3rd International Conference on Advances in Civil and Environmental Engineering (ICACEE-2024)
University of Engineering & Technology Taxila, Pakistan
Conference dates: 21st and 22nd February 2024; ISBN: 978-969-23675-2-3

Study of River Chenab Morphology Upstream Panjnad Barrage

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ABSTRACT

The present research focuses on studying the river Chenab morphology upstream of the Panjnad (PJD) Barrage, which has altered Chenab's flow, causing erosion on the Reduced Distance (RD) 55+000 to 35+000 along the Right Marginal Bund (RMB). A field survey was conducted to understand river morphology focused on sedimentation, erosion, and island formation. An 18 km study Upstream (U/S) along Chenab and Sutlej utilized plane table survey methods with tools like levelling tools, compasses, and plane table boards. Mapping terrain between the Right Guide Bank (RGB), Left Guide Bank (LGB), RMB, and Left Marginal Bund (LMB) was the goal. A detailed drawing of the river's topography from the main weir was made due to Chenab's low flow creating islands near bay number 13–50.The studied river section, RD: 35+000 to 55+000, shows braiding, unstable sandbars, and monsoon-driven sediment influx, impacting canal diversion and morphology. Erosion from RD 35+000 to 55+000 on the Chenab's right bank persists despite prior efforts using j-head spurs, sloping spurs, and mole head spurs. Sutlej's floods damage areas along LMB up to J-Head Spur RD 5+500 LMB. Concentrated discharge threatens the upper curved part of the RGB. (U/S island formation impairs PJD's discharge by blocking the Annexe weir. A permanent island divides Chenab streams from RD 36+000 to the confluence, threatening infrastructure along RMB (RD 36+000 to 50+000). The project benefits both industry and society by enhancing irrigation reliability, and water supply and reducing flood risks in nearby areas.

KEYWORDS: River morphology, Rightwards Tendency, Erosion and Sedimentation, Training works, Island Formation

1. INTRODUCTION

Alluvial channels are categorized as straight, meandering, or braided [1-2] (Figure 1). Straight rivers exhibit minimal sinuosity at bank full conditions while meandering rivers feature alternating curves with low gradients, prone to bank erosion [3]. Braided rivers, wide and shallow, divide into branches by semi-stable or unstable bars or islands. Channel patterns align closely with bar nature, influencing the style of meandering or braiding [4]. River channels self-organize through interactions among bars, channels, floodplains, and vegetation, shaped by sediment sorting processes and bank erosion [5].

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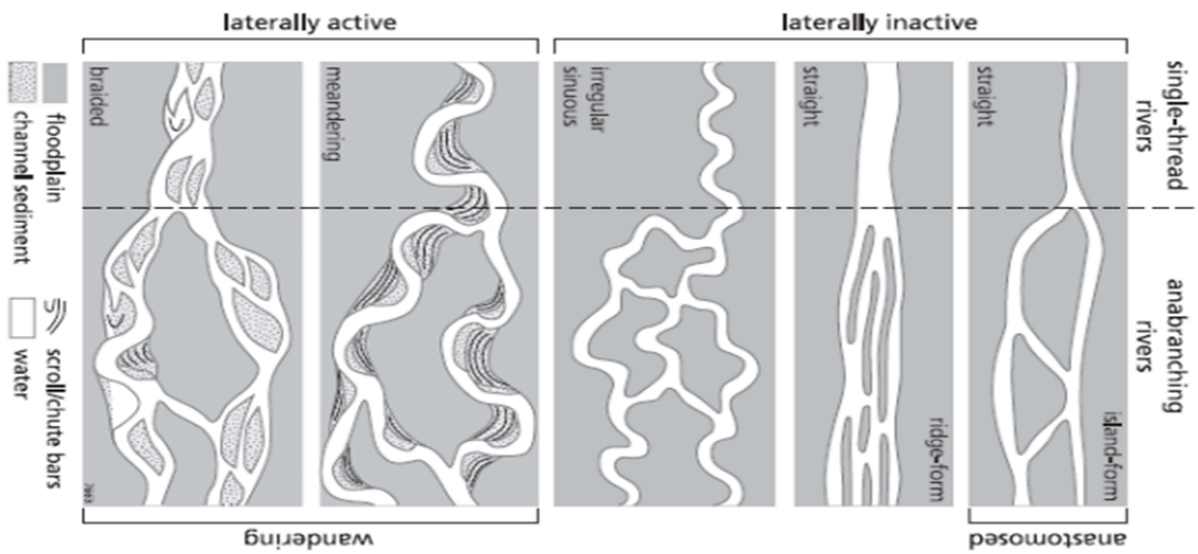


