canal, Yangtze River Delta and Pearl River Delta high-grade waterway network has been basically established, with the connection between trunk and branch lines, the river and the sea. (Ministry of Transport 2021). By the end of 2020, the navigation mileage of inland waterways in China reached 127700 kilometers, including 14400 kilometers of high-grade waterways of class III and above, accounting for 11.3% of the total mileage (Fig. 1) (2020 statistical bulletin on the development of transportation industry, 2021). According to the outline of comprehensive national transport network planning, it is expected that by 2035, the national high-grade waterway will reach about 25000 km.

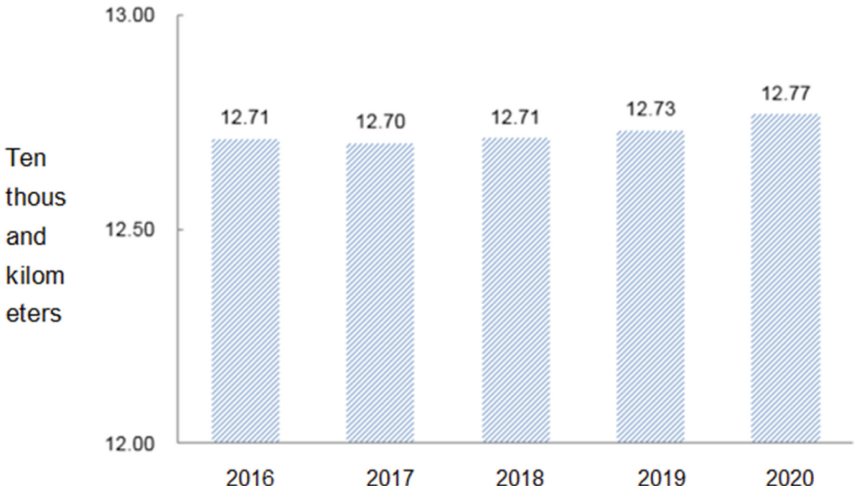

Fig. 1. Mileages of inland waterway in China from 2016 to 2020

Inland waterway maintenance is the basic work to keep the navigation dimensions and ensure the safety of ship navigation. With the continuous increase of navigation mileage of inland waterway, inland waterway shipping has gradually shifted from large-scale construction to large-scale maintenance, and the work of waterway maintenance is becoming more and more arduous. Generally speaking, inland waterway maintenance includes regular measurement of water depth, adjustment and maintenance of navigation aids, temporary dredging of local navigable river sections, protect and repair of inland waterway regulation buildings, etc. (technical code for channel maintenance, 2021). The above work involves many engineering and technical measures, which resulting in construction operations and inevitably producing energy consumption, sewage and waste gas emission and ecological disturbance. Therefore, in June 2021, the Ministry of transport issued the technical guide for green maintenance of inland waterway to guide the ecological and environmental protection in waterway maintenance. However, the current theoretical framework of green maintenance is not clear, the energy-saving and environmental protection technology system in inland channel maintenance has not been established, and the specific engineering and

technical measures are still in the initial research and development stage. To solve this problem, based on the specific content of channel maintenance, this paper identifies its impact on the ecological environment, puts forward the main measures of inland waterway maintenance, and clarifies the implementation path of green maintenance.

2 Impact of Inland Waterway Maintenance on River Ecosystem

2.1 Inland Waterway Maintenance

Channel maintenance usually includes maintenance dredging, regulating structures maintenance and navigation aids maintenance. Table 1 combs the typical construction processes of different waterway maintenance works.

