

# A Review Study on Energy Dissipators for Hydraulic Structures: Hockey Groynes in River (Wave Breakers) as a Case Study

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## Abstract

Increasing challenges facing natural water systems and hydraulic structures, understanding river wave behavior and managing them has become a priority in the design and implementation of water control projects. These waves are often caused by sudden flow changes, such as gates opening or flooding. They are dynamic phenomena with high hydraulic energy, which can cause bed and bank erosion and endanger water structures. Hence, the need to implement effective techniques to disperse and dissipate this energy has emerged. The most prominent is using bottom groynes positioned downstream (d/s) of the hydraulic structures, with a focus on optimizing flow distribution and reducing local scour, a standard engineering solution for reducing flow velocity and creating energy dissipation zones within the stream. Hockey groynes, are an advanced model of these barriers, with their curved design being more effective at dissipating waves and mitigating their effects in safe and stable ways. Flow control also represents a key regulatory basis for managing water flow, whether through gate operating systems or physical interventions in the riverbed. This control is significant in locations with variable natural flows, such as dam outlets, where operational errors can generate destructive shock waves. In this context, bottom barriers and dykes are installed at carefully considered intervals to gradually reduce water velocity and optimize the distribution of energy and velocity across the river section. This contributes to bed protection and enhances longitudinal and lateral flow stability. Studies confirm that dispersing hydraulic energy through these structures effectively reduces engineering and environmental losses. Furthermore, adopting flexible designs based on accurate hydraulic modeling helps improve performance and integration with the characteristics of the local water system. Therefore, combining theoretical knowledge of hydraulic phenomena with the use of innovative methods such as hockey dykes represents an advanced step toward achieving water resource sustainability and protecting river infrastructure from risks associated with flow changes and energy surges.

**Keywords:** River Waves, Hockey Groynes, Flow Control, Environmental Hydraulics, Hydraulic Power.

## دراسة مراجعة لمشتتات الطاقة للمنشآت الهيدروليكية: السنون الحجرية في النهر (كاسر الامواج) كدراسة حالة

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### الخلاصة

تشكل المنشآت الهيدروليكية ومنها ( السدود) بأنواعها أهمية حيوية بالغة لدول العالم بشكل عام ، لكونها ركيزة أساسية في تطوير البنى التحتية لبلد ما من جهة ، وداعم لا يستهان به لبناء اقتصاد متين متعدد الأقطاب من جهة أخرى . وبسبب التغيرات المناخية والارتفاع الملحوظ لدرجات الحرارة واثارها السلبية على سائر الكرة الأرضية من : زيادة تصحر الأراضي والشحة المائية ناهيك عن الاستغلال غير الممنهج لمصادر المياه الطبيعية وغيرها من العوامل التي قد تكون سبباً في صراعات محلية او إقليمية لتحقيق ما يعرف بالأمن المائي. ولعل سد الموصل Mousel Dam نموذج حي للمنشآت الهيدروليكية ذات البعد (ليس المحلي فحسب) بل الإقليمي والدولي الذي شغل الرأي العام على مدى عقود من الزمن منذ أنشأته في بداية ثمانينيات القرن الماضي وحتى وقتنا الراهن أي ما يزيد عن الخمسون عاما اجتهدت فيها وزارة الموارد المائية العراقية متمثلة بالهيئة العامة للسدود والخزانات( الإدارة المباشرة لسد الموصل) والهيئة العامة للمساحة ( كمراقب لسلامة السد) وفق أسس علمية رصينة مواكبة فيها التقدم العلمي العالمي وتطور التقانة الجيومكانية لتحقيق افضل النتائج في الكشف عن التحرفات Deformation او التشوهات التي قد تحصل في الحركة الأفقية والرأسية لجسم السد والمنطقة المحيطة به التي سيتم توضيحها بإسهاب في هذا البحث. سأستعرض في هذه الدراسة مراحل تطوّر عمل الرصد الحقلّي لنقاط التثليث في شبكة المراقبة الجيوديسية GCN-Geodetic control Network لسد الموصل والمنطقة المحيطة به آخذين بعين الاعتبار التوصيات الفنية والهندسية المعتمدة للمهندس الاستشاري آنذاك بنظرة هندسية جيوماتيكية وبأسلوب تحليلي مقارن بهدف تحديد نقاط الضعف Weakness Points في عملية مراقبة سلامة سد الموصل مع ادراج الاستنتاجات والتوصيات اللازمة. الكلمات المفتاحية: مراقبة تحرفات السدود، شبكات الضبط الجيوديسي، الازاحة الأفقية والرأسية ، نقاط الضبط الأرضي ، سلامة السدود.