Figure 1: Classification of alluvial river pattern [2]

The four main categories of river morphology are: sediment load, bed/bank material, channel features (width, depth, slope, and shape), dynamic flow (rate, discharge, roughness, and shear load), and human interventions such as regulation [6]. Variations in these variables lead to morphological shifts. Hence the relationship between flow patterns and branch channel movement and flow dynamics, sediment behavior, and river bank erosion is important [7].

River silt concentration increases due to river bank erosion, which affects infrastructure and agriculture [8]. Different soil layers, hydrology, and river structures all contribute to assessment complexity. Changes in downstream width are accelerated by cohesive bank erosion that is connected to discharge [9]. Bank erosion is accelerated by sand bars and central islands. Peak discharge is a major factor in erosion [10], which is exacerbated by weathering. Erosion is also affected by vegetation, soil properties, frequency of freeze-thaw cycles, and grain size of the sediment at the bank toe [11]. The composition of the sediment, particularly the fine particles, affects erosion; however, low, silty banks suffer more erosion because of the frequent wetting. Until channel stability, bank retreat is a cyclic pattern involving sub-aerial processes, fluvial erosion, and bank failure [7].

To determine the suitable training works for keeping the river flow away from vulnerable reach of the RMB and to ensure the safety of the RGB and activate the channel leading to Annexe weir, a model of Chenab river representing the river approach of about 6 miles upstream (U/S) of Panjnad (PJD) Headworks along with about 5.5 miles reach of Sutlej river which joins the Chenab just U/S of the Head Works was set up at Hydraulic Research Station Nandipur Gujranwala [12] on scales. All the flood bunds and training works existing along the study reach were represented. The study reflected that changes in flow conditions created river engineering problems along the RMB and RGB of the head works.

The challenges in understanding water quality stem from limited data on factors like emerging pollutants and dissolved oxygen, impeding the identification of pollution sources.

Furthermore, research gaps persist in comprehending how climate change influences water flow and basin hydrology, necessitating improved models to assess socioeconomic impacts on local communities. Inadequate information on riverine ecology and biodiversity demands comprehensive surveys and conservation strategies, particularly concerning human-induced effects such as damming. Additionally, a lack of insight into stakeholders' water needs, policy effectiveness, and societal implications of water scarcity calls for extensive research to enable sustainable water management and fair distribution. Thus, understanding Chenab's erosive tendencies at PJD Barrage and assessing damages to river training works and infrastructure is crucial.

The objective of this study is to identify effective training works to divert river flow from the vulnerable stretch of the RMB, ensuring the safety of the RGB and activating the channel leading to the Annexe weir. The focus lies in grasping the flow patterns and morphological dynamics of the Chenab and Sutlej River U/S of the PJD barrage. Understanding the inherent rightward tendency of Chenab's main current is crucial. Proposing effective protective measures for the RMB and its associated structures/river training works is imperative. Investigating the fundamental causes behind the river's erosive nature is a central objective. Overall, the aim is to gain insights into these river systems' behavior and tendencies, particularly to understand the current state of vulnerable structures while comprehending the underlying reasons for their erosive nature. The study emphasizes the dynamic nature of river systems, highlighting the need for adaptive measures to ensure the resilience and safety of critical infrastructure.