Table 1. Construction process of typical channel maintenance method

Construction content	Main process
Maintenance dredging	construction preparation → pre dredging survey → dredging operation → dredged material transportation → dredged material treatment
Waterway regulating structures maintenance (spur dike maintenance)	construction preparation → fixed-point riprap → demolition of damaged spur dike part
Waterway regulating structures maintenance (revetment and bottom protection)	construction preparation → sinking mattress → water riprap
Navigation aids maintenance	site inspection → navigation acids position adjustment → navigation aids cleaning, derusting and painting → parts replacement

2.2 Environmental Impact

1) aquatic environment impact

In terms of water regime impact, dredging and excavation will cause hydrodynamic variation and thus brings aquatic habitats changes. In terms of water quality impact, it will be deteriorated by the underwater construction work such as sinking mattress, riprap and dredging which increase the concentration of suspended solid. Feng (2017) simulated the diffusion of suspended solids during the dredging works of Taipingkou waterway in the middle reaches of the Yangtze River. It was shown that the diffusion range of which increment of suspended solids was greater than 10mg/L was no longer than 3km. The field monitoring of typical waterway regulation projects shows that the influence of sinking mattress and riprap can be control within the 200m of the construction site. Suspended solids will also be increased by the sediment overflow during the dredged material transportation. Field observation and experiments showed that the sediment concentration in the turbidity zone formed around the vessel is 3 ∼

10 times higher than before. However, due to the rapid settling velocity, the sediment concentration has decreased to about twice as much as before 20 minutes after construction completion. (Dai et al. 1997). In the maintenance of navigation aids, the process of cleaning, derusting and painting is carried out in water. Toxic chemicals produced during the rust cleaning and painting of navigation aids may cause water pollution.

2) Ecological impact

Sinking mattress and riprap directly occupy the habitat of benthic organisms, resulting in their direct burial and coverage. Moreover, surrounding fish will be dispersed due to the disturbance. However, studies have shown that the complex flow conditions formed by sinking mattress and enrockment have a contribution to the formation of artificial reef effect, which can ensure the living space of fish and providing them with spawning grounds, wintering grounds and feeding grounds (Chang et al. 2019). The increasing concentration of suspended solid caused by wading construction brings adverse impact on plankton, benthos and fishery resources. However, the water quality will recover to the original level very soon as sediment can quickly settle down. So this kind of impact could be regarded as short-termed and temporary (Xie and Ding 2020). In addition, excavation directly destroys the habitat of benthos and causes them to be buried (Ma Yi 2014). Organic matters and heavy metals in bottom sludge will be released to water bodies, and endanger human health through food chain transfer and biological amplification effect (Zuo et al. 2014). Currently the utilization rate of dredged soil is low and most of it is directly dumped to the designated dumping area (Fu et al. 2011), which will cause resuspension of sediment and bury benthos in the short term. Land filling of dredged soil occupies land resources, and pollutants lead to potential ecological risks through rainwater runoff and infiltration (Zuo et al. 2014).

3) Other effects

The construction wastes, batteries, solar panels, rust and other wastes generated from the replacement of navigation aids will poses a threat to the environment if they are improperly disposed (Yan 2017). In addition, regular sailing inspection triggers huge air pollutants and greenhouse gas emission as a result of fuel consumption, which put great pressure on the goal of carbon emission reduction (Yan 2017). In addition, the mechanical vibration noise generated by vessels will give rise to the hearing damage of fish and affect the foraging behavior (Liu Dan et al. 2021), especially pose a great threat to the communication and hearing of the Yangtze finless porpoise (Zhang Tianci et al. 2018). Fuel oil leakage、improper disposal of vessel domestic sewage, oily sewage and garbage will bring about water pollution and damage the aquatic ecology as well.

The environmental impact of inland waterway maintenance was showed in Fig. 2.