## 1- Introduction

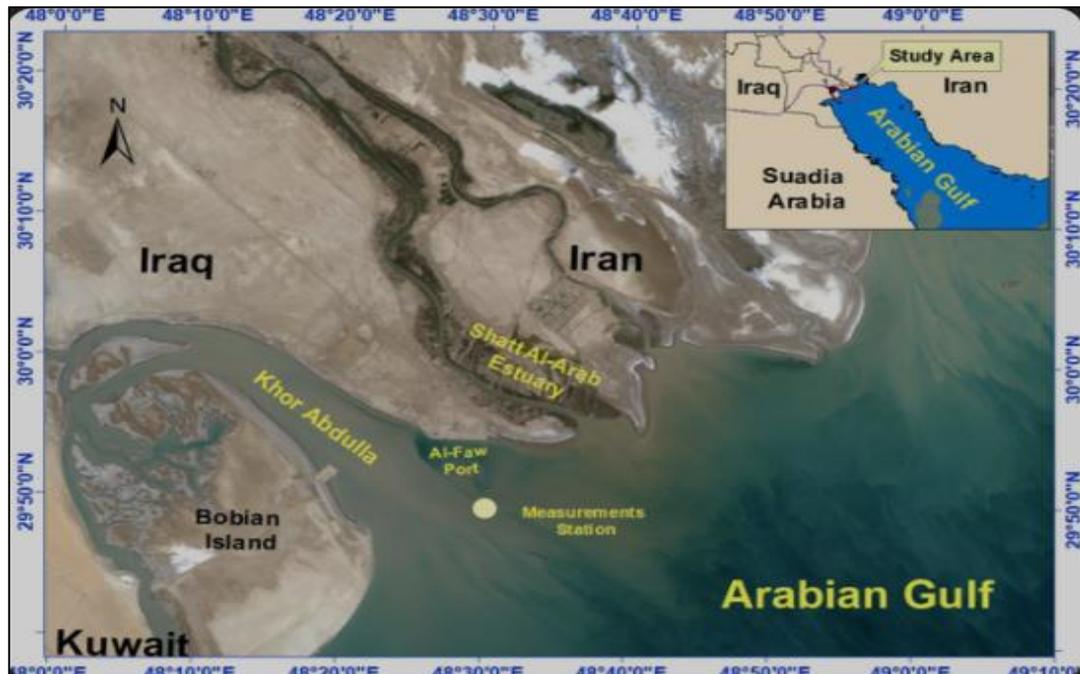
River waves are a complex hydraulic phenomenon resulting from sudden changes in water flow within open channels, whether caused by natural processes or human activities such as the opening and closing of dam gates, bank collapse, or sudden discharges from control structures [Anthony, 2015; Saikumar et al, 2022]. These waves cause a temporary increase in water height and velocity, which can cause erosion of riverbeds and banks, negatively impacting water infrastructure and communities along waterways [Das et al, 2014; Novak et al, 2021]. In this context, several techniques have emerged to mitigate the impact of these waves, most notably the use of barriers or engineered barriers installed in the riverbed. Among these solutions, the design of "hockey groynes " has emerged as a recent innovation that has demonstrated high efficiency in modifying flow dynamics and mitigating the impact of river waves [Alauddin & Tsujimoto, 2012; Hasan & Toda, 2024]. These barriers derive their name from their streamlined, hockey-stick-like shape, which allows them to disperse wave energy and distribute it more evenly [Hird, 2024]. In this research, the hockey groynes were deliberately installed downstream (d/s) of the hydraulic structures to evaluate their effectiveness in controlling flow patterns, mitigating erosion, and improving channel stability (Rubinato et al, 2020; Ahmed et al, 2025, Alasqah et al, 2025) . The selection of this placement reflects practical considerations in groyne design, as downstream configurations can influence energy dissipation and sediment transport differently compared to upstream installations. This review aims to highlight the effectiveness of riverbed hockey groynes as an innovative method for controlling river waves by reviewing the scientific literature and previous relevant applied studies. The focus is on the basic concepts of wave behavior, the working principle of groynes, the influence of geometric dimensions, groynes spacing, and different flow conditions. This review is important because it provides a comprehensive reference for researchers and engineers working in water resource management and environmental hydraulics. It helps them select appropriate solutions to mitigate the potential risks associated with river waves, especially in areas prone to flooding or sudden changes in levels. Furthermore, the study addresses existing research gaps in the literature and presents the challenges facing the design and implementation of these dams in various river environments. This paves the way for future research that will contribute to improving their operational efficiency and expanding their use in waterway management projects.