2. METHODOLOGY

2.1 Region of study

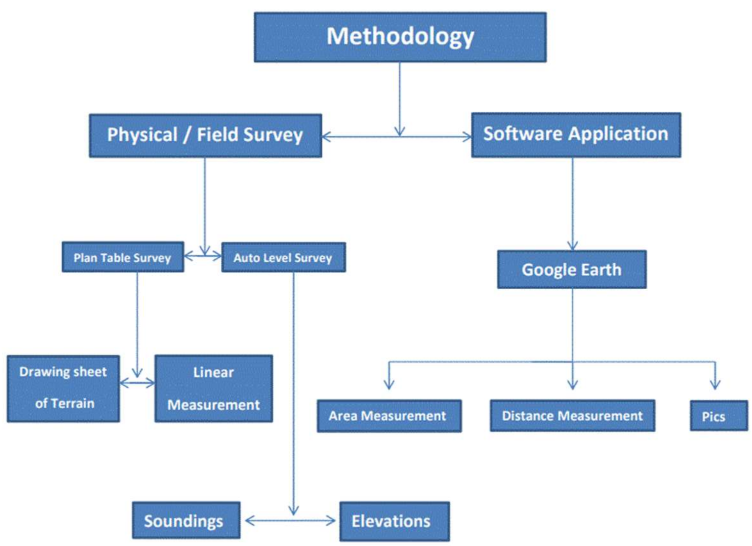
The primary terrain of the River Chenab was surveyed to conduct a physical study using plain table surveying and Google Earth maps. The flow chart of the methodology adopted in this study is depicted in Figure 2a. The study site consisted of the U/S side of the PJD Barrage, which is delimited by the left and right marginal flood bunds. Plain tabling, or the study of river stream behavior, including flow length, width, meandering pattern, erosion, and sedimentation, yielded the morphological details of this terrain. The beginning of the survey was at an RD:55+000 of RMB U/S. The Chenab River's mainstream runs from RD:55+000 to RD:36+0000 along the RMB. Because of erosion, flood damages happened in this area during every flood season. To mitigate the effects of flooding and safeguard the RMB, various geometrically shaped hydraulic structures and spurs have been built within this reach. The most popular geometrical shapes found in this reach are solid stone studs, sloping spurs, J-head spurs, and Mole head spurs. For that reason, stone pitching is also available along the RMB's riverside slope. The Chenab River's main stream split into two sub-streams from RD:36+000 RMB.

One of the sub-streams flows along the RMB and approaches the barrage, while the other one flows on the left side. Between Bay No. 1 and 12, these two sub-streams reunite at the RD:3+000 U/S main weir and combine mainstream approaches to the main weir. About 15 km (measured through Google Earth) to the south, the Satluj River also joins the Chenab River in a left-side sub-stream. Between these sub-streams, from the beginning to the point of joining at RD:3+000 U/S, a permanent island is formed. This island is situated about 800 feet (field measurement) from the main weir, spanning from Bay No. 13 to 50. The primary cause of island formation is the year-round low supply at PJD Barrage. This island lowers the barrage's ability to pass floods and also lowers the effectiveness of the barrage [4].

2.2 Field survey

For this research work, a physical study was conducted by adopting a Plane Table Survey of River Chenab terrain from RD 55+000 of RMB to the main weir U/S PJD Barrage. The fastest surveying method is plane table surveying. Plotting the plan and conducting field observations can be done concurrently in this kind of surveying. When using a plane table for surveying, the topographic details are arranged on the map after the geometrical conditions of the site are recorded using the plane table and alidade.

The plane tabling was performed utilizing the required apparatuses. Observations about the objects were made while scaling down the distances and objects were plotted on a drawing sheet (as shown in Figure 2). Using the trough compass, the magnetic meridian north line was indicated on the plane table sheet. The plane Alidad was utilized for drawing or object sighting. Dumpy level (optical instrument) was used to validate points in the horizontal plane. Other required apparatuses like U-Frame Levelling Stave Ranging Rod, Coloured Flags, Tube-Level, Generator boat etc. were also utilized when and where required. In addition to this, Google Earth Map was also used in order to understand river reaches and indicate vulnerable regions.



(a)