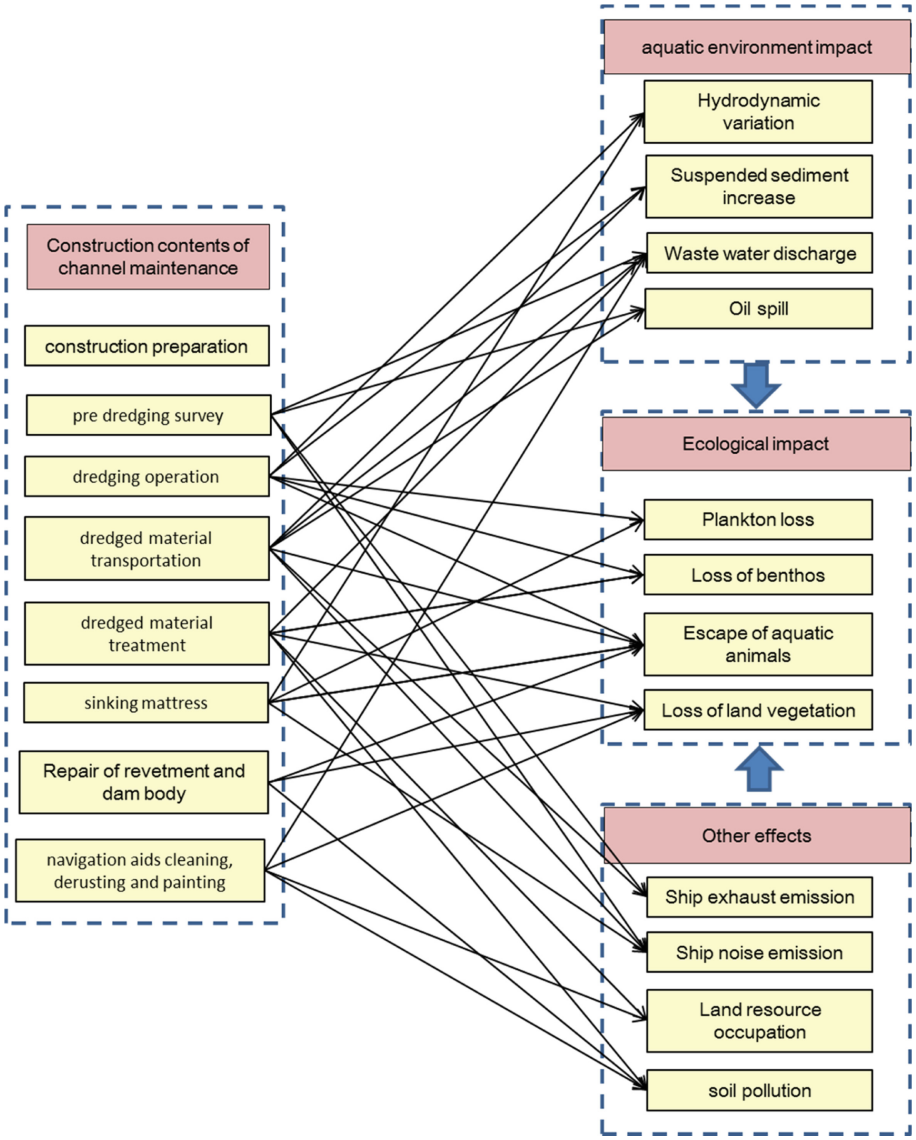

Fig. 2. Environmental impact of inland waterway maintenance

3 Theoretical Framework of Green Conservation of Inland Waterway

3.1 Notion of Green Conservation of Inland Waterway

The demand for waterway transport has always been a very important part of river comprehensive development all over the world. For example, Germany puts waterway

transport in the first place in river development, and France implements the comprehensive development plan of Rhone River, which is led by waterway transport, power generation and irrigation. The same situation is also true in the southern water system of China. In order to further improve the water transport capacity and economic benefits, many large rivers in the world are carrying out or have been carried out large-scale waterway regulation projects. The traditional waterway construction and maintenance mainly focus on effectiveness and stability of the projects, and do not much consider the ecological and environmental impacts. As people pay more and more attention to the environment, the industry began to explore the notion of ‵green channel'. Yan et al. (2018) believe that ecological channel refers to integrating the navigation function of channel with the function of river ecosystem, and maintaining the structure and function of navigation river ecosystem on the basis of playing the basic function of channel. Liu Xinyi (2017) believes that combining the navigation function of channels with the original water ecosystem can not only hold the basic function of safe, convenient, smooth and efficient water transport, but also have a reasonably balanced ecosystem structure, stable self-regulation and recovery ability and pleasant overall landscape effect, so as to finally realize green and sustainable development. Liu Junwei (2015), Lei Guoping (2016) and Liu huaihan (2020) focus on the Yangtze River, which is the longest and highest navigable river in China, with discussion of the theory and key technology for the construction of ecological channel. In recent years, China has also carried out positive practices in green channels, such as the channel regulation project of Jingjiang river section in the middle reaches of the Yangtze River, the 12.5 m deep-water channel project below Nanjing of the Yangtze River, the Beijing Hangzhou canal, etc.

