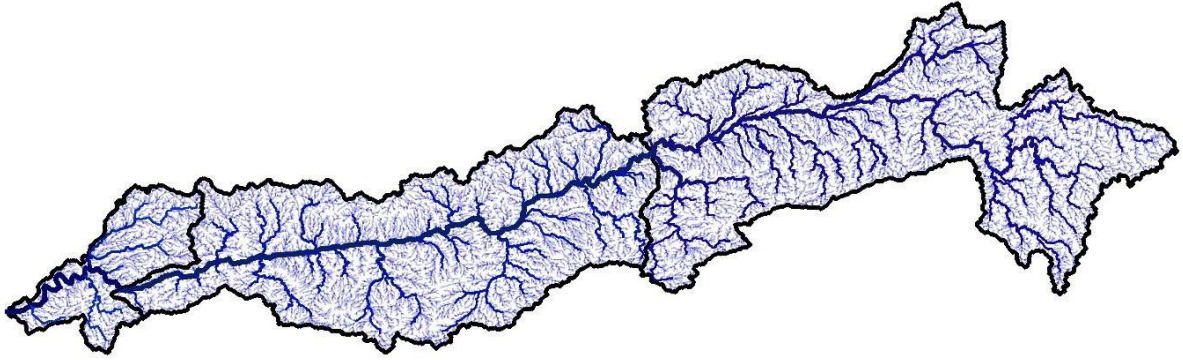




National River Conservation Directorate
Ministry of Jal Shakti,
Department of Water Resources,
River Development & Ganga Rejuvenation
Government of India

Learnings from International Basins



March 2025



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Learnings from International Basins



National River Conservation Directorate (NRC D)

The National River Conservation Directorate, functioning under the Department of Water Resources, River Development & Ganga Rejuvenation, and Ministry of Jal Shakti providing financial assistance to the State Government for conservation of rivers under the Centrally Sponsored Schemes of 'National River Conservation Plan (NRCP)'. National River Conservation Plan to the State Governments/ local bodies to set up infrastructure for pollution abatement of rivers in identified polluted river stretches based on proposals received from the State Governments/ local bodies.

www.nrcd.nic.in

Centres for Narmada River Basin Management and Studies (cNarmada)

The Center for Narmada River Basin Management and Studies (cNarmada) is a Brain Trust dedicated to River Science and River Basin Management. Established in 2024 by IIT Gandhinagar and IIT Indore, under the supervision of cGanga at IIT Kanpur, the center serves as a knowledge wing of the National River Conservation Directorate (NRC D). cNarmada is committed to restoring and conserving the Narmada River and its resources through the collation of information and knowledge, research and development, planning, monitoring, education, advocacy, and stakeholder engagement.

www.cnarmada.org

Centres for Ganga River Basin Management and Studies (cGanga)

cGanga is a think tank formed under the aegis of NMCG, and one of its stated objectives is to make India a world leader in river and water science. The Centre is headquartered at IIT Kanpur and has representation from most leading science and technological institutes of the country. cGanga's mandate is to serve as think-tank in implementation and dynamic evolution of Ganga River Basin Management Plan (GRBMP) prepared by the Consortium of 7 IITs. In addition to this, it is also responsible for introducing new technologies, innovations, and solutions into India.

www.cganga.org

Acknowledgment

This report is a comprehensive outcome of the project jointly executed by IIT Gandhinagar (Lead Institute) along with eleven other participating institutions under the CAMP project, under the supervision of cGanga at IIT Kanpur. It was submitted to the National River Conservation Directorate (NRC D) in 2024. We gratefully acknowledge the individuals who provided information and photographs for this report.

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PREFACE

This report provides an analysis of international river basin management experiences. The purpose of this document is to extract lessons from global practices in river basin management that can effectively inform and enhance water governance policies and strategies in India.

The report delves into a selection of international river basins, each with varied characteristics and management approaches. These case studies include the Thames River in the United Kingdom, the Rhine River in Central Europe, and the Murray-Darling Basin in Australia, among others. By examining these diverse examples, the report offers a perspective on how different regions across the world address complex water resource challenges.