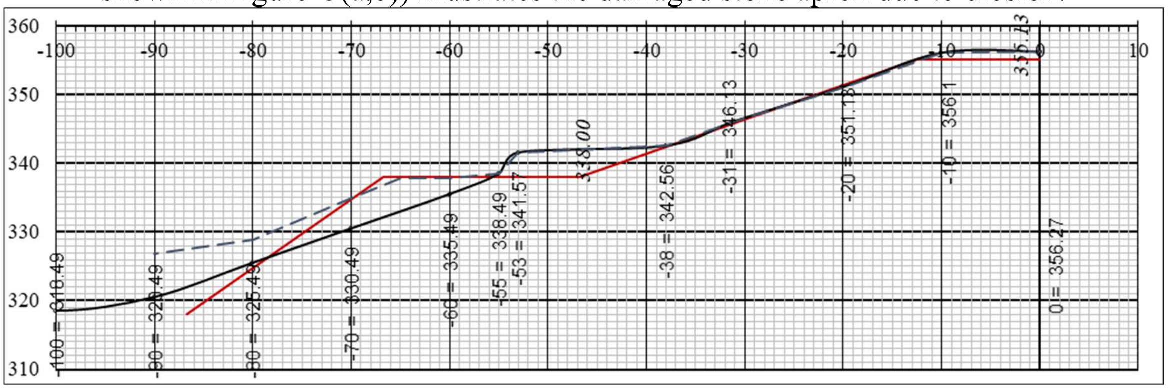
(b)

Figure 2: (a) Flow chart of the methodology, and (b) marking river right edge at J-head spur RD:36+700 RMB

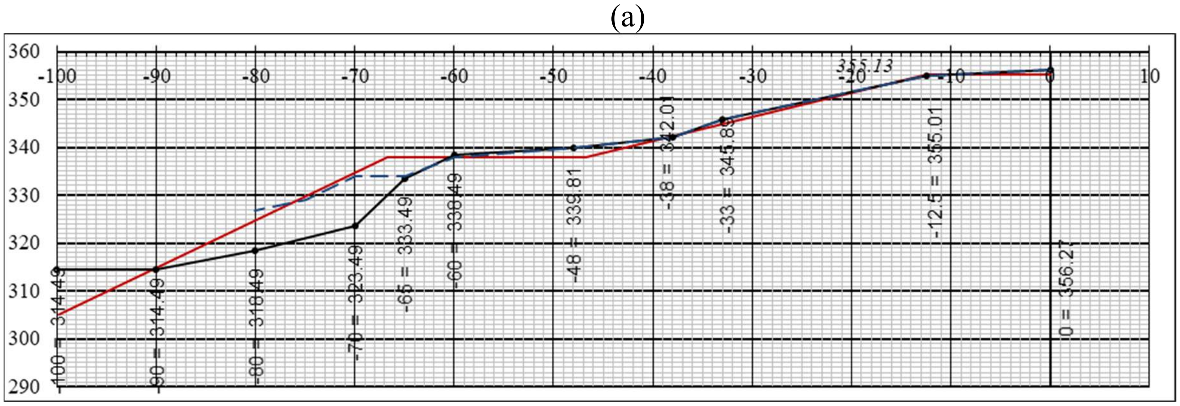
The survey was started from RD 55+000 RMB U/S PJD to the main weir with the reference North direction. A Prismatic Compass was used to determine the North direction and also cross-checked by using a mobile Compass. Drawing sheet of Barrage layout U/S fixed on plane table board. The primary setting of the plane table board was done including centering, leveling, and orientation. Centring was done by U-Frame and levelling of the plane table board was done by tube level. For taking linear measurements, dimensions, and river widths, the Auto-Level was also prepared for the primary setting including centering, levelling, and focusing

River Chenab terrain was prepared parallel by observed data taken from Auto-Level and Plane table board. Distances were measured through Auto-level cross-hairs by sighting ranging rods at the desired location. Different variation in the river flowing behavior such as flood damages along banks and spurs, erosion, sedimentation, and island formation was observed and marked on the drawing sheet during the survey work. A generator-mounted boat was used for moving in river from one place to another during survey work.

The sounding observation was made during a field survey at J-head Spurs RD:36+700, J-Head spur RD:40+900, Mole Head Spur RD:42+200, and J-Head Spur RD:48+800 RMB U/S PJD Barrage, to observe the flood damages along these hydraulics structures. A boat along with a sounding rod and a sounding rope was used for taking field observations. After taking sounding observation and plotting cross-sections of all structures along different cross-section lines, it was observed that entire stone aprons of all structures were found damaged along all the cross-section lines. Minor, moderate, and heavy damage was observed along different cross-section lines of these structures. The cross section lines 45 left and 90 right U/S of J-head RD:36+700 RMB (as shown in Figure 3(a,b)) illustrates the damaged stone apron due to erosion.