Channel maintenance is an important link in the whole life cycle of the channel and a necessary guarantee for the channel to continue to give full play to its transport function. Clarifying the scientific connotation of ecological channel is the premise and foundation of ecological channel research. ‘The technical requirements for assessment of green transportation facilities Part 3: green channel’ (JT/T 1199.3-2018), formulated in 2018, defines green channel as: within the whole life cycle of the channel, take sustainable development as the concept, carry out technical and economic analysis and environmental impact assessment; through reasonable planning, design, construction and maintenance management, reduce resource and energy consumption, reduce pollution emissions, protect the ecological environment to the greatest extent, pay attention to the improvement of quality construction and operation efficiency, and build a channel for harmonious development with resources, environment, ecology and society. Among them, specific evaluation indicators is set up for channel maintenance, covering whether the construction and materials used for channel maintenance are environmental-friendly, whether the maintenance frequency is appropriate, whether the waste disposal is reasonable, etc. Since this standard focuses on design and construction stages, the requirements for maintenance are not integrated. It defines whether the specific channel maintenance operation “reaches green”, but it does not answer “how to achieve green”. In order to make up for these deficiencies, the Ministry of transport issued the technical guide for green maintenance of inland waterways in

2021, which gives the definition of green maintenance of waterways, that is, on the basis of ensuring the functions of waterways, implement the concept of environmental protection, energy conservation and carbon reduction, and apply new materials, equipment, processes and technologies to reduce the impact on the ecological environment.

In general, the discussion and practices of green channel have developed rapidly in recent ten years. In general, the discussion and practices of green channel have promoted rapidly in recent ten years. The understanding of green channel has also experienced many changes. One is altering from simply doing good environmental management of channel construction to paying attention to the coordination of construction and environment, and afterwards to integrating the concept of ecological civilization and sustainable development into construction. Another is altering from only optimizing the construction scheme to concerning the harmony between shipping and river ecosystem in the whole life cycle of channels, which involves maintaining the biodiversity of aquatic species, maximizing the ecological services of river ecosystem, ensuring the health and sustainability of rivers, and improving the safety carrying capacity of the waterway.

3.2 Principles of Green Maintenance of Inland Waterway

Green channel maintenance is an important embodiment of green channel, and the sustainable development concept of harmonious coexistence with natural ecology should be fully implemented. Therefore, the overall principle of green maintenance is to meet the needs of channel use to the greatest extent with the least resource consumption and the least impact on environment. Specific principles include (Fig. 3):

1) Greening maintenance operation. For example, construction activities such as maintenance dredging and obstacle removal should be arranged without long-term and severe impact on river water quality and ecological function.
2) Ecologicalization of structures and materials. On the premise of meeting the use function, new structures and materials can be used to make up for the interference of the channel to the ecosystem.
3) Minimizing material and energy consumption. It includes reducing the direct consumption of consumables, materials & equipment, and selecting energy-saving appliances.
4) Reducing pollution discharge from maintenance activities. For example, activities such as patrol, mapping and inspection, and the use of ships and vehicles also produce some pollution, which should be minimized.
5) Under the goal of “double carbon”, the ecological function of the channel should be better through conservation as far as possible, so as to enhance the positive role of the river in climate change.

Fig. 3. Principles of green maintenance of inland waterway

3.3 Research Framework for Green Conservation of Inland Waterway

The research on the green maintenance of inland waterways can be divided into four aspects: basic theoretical research, ecological impact mechanism research, green conservation technology research & development, and implementation path research (Fig. 4.).