Inside this report, readers will find case studies of each basin, beginning with an overview of its geographical and historical context, as well as the key management and environmental challenges it faces. For instance, the report discusses the successful restoration of the Thames River and the collaborative efforts to combat pollution in the Rhine. It also addresses the issues of water overuse and climate change impacts in the Murray-Darling Basin. Furthermore, the report analyzes the strategies and interventions implemented in these basins, such as legislative frameworks, technological innovations, and community engagement practices. It evaluates the outcomes and impacts of these interventions, providing a comparative analysis of their successes and shortcomings.

This report is structured to be a practical and informative tool for policymakers. The insights and lessons derived from the international case studies are intended to help in the formulation of context-sensitive policies. By understanding the diverse approaches and their results, policymakers can adapt and implement strategies to enhance the sustainability of river basins in their own regions.

The creation of this report was made possible through the dedication and expertise of numerous individuals and institutions. We extend our sincere appreciation to the team members in all the 12 institutions involved.

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Introduction

Rivers have long been the lifeblood of civilizations, serving not only as sources of water and food but also as cultural, economic, and political arteries. In today's rapidly changing world, the sustainable management of river basins is more critical than ever. This report examines international experiences in river basin management, drawing on case studies from rivers such as the Thames in the United Kingdom, the Rhine in Central Europe, and the Murray–Darling Basin in Australia. These case studies offer lessons for contemporary water resource management and provide a perspective on how integrated approaches can restore, protect, and enhance river systems that are under increasing pressure from urbanization, industrialization, and climate change.

The Thames River, once declared ecologically dead, has become a success story in river restoration. Through a series of coordinated interventions, including reactivation of floodplains, upgrading wastewater treatment facilities, and implementing structural enhancements along its banks, the Thames has witnessed a remarkable recovery in water quality and biodiversity. This transformation was not achieved overnight; it resulted from decades of evolving policies and cross-sector collaboration among governmental agencies, local communities, environmental organizations, and research institutions. The Thames case study highlights the potential of basin-scale management to reverse historical degradation and promote sustainable water use in densely populated regions.

Across the continent, the Rhine River presents another instructive example. Historically burdened by severe industrial pollution and rampant habitat degradation, the Rhine's condition deteriorated to the point where it was infamously dubbed the “sewer of Europe.” In response to catastrophic pollution events and widespread public outcry, European nations embarked on an ambitious, coordinated management programme. The Rhine Action Program and subsequent “Rhine 2020” initiative implemented a suite of measures aimed at reducing pollutant loads, restoring natural habitats, and reestablishing connectivity in the river's floodplains. This integrated approach has resulted in significant improvements in water quality, the reintroduction of migratory species such as salmon, and enhanced flood risk management. The Rhine's transformation illustrates the importance of transboundary cooperation and the need for consistent policy enforcement across different jurisdictions to achieve long-term ecological restoration.

In Australia, the Murray–Darling Basin—a vast river system underpinning one of the country's

most important agricultural regions—faces its own set of challenges. Over-allocation of water for irrigation, combined with a series of prolonged droughts and climate variability, has led to critical water shortages and significant ecological decline. The Basin Plan, instituted under the Water Act 2007 and refined over subsequent years, represents Australia’s comprehensive attempt to rebalance water allocation among agricultural, urban, and environmental needs. Strategies such as water buybacks, investment in modern irrigation technologies, and the implementation of environmental watering regimes have been key to restoring river health and ensuring sustainable water availability. Despite considerable progress, the Murray–Darling Basin continues to serve as a stark reminder of the challenges posed by climate change and human overuse, reinforcing the need for adaptive, forward-looking water management strategies.

The international case studies explored in this report collectively underscore several core themes. First, integrated water resource management (IWRM) that encompasses both technological interventions and participatory governance is essential for addressing the complex, interrelated challenges facing river basins today. Second, long-term, adaptive management is necessary to contend with dynamic environmental and socio-economic conditions. Third, effective restoration and conservation efforts require the collaboration of a broad range of stakeholders, including governments, local communities, industry, and academic institutions. Each basin presents unique challenges—whether it is the over-extraction of water, pollution, biodiversity loss, or the impacts of climate change—but the underlying lesson is clear: sustainable river management must be holistic, adaptable, and inclusive.