## 2- River Waves Dynamics Impact

River wave dynamics are a factor influencing river hydromorphological processes. Waves generated by sudden changes in discharge or navigation can generate high shear forces on the river bed and banks. For example, [Chanson ,1999] indicated that waves generated by river navigation have increased lateral erosion rates in some European rivers, affecting bank stability and the ecological structure of the river system. Theses waves are one of the most prominent hydraulic phenomena that appear in rivers

and open streams under climate change due to sudden or gradual changes in flow characteristics, such as speed and depth [Chanson & Wang, 2021; Beltaos & Burrell, 2021, Tayyeh et al, 2024]. They are considered a critical phenomenon affecting water systems' hydrological and engineering stability. These waves are generated by natural and human factors, such as flash floods resulting from heavy rainfall or snowmelt, landslides along river banks, and human interventions such as the sudden or unplanned opening or closing of dam gates [Hariri-Ardebili, & Lall, 2021; Akbar et al, 2024]. This generates a wave that advances through the river at varying speeds, affecting its stability [Dempwolff et al, 2022; Li et al, 2025]. River waves can be classified into several main types, including hydraulic jumps, step waves, and waves generated by dam breaches or dam failures. These waves travel at speeds and directions that vary depending on the type of wave, the depth of the flow, and the steepness of the channel. Rapid waves are typically generated near flash floods or when sluice gates are opened, while step waves propagate along the length of the channel. Locations most susceptible to wave formation are typically areas with sudden changes in channel width or depth, or near hydraulic structures such as dams and estuaries. To optimally control these waves and reduce their harmful effects, a combination of engineering structures such as underdecks and hockey sticks, along with flow control systems, is used. These solutions dissipate wave energy, reduce water velocity, and distribute the energy more evenly [Lighthill & Whitham, 1955; Chanson, 2009, Tayyeh, H et al, 2024]. Gradual or unsteady waves, which result from gradual changes in discharge, are often analyzed using the Saint-Venant equations for unsteady currents [Crossley, 1999; Aldrighetti, 2007]. In addition to waves generated by barrier breaches or dam collapses, which are considered among the most dangerous types of waves due to their high speed and destructive impact, river waves are characterized by several properties, such as wave height, wavelength, waterfront velocity, and energy loss [Yeh et al, 2022; Fenton et al, 2023]. These properties are important for understanding wave behavior and predicting their effects [Park et al, 2017]. River waves have complex hydrodynamic and geomorphological effects. They contribute to accelerating bed erosion rates and increasing bank fragility and stability due to poor soil cohesion. They can also directly damage hydraulic structures and structures due to their exposure to repeated dynamic stresses. Furthermore, these water disturbances alter the ecological structure of the river system by affecting water quality, fragmenting habitats, and decreasing biodiversity, negatively impacting the sustainability of the local ecosystem [Gabel et al, 2017; Chakraborty et al, 2021; Ravanfar et al 2024]. To address these risks, understanding the river wave generation and transmission mechanism is essential for designing protection systems such as bottom buffers or artificial barriers [Van Heteren, 2015], which help reduce wave energy and safely disperse it within the water system [Masselink & van Heteren, 2014; Tiron et al, 2015]. Therefore, studying river waves is not limited to a theoretical aspect; it represents an engineering and scientific necessity for protecting infrastructure and ensuring the sustainability of water resources [Vogel et al, 2015]. Figure (1), which illustrates the characteristics of surface waves in the Iraqi marine waters of the northwest Arabian Gulf, represents an important visual tool to support the content

of the study. It not only presents descriptive data, but also enables a deeper understanding of wave dynamics by highlighting their movement patterns, directions, and intensity. The importance of this diagram lies in its ability to explain the relationships between waves and coastal processes, such as coastal stability, erosion rates, and sedimentation. It also provides a reliable scientific basis for engineering planning of marine projects and infrastructure (such as ports and oil facilities). The figure also allows for the link between changes in wave dynamics and the environmental distribution of marine organisms, thus contributing to the assessment of the potential impacts of climate change on the coastal system.