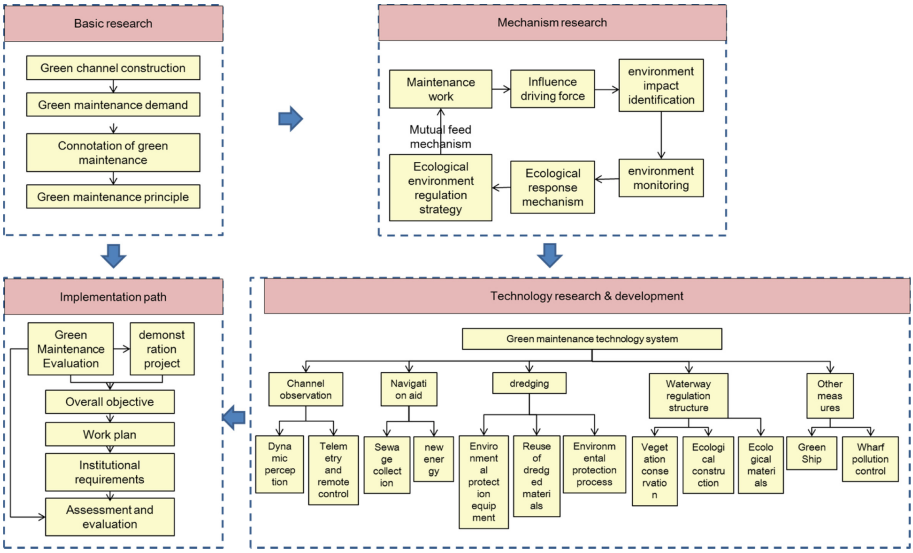

Fig. 4. Theoretical framework of green conservation of inland waterway

The basic research focuses on analyzing the specific needs of channel green maintenance according to the relevant definitions and contents of green channel, so as to put forward the concept and connotation of green maintenance and the basic principles of green maintenance. Mechanism research starts with the content of maintenance work, analyzes the main driving forces of various channel maintenance behaviors on the impact on the ecological environment, so as to identify the ways,

scope and degree of the impact on the ecological environment, and studies the response mechanism of the ecological environment to channel maintenance. Based on the environmental monitoring and ecological investigations, mitigation measures and regulation strategies for maintenance work was put forward.

Technology research & development will focus on forming a green maintenance technology system according to the ecological environment impact and response mechanism, including channel observation, navigation aid maintenance, maintenance dredging, channel regulation, and other measures. In terms of implementation path, according to the results of basic research, mechanism research and technological research & development, we will build green maintenance evaluation standards and demonstration projects, so as to put forward the overall goal of green maintenance and incorporate it into the maintenance work plan. With the increase of technical maturity, the relevant maintenance technical requirements are gradually incorporated into the maintenance management system and technical specifications. According the result of green maintenance assessment, the green evaluation standard of green maintenance is dynamically improved.

4 Major Measures for Green Maintenance of Inland Waterway

Three maintenance activities that have the most significant impacts on the environment is discussed, including dredging, regulating structure rectification and navigation aid maintenance. The major measures for these activities are listed in Table 2.

4.1 Dredging

In general, the main adverse environmental impact of dredging is the shapely increased concentration of suspended solids (SS). The diffused SS may consequently pollute the water sources of residential areas and interfere the growth of aquatic organisms. Green measures so aim on SS control. Compared with traditional dredgers, grab dredgers, drag suction dredgers, suction cups and cutter suction dredgers are more environmental friendly. For example, the cutter suction dredger cuts the underwater medium by the cutter and then pumps the mud to the designated place; the drag suction dredger generates mud by joint force of dredger movement and underwater rake head, and the mud is also pumped away (Liao Yongtao 2016). The positive pressure of the mud pump would greatly reduce the diffusion of mud. The use of environmental rake head would further enhance the effectiveness of SS control (Ren et al. 2017). For example, drag suction dredgers adopt the rake head with eddy current protective cover or the rake head installed with a closed plate; cutter suction dredgers adopt disc type, shovel suction type and screw type reamers; grab dredgers adopt fully enclosed leak proof grabs. Dredging ships, vehicles and equipment powered by fuel oil will have air pollution. Using the ships, vehicles and equipment that meet emission standards or electric power is an effective measure to reduce these air pollution.