This report seeks to translate these international lessons into actionable insights for policymakers and practitioners. By comparing the approaches taken in different regions and identifying best practices, it aims to provide a roadmap for revitalizing and managing river basins in a manner that not only meets current water demands but also safeguards ecological and social well-being for future generations. The following sections will detail the objectives of the report, list the major international basins under review, and outline the structure and key highlights of the case studies presented.

Objective of the Report

The primary objective of this report is to provide an analysis of international river basin management experiences, with the aim of extracting lessons that can inform and improve water governance practices. In an era marked by rapid urbanization, climate change, and escalating

water scarcity, understanding the successes and challenges of well-managed river basins is crucial. By reviewing case studies from some of the world's most iconic rivers, this report seeks to establish a framework for integrated and adaptive river basin management that policymakers, water managers, and stakeholders can apply to local and regional contexts.

List of Major International Basins

Key highlights and structure of the report

This report is structured to offer a comparative analysis of international river basin management. The key highlights include:

- **Case Study Overview:** Each case study begins with a background that covers the geographical setting, historical context, and major challenges faced by the river basin. For example, the Thames case study outlines how urban renewal and restoration projects have reversed severe ecological degradation, while the Rhine study discusses cross-border collaboration and the significant reduction in pollutant levels over the decades.
- **Problem Statements:** For each river basin, the report identifies the core environmental and management challenges—such as pollution, over-extraction, flood risk, and biodiversity loss—and examines the specific factors contributing to these issues. This section not only describes the challenges but also contextualizes them within the broader socio-economic and climatic trends impacting the region.
- **Strategies and Interventions:** A central part of the report is dedicated to analyzing the approaches adopted to overcome these challenges. This includes legislative reforms, technological innovations, community engagement practices, and restoration initiatives. The report details how integrated water management plans and adaptive governance models have been implemented in each basin, highlighting the importance of continuous monitoring and stakeholder collaboration.
- **Outcomes and Impact:** The report evaluates the tangible results of the interventions, presenting evidence of environmental recovery, improved water quality, and enhanced socio-economic benefits. Comparative data on water quality, flood management, and biodiversity restoration provide a sense of the progress made over time.
- **Lessons Learned and Recommendations:** Drawing from the successes and shortcomings observed in each basin, this section synthesizes key lessons for policymakers. It emphasizes the need for long-term commitment, cross-jurisdictional cooperation, and the integration of traditional knowledge with modern management

practices. Recommendations are offered to guide future policies and investments in river basin management.

The structure of the report is designed to be wide ranging and practical. By organizing the content into distinct yet interrelated sections, it allows readers to gain an understanding of each case study while also appreciating the common themes and divergent approaches across international contexts. The usefulness of learning from these experiences lies in the ability to adapt and tailor proven strategies to local challenges. Policymakers can leverage these insights to formulate context-sensitive policies that enhance the sustainability of their own river basins.

Case Studies of International Basins

Thames River

Case Study Overview

Project background and location

The River Thames, spanning 346 km, is the longest river entirely within England and the second longest in the UK. It originates at Thames Head near Kemble in the Cotswolds and flows into the North Sea at the Thames Estuary near Southend-on-Sea. The river is fed by several tributaries, including the Lea (68 km), Leach (30 km), Churn (37 km), Coln (52 km), Windrush (48 km), Kennet (77 km), Evenlode (68 km), Ock (37 km), and Loddon (32 km) (“The Thames River Basin,” n.d.). These waterways play a vital role in flood management, serve as an essential water supply, and support diverse wildlife. However, increasing urbanization and the spread of invasive species threaten these fragile ecosystems, prompting conservation efforts to restore and protect the river and its surroundings.

The Thames River Basin District (RBD) covers a relatively small portion of the UK’s land area but supports a significant population of approximately 15 million people. Most reside in London, with other rapidly expanding urban centres including Reading, Swindon, and Crawley. As land use intensifies, both urban and rural areas experience greater rainfall runoff due to development and increased land productivity. The district contains several ecologically significant wetlands, and protected marshes, many of which are critical for wildlife conservation. The Thames is further sustained by chalk streams, such as the River Kennet and Lambourn, designated as Sites of Special Scientific Interest (SSSIs). These habitats are home to native species like otters, kingfishers, and water voles. In addition, the river encompasses

areas that provide drinking water, designated bathing sites, and rare natural habitats. Preserving these valuable environments is essential as human activity reshapes the landscape.