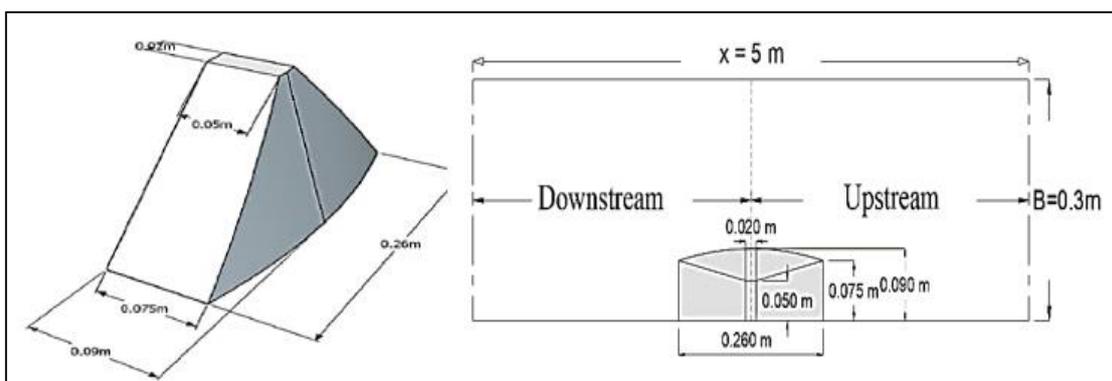


**Figure 1:** Surface wave patterns in the Iraqi marine water's northwest of the Arabian Gulf and their role in interpreting coastal dynamics

### 3- Hockey Groynes Baffles

Hockey groynes are innovative hydraulic elements used as bottom barriers in waterways [Alasqah et al, 2025]. Named for their resemblance to a hockey stick, they typically consist of a sloping or curved section facing upstream, helping disperse incoming water's energy, especially during river waves [Fleming, 2019; Chakraborty, & Chakraborty, 2021]. These groynes effectively improve flow stability by reducing water velocity and increasing local depth. This, in turn, contributes to reducing bottom erosion [Choufu et al, 2019], reducing the risk of erosion, and improving energy dissipation efficiency [Luo et al, 2015]. These groynes are typically installed in river or channel beds at carefully calculated intervals and can be staggered or staggered to achieve optimal flow distribution. From an engineering perspective [Shampa et al, 2020], the design of hockey

groynes is subject to several important hydraulic considerations, including the angle of inclination, the height of the weir, and its location within the cross-section of the waterway [Chen, 2015; Patel, & Kumar, 2024]. These factors directly affect the weir's ability to disperse shock waves and reduce their destructive force. These groynes are used near the inlets and outlets of control facilities such as dams and pumping stations, where streams are subject to sudden changes in flow [Varman, 2025]. They are highly effective in reducing the effects of waves caused by gate openings or changes in discharge. In addition to their role in hydraulic protection, hockey barriers also contribute to improving the longitudinal and lateral velocity distribution within the stream [Brownlie, 2021; Müller et al, 2021], which positively impacts soil stability and the balance of the aquatic ecosystem. Numerous studies and laboratory experiments have shown that these groynes significantly reduce energy loss compared to conventional barriers [Vasconcelos et al, 2024; Jensen et al, 2024, Jasim et al, 2025]. The flow around groynes characteristics was analyzed non-dimensionally, and velocity in the river's upper zone decreased while it increased in the middle and lower zones. The variations of water depth are maximum near the flume wall where the groins are put. The flow deviation about the groin impacted the wall downstream with a high velocity, and the flow was supercritical at the downstream part, as shown in (Figure. 2). Their performance can also be enhanced using different materials, such as reinforced concrete or polymers, to suit different stream conditions. It is worth noting that using these groynes represents a practical application of environmental hydraulics concepts, as they balance engineering protection with maintaining the natural flow behavior of the river [Zakir, 2024; Priyanka et al, 2024]. Given their effectiveness and relative simplicity of installation, hockey barriers are an economical and innovative solution to addressing river wave challenges. They can be integrated into sustainable river management plans to control water flows and reduce their impact on the environment and adjacent structures.