(a)



(b)

Figure 3: (a) x-section line at 45 L. U/S nose, and (b) x-section line at 90 R. U/S

3. RESULTS AND DISCUSSION

3.1 River Chenab rightwards tendency

From RD:50+000 to RD36+700 RMB U/S, the river flows rightwards along RMB in a single stream. For the safety of public infrastructures and RMB from river erosion and damages, the river training works including J-Head spurs, Mole head spurs, sloping spurs, stone studs, and apron along RMB are provided in this reach. This reach permanently remains at risk of flood damage because the river's main current flows rightwards along RMB.

Figure 4(a,b) illustrates that the River reaches from RD 36+000 to 50+000 along the RMB U/S of the barrage and witnesses the flow of the Chenab's primary current. However, this specific stretch confronts a threat of erosion along the RMB and the accompanying structures, such as spurs. These spurs, erected with the explicit purpose of safeguarding public infrastructure and the Right RMB, face vulnerability due to the force and direction of the river's flow. The multifaceted nature of these observations underscores the complex and intertwined relationship between the river's flow patterns, the functionality of the barrage, and the ecological impact on the surrounding areas. In-depth comprehension and strategic addressing of these complexities serve as the cornerstone for devising effective mitigation strategies and ensuring the sustainability of infrastructure.

The comprehensive field study conducted during data collection offered an understanding of the intricate dynamics within the Chenab River's course, particularly concerning its interaction with the PJD Barrage. At a crucial juncture approximately 2000 ft (field measurement) U/S of the main weir, the convergence of the river's main streams occurs by joining sub-streams, aligning notably with the left side along the LMB. However, the width of this mainstream flow, estimated at around 1000 ft (field measurement), emerges as a pivotal factor, particularly at bay no. 1-12, owing to the variable nature of the river's supply at the PJD Barrage, which is also consistent with Nanson and Knighton [2].

The section of the research focuses on the river reach from RD 50+000 to RD 36+700 U/S of the PJD Barrage along the Right Marginal Bund (RMB). The river flows rightwards along the RMB in a single stream, posing challenges related to river erosion and potential damage to public infrastructure. To mitigate these risks, river training works have been implemented in this reach, including J-Head spurs, Mole head spurs, sloping spurs, stone studs, and apron along the RMB. The significance of this study is rooted in the constant threat of flood damage in this particular stretch due to the primary current's rightward flow along the RMB. This observation aligns with the findings of Parker [3].

Figures 4(a,b) provide visual representations of the vulnerable reach RD 36+000 to 50+000 U/S of the barrage, illustrating the flow of the Chenab's main current. Despite the protective measures implemented, this stretch faces a persistent risk of erosion along the RMB and associated structures, such as spurs. The vulnerability arises from the force and direction of the river's flow, impacting the effectiveness of protective spurs. The complexity of these observations emphasizes the intricate relationship between river flow patterns, the functionality of the barrage, and the ecological impact on the surrounding areas. To effectively address these complexities and ensure infrastructure sustainability, a deeper understanding is required.

(a)

(b)

Figure 4: (a) Vulnerable Reach RD36-50, (b) Erosion along Chenab right bank

3.2 Sub-Stream Formation

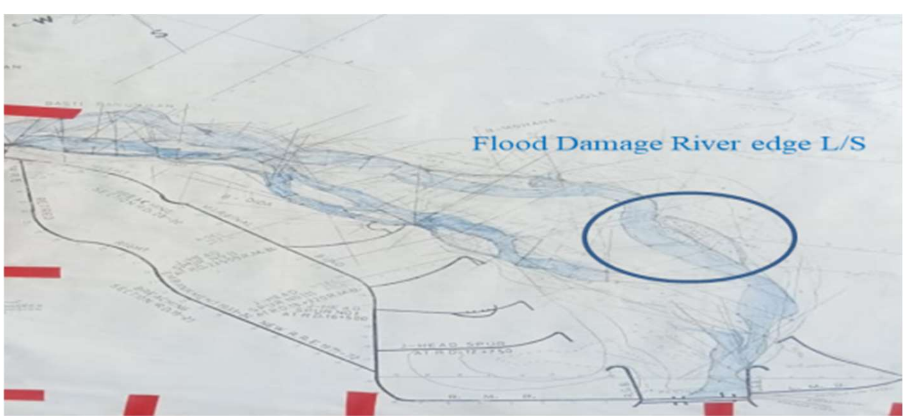
Figure 5 illustrates that the river Chenab main stream is divided into two sub-streams at RD 36+700 RMB (U/S) PJD Barrage. These two sub-streams approach Barrage separately and join each other at RD:3+000 U/S PJD. After the joining of sub-streams, a main-stream is developed which approaches the main weir in front of Bay No.1-12. The right-side sub-stream flows along RMB towards Barrage and the other one flows on the left side parallel to LMB.