Figure 1: Map of the Thames RBD and management catchments. Source: (Environment Agency, 2022, p. 10)

The Thames RBD consists of 17 management catchments (see Figure 1). Below this level are operational catchments, which group smaller water bodies based on shared geographical features or common environmental pressures. Some operational catchments are designated for larger water bodies, such as groundwater systems, which can extend beyond management

catchment boundaries and even across different river basin districts. Within the Thames RBD, there are a total of 38 operational catchments.

Problem statement: Management and Environmental challenges

Two key challenges of restoring The Thames River. One was building a viable management structure, improving incentive alignment, and prioritising the environment over other interests. Two, to identify the sources of environmental damage, gradually restrict activities, and find ways to rejuvenate the environment while engaging with various stakeholders.

Project Description

Goals and objectives

- Preventing deterioration of the status of surface waters and groundwater
- Achieving objectives and standards for protected areas
- Aiming to achieve good status for all water bodies
- Reversing any significant and sustained upward trends in pollutant concentrations in groundwater
- Cessation of discharges, emissions and losses of priority hazardous substances into surface waters
- Progressively reducing the pollution of groundwater and preventing or limiting the entry of pollutants

Strategies and interventions

Integrated Water Management: The Water Framework Directive (WFD) promotes a holistic, ecosystem-based approach to water protection and sustainable use, considering the entire hydrological cycle (*River Basin Planning Process Overview*, 2023).

Legislative Framework:

The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017 implement the WFD, along with aspects of the Groundwater Directive and Environmental Quality Standards Directive.

The European Union Withdrawal Act 2018 retained the WFD requirements in UK domestic law.

Key Requirements under WFD Regulations:

River Basin Management Plans (RBMPs) must be created, reviewed, and updated every six years.

Environmental objectives are set for groundwater and surface waters, including estuaries and

coastal waters.

Programmes of measures are developed and implemented to achieve these objectives.

Implementation Timeline:

First RBMPs published in December 2009.

Updates completed in February 2016 and December 2022.

River Basin Planning (*River Basin Planning Process Overview, 2023*)

Approach: The Environment Agency follows a cyclical *plan-do-check-review* approach, ensuring continuous adaptation and improvement in river basin planning.

Stages of the Environmental Planning and Delivery Framework:

Define Aspirational Outcomes:

Establishes environmental objectives (e.g., achieving good water status).

Sets assessment standards, targets, and planning boundaries.

Includes stakeholder consultations (Working Together step).

Assess Current and Past Conditions:

Evaluates environmental status and trends (improving, declining, or stable).

Identifies environmental problems (e.g., failing protected areas, water body deterioration).

Uses classification methods and partner data to determine issues.

Establishes baselines for future assessments.

Forecast Future Conditions:

Considers climate change, population growth, land use, and emerging threats.

Plans proactive interventions to address risks before they worsen.

Decide on Required Actions:

Identifies technically feasible and cost-effective solutions.

Conducts economic appraisals to prioritize beneficial actions.

Defines target conditions and timelines for achieving objectives.

Implement Actions:

Develops national and local implementation plans with stakeholders.

Ensures coordinated and integrated delivery.

Accommodates opportunistic actions based on new policies, partnerships, or funding.

Monitor and Adjust Plans:

Reviews progress every six years.

Updates objectives and measures as needed.

Conducts economic assessments to guide future investments and government policies.

This structured and adaptive process ensures effective water management and long-term

environmental sustainability (*River Basin Planning Process Overview*, 2023).

Key stakeholders and partnerships

Authorities:

Secretary of State for Environment, Food and Rural Affairs:

- Ensures WFD Regulations are implemented.
- Oversees economic analysis, approves objectives, measures, and plans.
- Provides guidance to the Environment Agency and other bodies.
- Ensures compliance with EU water-related directives.
- Environment Agency:

Develop and update river basin management plans.

- Identifies and monitors protected drinking water areas.
- Proposes environmental objectives and measures.
- Engages the public and ensures access to relevant information.
- Ensures compliance with WFD and related directives.