**Figure 2:** 3D view of impermeable groyne.

#### 4- Flow Control and Structure Protection

Flow control is a fundamental concept in hydraulics and water resources management. It refers to all processes and techniques that regulate the speed, quantity,

and direction of water flow within open channels such as rivers and canals or closed systems such as supply pipelines. Flow control is exercised through various engineering structures, notably sluice gates, dams, side channels, dikes, and modern intelligent systems using sensors and automated programming [van Nooijen et al, 2021; Khoram, 2022]. This type of control aims to maintain the balance of the hydrological system, reduce risks resulting from sudden or excessive flows, ensure equitable water distribution among users, and protect facilities and infrastructure from erosion and collapse [Oyebode et al, 2023, Waseen et al, 2025]. In river waves, flow control is a critical element, as sudden discharge or excessively rapid opening of gates can generate high-energy shock waves that can destroy banks and damage downstream structures [Xu et al, 2023; Mandal & Majumdar, 2024]. This is where precise gate operation schedules or the use of accompanying structures such as hockey sticks to reduce wave impact become crucial. Flow control methods include direct mechanical methods, such as adjusting gate angles or changing flow profiles using variable-width structures, and innovative electronic methods that rely on real-time sensor systems to adjust opening and closing rates according to water levels and demand [Shah et al, 2024]. Flow control is also linked to environmental requirement, such as supporting the ecological flow required to sustain aquatic life and reducing pollution by controlling water residence time in a given stream [Allan et al, 2021; Quaranta et al, 2023]. It is worth noting that the effectiveness of any flow control system directly depends on the accuracy of water system modeling, understanding the characteristics of unsteady flow, and calculating the impact of waves resulting from any change in flow [Ming et al, 2023], whether natural or artificial. Studies have shown that combining physical structures such as bottom barriers (including hockey groyne) with intelligent digital systems provides the best dynamic response to mitigate wave effects and ensure flow stability and safety under all conditions [Andreeva et al, 2023]. Therefore, flow control is not merely a regulatory tool; it is an integrated system that protects resources and facilities and achieves sustainable river flow management under various natural and human influences.

## **5- The Role of Hockey Groyne in Controlling Water Energy**

Groyne are essential engineering elements used in open-flow systems to control water energy and direct its flow to minimize its adverse effects, especially during river waves or flash floods [Jafari, 2024]. Weirs typically consist of protrusions or obstructions designed with specific shapes and dimensions to achieve various hydraulic objectives. They can be classified into several main types, including straight weirs, which are constructed nearly perpendicular to the flow direction to reduce current velocity and protect banks; curved weirs, which curve downstream to effectively direct the current; and sloping weirs, which are positioned at various angles to gradually distribute hydraulic energy. Other types include submerged weirs, which are constructed below water level to reduce current energy while maintaining the aesthetic appearance of the stream; composite weirs, which combine more than one type to achieve specific strategies; and

hockey weirs, which are an advanced type thanks to their reverse-curved design, which contributes to dissipating and redistributing wave energy more efficiently [Herget, 2024; Banks et al, 2025]. They are often arranged at intervals to create a cumulative effect that helps reduce flow velocity and distribute hydraulic energy more evenly across the section. Bottom dams vary in shape depending on their intended use [Melling et al, 2021; Seemann et al, 2023]. They may be horizontal, have a specific slope, or adopt more sophisticated geometric designs like curved or ladder-like shapes. Each shape serves a specific purpose related to the flow characteristics and the desired degree of energy loss. The function of these dams goes beyond being merely a barrier in the stream; They play an effective role in breaking up shock waves and creating energy dissipation zones where current velocity decreases and bottom roughness increases, reducing bottom erosion and protecting banks from erosion. These barriers are also used to limit sediment movement, causing it to settle in the calm areas behind each barrier, reducing the risk of channel blockage or erosion of the lower areas of the system. From an environmental perspective, the presence of bottom barriers also contributes to creating a diversity of flow conditions, which enhances the aquatic environment and provides suitable habitats for organisms within the river system.