The additional environmental problem of dredging is the disposal of dredged soil. Randomly discarded dredged soil is a kind of pollution, but it is possible to recycle

Table 2. Main measures for green maintenance

	Air pollution control measures	Water pollution control measures	Ecological protection and restoration measures	Resource conservation and intensive utilization	Other measures
Maintenance dredging	-Use ships, vehicles and equipment that meet the exhaust emission limit standards	-Select dredging ships or dredging equipment with environmental protection function; -Dredging vessels use machines and tools to manufacture relatively few suspended solids and control the diffusion range of suspended solids; -As far as possible, the loading shall not overflow. The operation with overflow can adopt the form of underwater overflow and other relatively environmental protection -Anti pollution enclosure for water source		-Classified utilization of dredged soil -Dredged soil shall be transported out without being thrown and sealed;	-Control plane scale, silt preparation depth and operation time, and strictly control over excavation; -Optimize the dredging scheme to avoid environmentally sensitive areas; -Positioning technology and visualization technology are used to assist precise dredging -Equipped with pollution emergency equipment
Renovation and maintenance of buildings			-Increase environmental protection or ecological functions for general renovation buildings, if possible -The function or local improvement of repairing defects for ecological regulation buildings		-Select plants with barren resistance, flooding resistance, drought resistance, easy reproduction, high survival rate, developed roots and easy sprouting; -The selection of exotic plants shall be confirmed to have no potential ecological hazards
Aids to navigation maintenance	-Use ships, vehicles and equipment that meet the exhaust emission limit standards -Navigation aids of remote control and telemetry system are adopted to reduce on-site cruise inspection;	-If possible, the buoy shall be ashore cleaned, painted and repaired -Control the use of paint -Collect and clean the sewage, waste and oil pollution of navigation aids by categories;	-Only trim the trees around the shore mark that block the intervisibility range;	-choose environmentally friendly products and materials with high strength, corrosion resistance and aging resistance when replacing batteries and other consumables -Energy saving lamps and solar energy are used for power supply, when the lighting duration and brightness of navigation aids are enough;	-Local materials, or natural degradable raw materials; -Dispose the collected solid wastes (such as old batteries, attachments, etc.) according to the requirements of national regulations

dredged soil. The actual use of dredged soil is closely related to its physical and chemical elements (Xie and Ding 2020). According to the technical status, the clean dredged soil can be used for land reclamation, ecological beach consolidation, sand pillow filling, artificial island construction or wetland construction, etc. For example, in the regulation of the north channel of the Yangtze River Estuary, the throwing and blowing process of secondary transportation is adopted to blow and fill the dredged soil to the water area of Hengsha east beach for siltation promotion. Most of developed countries have formulated a complete set of policies and technical standards related to the utilization of dredged soil (Zhao et al. 2013). The contaminated dredged soil shall be transferred and treated on shore. The pre-treatment shall be carried out according to the degree of pollution. The dredged soil that is identified as hazardous waste shall be delivered to a qualified treatment enterprise. When the dredged soil has to be discarded partly, the setting of the dumping area should avoid the ecologically sensitive areas such as nature reserves, fish spawning grounds, feeding grounds, wintering grounds and scenic spots, and set up anti-pollution screens and anti-pollution curtains to reduce the scope of influence.

Optimizing the dredging scheme prior to operation is the basic work. A scientific dredging scheme should avoid environmentally sensitive areas and plan a reasonable dredging scale, silt preparation depth and operation time. Auxiliary technologies such as positioning technology and visualization technology can ensure the accurate implementation of dredging scheme and control overbreak to the greatest extent (Xie and Ding 2020).