Outcomes and Impact

Environmental benefits

In 2010, the River Thames received the Thiess International River prize in recognition of major restoration efforts (*River Thames*, n.d.). Once declared biologically dead 60 years earlier, the river has undergone a remarkable recovery. Thanks to the efforts of the Environment Agency, along with its predecessors and partners, water quality has improved, and habitats have been restored. As a result, a diverse range of wildlife has returned, including otters and 125 species of fish in the tidal Thames (*River Thames and Ganges River - The Resilient Rivers Hub*, n.d.).

Social benefits

Enhanced governance structures, creating a model for thinking about participatory environmental governance. Enhanced water quality, and employment in water management efforts.

Lessons Learned and Recommendations

Key takeaways from the project

Best practices and strategies for replication

A word of caution is in order. There is much to learn from other experiences, but a direct replication of frameworks or strategies may be infeasible. There are “Limits to Leapfrogging” (Shah et al., 2001). The contextual differences between the Thames River and the Narmada River are vast. The hydrological systems and terrain are different. The nature of human interactions with the rivers is different in terms of population density and even the composition

of the social positions of the communities. There are noteworthy frameworks and strategies to learn from the Thames River Basin management .

Towards Basins as Units of Environmental Governance: In 1960, the management of the Thames was highly fragmented, with multiple agencies overseeing different aspects of the river, leading to coordination challenges and conflicting interests leading to poor outcomes (Taylor, 2015). The Port of London Authority (PLA) controlled navigation, docks, shipping channels, pollution control, and river conservancy for the tidal Thames, while the London County Council (LCC) managed flood defences, drainage, and sewage treatment within London. The Metropolitan Water Board (MWB) oversaw water supply, relying on both the freshwater Thames and groundwater, whereas the Thames Conservancy handled water resources and pollution control for the non-tidal river. The Lea Conservancy Catchment Board was responsible for the Lea River, while the Essex and Kent River Boards (later River Authorities) managed water resources downstream but had no authority over the tidal Thames, causing tensions with the PLA (Taylor, 2015). This overlapping jurisdiction and division of responsibilities created inefficiencies and rivalries, making it difficult to establish clear authority over the river's management.

The emergence of the river basin as the “natural” scale for governing water resources was a gradual and contested process, requiring negotiations among various stakeholders (Taylor, 2015). The 1973 Water Act marked a major shift by consolidating 1,580 local agencies into ten Regional Water Authorities (RWAs), including the Thames Water Authority (TWA), which took control of the entire 5,000-square-mile Thames catchment. The TWA absorbed key institutions such as the Metropolitan Water Board, Thames Conservancy, Greater London Council's sewerage services, and the Port of London Authority's pollution control functions. However, strong political resistance to removing local democratic control over water and sewerage led to a compromise: RWAs were managed by large boards dominated by local authority representatives. The Greater London Council unsuccessfully attempted to take control of the entire Thames catchment but retained flood management and recreation duties, later opening the Thames Barrier in 1984. While basin-wide management was seen as a way to achieve integrated planning and economies of scale, the transition from local to centralized governance was uneven, shaped by conflicts between urban authorities, environmental groups, and competing water users across the Thames region.

Areas for further improvement or research

Reviewing participatory river management experiences for possible application/development

in Narmada River Basin. Instituting continuous comprehensive monitoring of water quality in full river system, as was done in the Thames river (Bowes et al., 2018). There is a need to provide comparative analysis of international rivers and Indian rivers. There are portions of the Lower Narmada Basin that have high density settlements that could learn from the Thames River restoration efforts. For example, there is work that compares Thames River to Hindon River in India (Sharma et al., 2021). Similar work could be done with Lower Narmada Basin areas.

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Darling River (Australia)