The river Sutluj joins the river Chenab in this left side sub-stream about 15 km (Google Earth) U/S main weir. A permanent island has developed in between to above narrated sub-streams from the starting point to the Barrage due to less supply of water on the Barrage around the year. This island spreads from bay No.13-50 just 800 ft (field measurement) far from the weir on the U/S side. Due to island formation the efficiency and flood passing capacity of the Barrage is reduced.

Figure 5: Sub-streams formation at RD 36+700 RMB (source: Google Earth)

3.3 Sutluj Confluence Point

Figure 6 (a,b) illustrates that the confluence of the Chenab and Sutlej rivers. An event occurring approximately 15 km U/S of the barrage, proved momentous during the recent flood season of 2023. A staggering discharge of 151904 Cs (source: Punjnad Barrage Irrigation Punjab) at Islam Headworks from the River Sutlej into the left stream of the Chenab led to severe erosion and substantial damage, spanning an 800ft (field measurement) width along the LMB U/S of the barrage. This damage extended from the confluence point to the termination at J-Head Spur at Rd:5+500 along LMB, illustrating the sheer force and devastating impact of such discharge variations. The bifurcation of these primary streams at RD:36+000 U/S of the barrage had lasting implications, contributing to the permanent formation of an island or Bela between these streams, persisting steadfastly from their inception until their eventual stage. This distinct divergence of streams significantly influences the river's morphological behavior [6,8], highlighting the intricate interplay between natural forces and the evolving course of the river.



(a)

(b)

Figure 6: (a) Actual sheet plane table survey, and (b) confluence point river Satluj (source: Google Earth)

3.4 Island Formation

Figure 7 (a,b) illustrates that river Chenab comes to the barrage with two main streams, and these streams start from RD35+000 U/S RMB and join just 2000ft U/S (field measurement) main weir. This supply exhibits inconsistency throughout the year, which is primarily allocated for canal off-takes. Consequently, to maintain the U/S pond level, a necessary action to manage the varying supply, the barrage gates must remain closed, emphasizing the challenges posed by the fluctuating river supply. The consequences of this fluctuation in supply manifest significantly in the emergence of islands or Belas in front of the main weir, specifically between gates no 13-50, positioned a mere 800ft(field measurement) U/S of the main weir. This Bela formation intensifies challenges during flood seasons, notably reducing the barrage's passage capacity and disrupting the smooth flow of the river's main current toward the barrage. This critical scenario emphasizes the complex impact of the river's varying supply on the barrage's operational efficiency and its ability to effectively manage floodwaters [4,5].

(a) (b)

Figure 7: (a) Old picture of Panjnad barrage main weir 1932, and (b) drone camera (source: Irrigation department)

4. CONCLUSIONS

PJD barrage, which was placed to the left of the Chenab's original flow plain, caused the river to constantly veer to the right. Changes in the Chenab's flow pattern after the construction of the barrage are the cause of erosion along the RMB and its aligned river training works/spurs U/S barrage. Persistent erosion along the RMB and related structures resulted from this deviation. In order to lessen this, different spurs were built along the bund to divert the flow in the direction of the barrage without jeopardizing the structure. However, because of the ongoing erosion, sedimentation caused islands and sandbars to form U/S of the barrage. The Chenab's natural course was altered by the ongoing island growth, which split the river into two major streams. The river split into separate channels at RD: 36+000 U/S as a result of this phenomenon, which was caused by erosion and the siltation that followed, which continued to cause islands to grow every year.

The comprehensive observations in this study brought to light the river engineering challenges arising from alterations in flow conditions along the RMB and RGB of the headworks. These findings underscore the critical significance of our research objectives. Addressing these challenges requires strategic interventions that go beyond traditional approaches. By shedding light on the complexities involved, this research serves as a foundation for informed decision-making and the implementation of effective river management strategies.

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