4.2 Regulating Structure Rectification

Regulating structures are permanent, which will not continuously generate water pollution or air pollution. Rectification of regulating structure focus on enhancing the effectiveness of ecological protection. For general dams, revetments, slope protectors, beach protectors, bottom protectors, the structural form can be transformed to improve the ecological function, with the consideration of original structure, flows, scouring and silting, damage degree, environmental requirements, habitat needs, etc.. For ecological regulating structures, it is mainly to maintain the original structure, materials and vegetation coverage. When it is found that the function has obvious defects, partly rectification is possible. Vegetation coverage is the most commonly used way to reflect the ecological function of regulating structures (Cao et al. 2018; Chen 2017). In order to coordinate with the surrounding ecosystem, native plants or exotic plants without potential ecological hazards should be selected. In addition, the selected plants have the advantages of barren resistance, flood resistance, drought resistance, easy reproduction, high survival rate, developed roots and easy germination, which can reduce the loss of plants, but they should still be inspected and replanted after the flood season.

4.3 Maintenance of Navigation Aids

In terms of environmental pollution, buoy maintenance is the most likely to cause adverse environmental impact on the river. Therefore, it is primary to transfer the buoy to the shore maintenance base for centralized cleaning, painting and repair. The

sewage, oil stain, garbage, etc. produced during operation can be conveniently collected and sent for appropriate treatment. Local materials or natural degradable raw materials are also advocated to reduce the difficulty of subsequent treatment and long-term adverse impact on the environment. When on-shore maintenance is not feasible, it is necessary to take some measures to prevent pollutants from entering the water body. Similar to dredging, it is better to use cleaner ships, vehicles and equipment for navigation aids maintenance, in order to reduce air pollution. Another measure is to promote the new technology of remote control and telemetry instead of on-site inspection, resulting in the less use of vehicles and ships. The increasingly mature remote control and telemetry technology of navigation aids enables the management department to monitor the location and energy status of navigation aids in real time. Compared with the timing incandescent lamps and batteries are mainly used, it is feasible to change the "monthly inspection" rule (Yan 2017).

Navigation aids continuously consume energy and modules (batteries, lamps, standards, calibration, reflective films, etc.). Correspondingly, environmental-friendly products and materials with high strength, corrosion resistance and aging resistance can decrease consumption. For example, the standard body made of non-metallic materials such as FRP and high-strength polyethylene can be free from maintenance within $5 \sim 10$ (Yan 2017). In addition, the use of energy-saving lamps and solar power supply can reduce daily energy consumption.

5 Implementation Paths on Green Maintenance of Inland Waterway

5.1 Develop Green Maintenance Evaluation Standards

With the gradual deepening of the research on the mutual feeding mechanism between the construction & operation of inland waterway and the river ecological environment, the evaluation standard of green maintenance of inland waterway can be established according to the ways, degrees and mitigation measures of ecological environment impact caused by waterway maintenance. The green maintenance work of the channel can be scored to determine the green level, according to the characteristics of the maintenance practice, the application of green maintenance technology, the degree of technological innovation, etc. The introduction of green maintenance evaluation standards can make horizontal and vertical comparison of green maintenance practices in different work contents and regions, so as to effectively guide and promote the green maintenance of inland waterways.

5.2 Carry Out Green Maintenance Demonstration Project

The channel maintenance work has obvious regional characteristics. The maintenance priorities and main contents of mountainous channels, plain river network channels and tidal channels are quite different. The channel maintenance of natural channels and artificial canals are also significantly diverse. Therefore, it is suggested to build green conservation demonstration projects, establish industry typical benchmarks, and build a

typical case base of channel green conservation for different regions and different types of typical segments, so as to provide reference for other channels to carry out green conservation.

5.3 Form Green Maintenance System Specification

With the increase of technical maturity and the standardization of operation, it is necessary to gradually integrate the concept, technology and measures of green maintenance into the daily maintenance of inland waterways, clarify the technical requirements and specific measures of green maintenance in the annual maintenance plan, and ensure the capital investment. At the same time, it is necessary to revise and improve the existing industry standard technical specification for waterway maintenance JTS/T 320-2021), incorporate the technical measures related to green maintenance into the technical specification, and institutionalize and daily green maintenance of inland waterways.