I. Case Study Overview

a. Project Background and Location

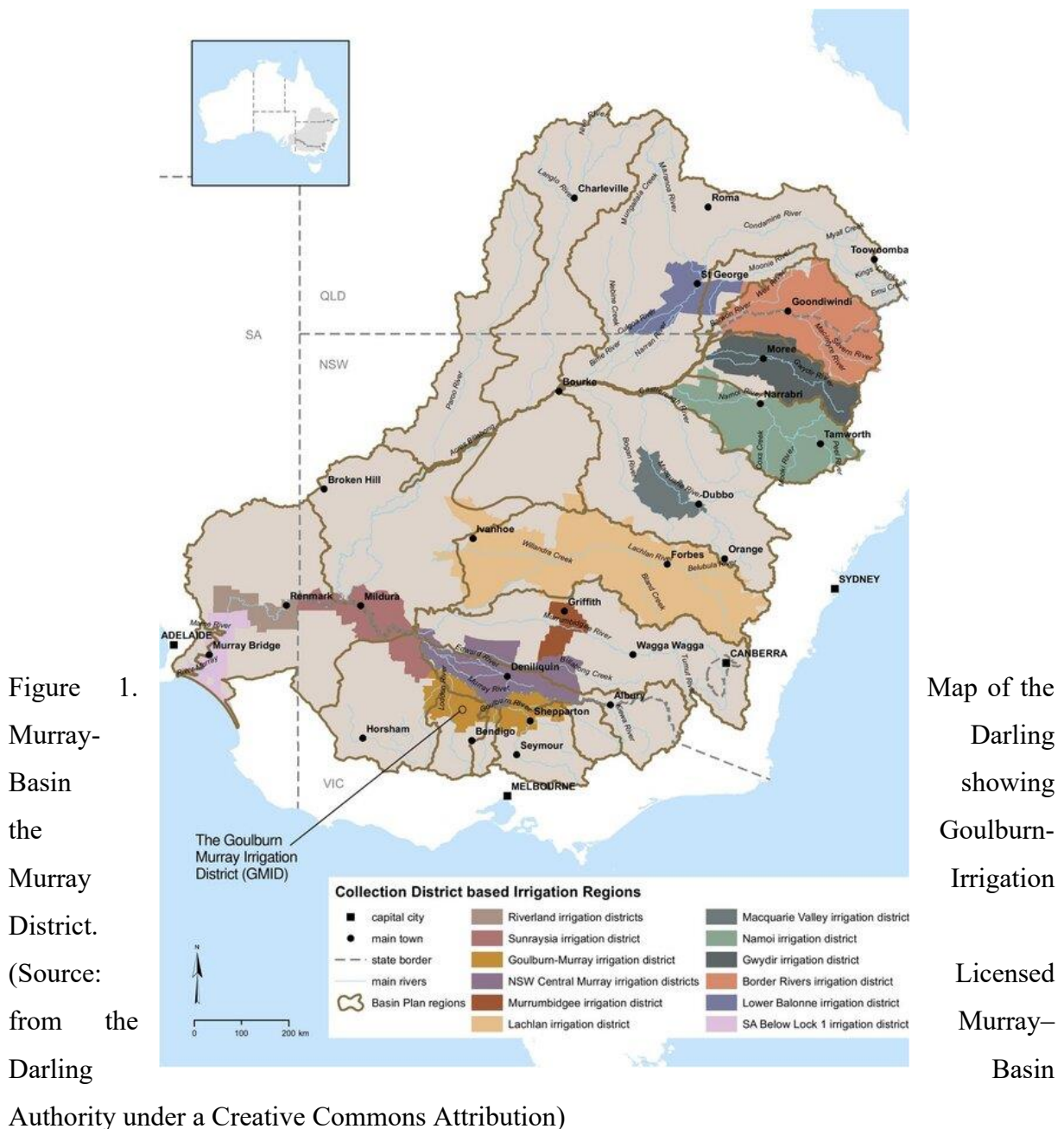
The Darling River is one of Australia's most significant river systems, stretching approximately 1,472 km from northern New South Wales (NSW) through Queensland before merging with the Murray River at Wentworth, NSW. It is part of the Murray-Darling Basin (MDB), which

covers around 1 million square kilometers (Thoms 2022). The MDB contributes to almost 40% of Australia's irrigated production with a gross value of around SAS billion per year. The total agricultural production of this region is worth around SA24 billion per year. Additionally, the MDB has extensive water-related environmental assets (rivers, wetlands, and floodplain forests, with 16 of the wetlands Ramsar-listed (including the Coorong)). The MDB also supports a rural and regional population of over 2.6 million people living in the Basin, including around 120,000 Aboriginal people whose ancestors sustainably occupied the region for tens of thousands of years (Guest 2017, Thompson et al. 2019, Prosser et al. 2021). The MDB system consists of a very large catchment with a quite small coastal lagoon system (the Coorong and in the past the Lower Lakes) with low net runoff to the coast and little influence on the coastal zone. This is very different to many other large river catchment estuarine-coastal systems (e.g. Great Barrier Reet, Mekong, Mississippi, Rhine, Yangtze, and Ganges). Figure 1 represents the Murray-Darling Basin showing the Goulburn-Murray Irrigation District.