The effectiveness of bottom barriers is directly related to several design factors, including the height of the bottom barrier, its geometric shape, the spacing between the barriers, and their position within the channel cross-section [Huang et al, 2022]. The relationship between flow depth and local velocity must also be considered when designing these barriers, especially in systems that experience sudden changes in discharge [Chanson & Wang, 2021], such as areas near dams or water gates. In such cases, bottom barriers are a key solution that helps protect the bottom from the effects of waves generated by the opening or closing of gates, reducing shock energy and improving channel stability.

Hockey groyne stand out as an advanced type of bottom barrier. They feature a curved, counter-current design, allowing the wave to break up at the point of contact and redistribute the energy along both sides of the channel, thus reducing its impact on the bottom and downstream structures [Harms, 2021; Jafari, 2024]. The results of experimental studies and numerical models [Li, 2024; Jafari, 2024; Alasqah et al, 2025] indicate that the choice of bottom barrier type depends on a balance between economic and engineering efficiency. Conventional bottom barriers are more economical in terms of design, construction, and maintenance costs due to their simple form and ease of implementation, making them suitable for channels with low hazards or relatively stable flows. In contrast, hockey barriers provide a higher level of control over water flow and energy dissipation, especially in critical locations near water control facilities, but their complex design and implementation requirements make them more expensive. Therefore, conventional barriers are preferred when seeking low-cost solutions with acceptable performance, while hockey barriers are the optimal choice in situations requiring greater hydraulic stability and improved infrastructure protection.

## 6- Hydraulic Energy Dissipation Strategies

Hydraulic energy dissipation is a process aimed at reducing the intensity and energy of flowing water, especially in fast-flowing situations or high-energy river waves, to protect the waterbed and structures from erosion and collapse [Song et al, 2024]. When water moves at high speeds, it carries much energy that can cause significant damage to canals, dams, and bridges. Engineering techniques such as bottom dikes, hockey sticks, calming basins, and speed bumps are used to disperse the flow energy and convert it into eddies and friction within the channel, reducing velocity and causing significant energy loss [Li, 2024]. These structures create turbulent areas and eddies that act as natural energy dissipators and help distribute the flow more steadily. From a design perspective, energy dissipation considers the appropriate location, dimensions, and angles of dikes to ensure optimal performance without causing excessive turbulence that could negatively impact the aquatic environment.

## 7- Case Study: Evaluation of the Performance of Hockey- Groyne Breakwaters in Riverbank Protection

This study was conducted in a laboratory channel equipped with a hookah-shaped breakwater model to evaluate its impact on river flow characteristics and bank protection from turbulent flow erosion. Three hookah angles ( $60^\circ$ ,  $90^\circ$ , and  $120^\circ$ ) and three submergence ratios (75%, 100%, and 125%) were tested at varying discharge rates. The results showed that the  $90^\circ$  angle and submergence ratios between 75% and 100% provided the most effective configuration, reducing bottom shear stresses and enhancing flow stability. This resulted in lower erosion depth compared to other breakwaters, thus providing better bank protection. Numerical simulations using ANSYS Fluent also demonstrated a direct relationship between bottom shear stress and erosion, enabling the design of an effective breakwater under field conditions. This practical case provides a clear model of how submerged hookah breakwaters can be used to achieve hydraulic stability and environmental protection for rivers, supporting sustainable river project planning (Alasqah et al, 2025).

## 8- Conclusions

- 1- Hockey groynes innovate and effectively act as bottom buffers against river waves. They contribute to the gradual dispersal of excess hydraulic energy, thus reducing its negative impact on the river course and adjacent structures.
- 2- Flow control is a fundamental component of integrated waterway management. It includes techniques and tools to control discharge and reduce the potential for shock waves, mainly when operating gates and dams.
- 3- Groynes, in their various forms, effectively reduce flow velocity and distribute energy. They create vortex zones that calm the water, protect the river bed from erosion, and improve flow stability.

- 4- Dispersing hydraulic energy is essential to preventing damage caused by high or irregular flow. Physical structures such as bottom dams and dikes help reduce soil loss and increase the lifespan of water structures.
- 5- Combining a scientific understanding of flow behavior with the use of innovative engineering solutions, such as hockey dams and bottom dikes, is a strategic option for achieving river environmental and hydraulic sustainability and enhancing the efficiency of water infrastructure in dealing with floods and high waves.

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