5.4 Carry Out Research and Development of Green Maintenance Technology

In view of the maintenance needs of inland waterway, it is necessary to continuously improve and optimize the existing green maintenance technical measures, further develop and apply the maintenance technology with low pollution emission, low energy consumption and low ecological interference, so as to continuously enrich and expand the green maintenance technology system of inland waterway. For example, we can develop and build intelligent channel sensing system, and dynamically sense the change of channel water depth in combination with mobile facilities (such as UAVs) and fixed facilities (such as navigation aids and channel hydrological stations), so as to reduce energy consumption and pollution emission caused by channel survey. It is necessary to develop low impact dredging equipment and processes according to the characteristics of maintenance dredging sediment, so as to meet the water quality requirements of ecologically sensitive river sections such as water sources and protected areas.

References

Cao MX, Shen X, Ying HH (2018) Study on ecological structures of waterway regulation in the Yangtze River below Nanjing. Port & Waterway Engineering 1:1–11

Chang LH, Xu B, Zhang P, Tang W (2019) The influence of spur dikes for deep-water channel regulation on fish habitat. Journal of Water Conservancy 515(09):1086–1094

Chen DQ (2017) Study on green channel regulation buildings in the middle and lower reaches of the Yangtze River. The Fortune Times 10:144

Chen YR (2021) Practice and reflection on green waterway construction on jingjiang river section in the middle reaches of yangtze river. Yangtze River Technology and Economy 15 (02):51–53

Dai CL, Zhang JQ, Zheng YG, Zeng FT (1997) Experimental analysis on the impact of loading overflow construction of self-propelled trailing suction dredger on the environment of nearby waters. Water Transportation Engineering 10:59–62

Feng TH (2017) Numerical simulation of suspended solids diffusion in Yangtze River Channel Dredging. Green Technology 08:47–51
Fu G, Zhao DZ, Cheng HF (2011) Comparison and analysis of comprehensive utilization of dredged materialsat home and abroad. Port & Waterway Engineering 451(03):90–96
Ju T, Zhang TC, Wang ZT, Xie Y, Zheng CH, Wang KX, Wang D (2017) Characteristics of riprapping underwater noise and its possible impacts on the Yangtze finless porpoise. Acoustic Technology 36(06):580–588
Liao YT (2015) Exploration on Energy Conservation and Emission Reduction of Dredging Ships Based on the Improvement of Dredging Machines and Tools. Dalian Maritime University
Liu HH, Lei GP, Yin SR, Kuang HW (2016) Ecological measures and technical prospect of Yangtze River trunk channel regulation. Water Transportation Engineering 511(01):114–118
Ma Y, Cheng TJ (2014) Influence of waterway regulation engineering on water ecological environment and countermeasures. Port & Waterway Engineering 497(11):115–119
Ministry of transport. In 2035, China will basically build a "four vertical, four horizontal and two networks" national high-grade waterway of 25000 kilometers. [EB/OL].
Ministry of transport: JTS / T # 320-2021 technical specification for channel maintenance. People's Communications Press, Beijing (2021)
Ren XL, Li X, Xiang GS (2017) Thoughts on the development of new environmental protection technology of dredger. Ship Materials and Market 147(05):59–64
Wang KX, Wang D (2015) Analysis of Impact of Waterway Adjustment Activities on Yangtze Finless Porpoise and Mitigation Measures. Environmental Impact Assessment 216(03):13–17
Xie PJ, Ding ZY (2020) Analysis of ecological impact and Countermeasures in the construction of inland waterway dredging. China Water Transport 20(01):128–129
Yan CZ (2017) On strengthening environmental protection in navigation mark management. Navigation 228(03):59–60
Yan DH, Dou P, Cui BS, Xie T, Wang H (2018) Theoretical framework kand key issues in cological inland waterway construction. Journal of Beijing Normal University (Natural Science) 54(6):755
Yuan Y, Zhao L (2017) Comparative analysis of inland waterway maintenance development at home and abroad. China Water Transport 17(01):42–45
Zhao DZ, Liu J, Cheng HF, Wang ZZ (2013) Current situation and future prospect of dredged material disposal in the Yangtze estuary deepwater navigation channel. Hydro-Science and Engineering 2:26–32
Zuo JP, Chen YM, Zhou JX (2014) Discussion on ecological dredging of inland waterway based on ecological protection. China Water Transport 14(03):176–178