The changes to the MDB over the 200 years since European colonisation and settlement have been extensive and include land clearing for agriculture in the 1500s and displacement of Aboriginal traditional owners, water resources developments in the period between the 1900s and 1990s, changed land use, overallocation of water for irrigation, and ongoing ecological degradation. A critical analysis of the major water reforms in the MDB over the past 30 years aimed at rebalancing the system and returning water to the environment, The MDB faces management challenges similar to many transboundary river systems because its governance is shared between the governments of the Australian Commonwealth and four states and one territory (Hart et al. 2020).

The MDB system is managed by the states of Victoria, New South Wales, South Australia, Queensland, the Australian Capital Territory (ACT), and the Commonwealth government. The formal management arrangements in the MDB, covering water sharing and its use, and other related matters such as land use and agriculture commenced soon after Federation in 1901. While these arrangements have evolved over time, they have often been characterised by fractious interactions between the states and between the states and the Commonwealth (Ross

and Connell 2016).



b. Problem Statement: Management and Environmental Challenges

The multiple ways climate change already affects the MDB and analysis of how a changing climate will be the major driver of change in this system over the next 30 years and beyond. The Basin will become hotter and drier, and governments, communities, industries, and ecosystems will be faced with major challenges in adapting to these changes. Despite major water reforms in the MDB over the last 30 years, there is still little integration between the management of water resources, the broader catchment, and interlinked policy issues, including regional development and agricultural transitions. This will need to improve in the future.

challenges facing the MDB are to be effectively addressed (Alston et al. 2016, Pittock 2019). The Darling River has been the center of several environmental crises, with major concerns including:

1. Water Overuse and Overallocation

- Excessive water extraction for irrigation and agriculture, particularly for cotton farming in Queensland and NSW, has led to critically low water levels.
- Unauthorized water diversions by some large agribusinesses have further worsened the problem.

2. Declining Water Quality

- High salinity levels, algal blooms, and pollution from fertilizer runoff, livestock waste, and urban sewage have deteriorated water quality.
- Blue-green algal blooms, particularly in stagnant sections of the river, produce toxins that are harmful to humans, livestock, and aquatic species.

3. Climate Change and Droughts

- Prolonged dry spells, particularly the Millennium Drought (1997–2009) and the 2017–2019 drought, caused extreme water shortages.
- Climate models predict reduced rainfall and higher temperatures, worsening evaporation rates and water scarcity.

4. Ecological Collapse and Fish Kills

- Mass fish deaths, notably in Menindee Lakes (2018–2019), resulted from low oxygen levels and toxic algal blooms.
- Native species like Murray cod, golden perch, and silver perch have been severely affected.

5. Indigenous Water Rights and Cultural Degradation

- Indigenous groups, such as the Barkandji people, have historically relied on the river for spiritual and subsistence purposes.
- Loss of natural water flow and pollution have impacted sacred sites and traditional fishing practices.

II. Project Description

a. Goals and Objectives

The primary goals of Darling River management initiatives include:

1. Sustainable Water Allocation – Ensuring equitable water distribution among agriculture, urban centers, and the environment.
2. Pollution Reduction – Minimizing salinity levels, nutrient runoff, and industrial waste discharge.
3. Biodiversity Conservation – Protecting native fish species, wetlands, and riparian habitats.
4. Climate Resilience – Developing long-term adaptation strategies for extreme weather events.
5. Community Involvement – Enhancing participation of Indigenous groups, farmers, and local communities in water governance.

b. Strategies and Interventions

1. The Murray-Darling Basin Plan (2012-Present)

The Basin Plan, which was legislated in November 2012, is a high-level plan aimed at ensuring that the water resources of the MDB are managed in an integrated and sustainable way to achieve ‘*a healthy working Murray-Darling Basin that supports strong and vibrant communities, resilient industries, including food and fibre production, and a healthy environment*’ (the Vision). The development of the Basin Plan was been highly controversial within the Basin, with considerable community outrage regarding the process, the actual final SDLs, the science and the socioeconomic analyses behind the establishment of the SDLs, the final volume of water to be recovered from irrigators, and the means by which it is to be recovered. In a recent Independent Panel for the Assessment of the Social and Economic Conditions in the Basin, they found considerable community concern regarding the Commonwealth's water recovery programme, the Basin Plan, and its implementation (IPSEC, 2020). These concerns included a distrust in governments (Commonwealth and state) to deliver good long-term policy and support rural and regional communities; a failure to adequately include people in conversations about government policy and their future, especially those who have not been on the upside of change, and a lack of consideration of the issues of Aboriginal people.

2. Water Buyback and Infrastructure Efficiency

- The government buys water entitlements from irrigators to return flows to the environment.
- Investment in water-saving infrastructure (e.g., drip irrigation and pipeline projects).

3. Environmental Watering Programs

- Controlled water releases from dams and wetlands to maintain river ecosystems.
- Managed by the Commonwealth Environmental Water Holder (CEWH).

4. Salinity and Pollution Control Measures

- Salt interception schemes to reduce salinity levels.
- Monitoring of pesticide, fertilizer, and industrial waste runoff.

5. Indigenous Water Rights and Cultural Flows

- Recognition of Indigenous water rights through Native Title laws and cultural water allocations.
- Indigenous-led conservation initiatives to protect sacred sites and traditional fishing grounds.

6. Riparian and Wetland Restoration

- Revegetation programs to stabilize riverbanks and improve water retention.
- Reintroduction of native fish species and control of invasive species like European carp.

c. Key Stakeholders and Partnerships

1. Government Agencies

- Murray-Darling Basin Authority (MDBA)
- Commonwealth Environmental Water Holder (CEWH)
- New South Wales and Queensland Water Departments

2. Local Communities and Indigenous Groups

- Barkandji Nation and Traditional Owners
- Menindee Lakes community members

3. Agricultural and Irrigation Groups

- National Farmers' Federation
- Cotton Australia

4. Environmental and Conservation Organizations

- Australian Conservation Foundation

- Landcare Australia

5. Scientific and Research Institutions

- CSIRO (Commonwealth Scientific and Industrial Research Organisation)
- Universities researching water resource management

III. Outcomes and Impact

a. Environmental Benefits

- Improved water quality and flow regulation through environmental water releases.
- Reduction in salinity levels, benefiting farms and ecosystems.
- Restoration of native fish populations and riparian vegetation.

b. Social Benefits

- Strengthened Indigenous involvement in water governance.
- Improved water security for communities dependent on the Darling River.
- Increased public awareness of water conservation through education programs.

c. Economic Benefits

- Enhanced long-term sustainability of agriculture through water efficiency.
- Expansion of eco-tourism activities, including river cruises and fishing.
- Reduced costs of water treatment and desalination.

IV. Lessons Learned and Recommendations

a. Key Takeaways

1. Balancing water allocation between agriculture, cities, and ecosystems is essential.
2. Climate change adaptation is necessary for long-term water security.
3. Traditional Indigenous knowledge plays a crucial role in river conservation.
4. Stronger regulations and enforcement are needed to prevent illegal water extraction.

b. Best Practices and Strategies for Replication

1. Water trading systems to ensure efficient water use.
2. Integrated catchment management to reduce runoff pollution.
3. Community-driven conservation to increase stakeholder engagement.

4. Eco-friendly farming techniques (e.g., regenerative agriculture).

c. Areas for Further Research and Improvement

1. Developing nature-based solutions for drought and flood resilience.
2. Strengthening cross-state and federal water governance.
3. Expanding real-time water monitoring systems.
4. Addressing emerging water pollutants (e.g., pharmaceuticals and microplastics).

Conclusion

The Darling River is a lifeline for ecosystems, agriculture, and communities, but unsustainable water management and climate change threaten its future. While policies like the Murray-Darling Basin Plan have improved conditions, ongoing challenges require adaptive management, stronger regulations, and increased Indigenous participation. By implementing sustainable water use practices, restoring degraded ecosystems, and integrating climate adaptation strategies, the Darling River can be revitalized for future generations.

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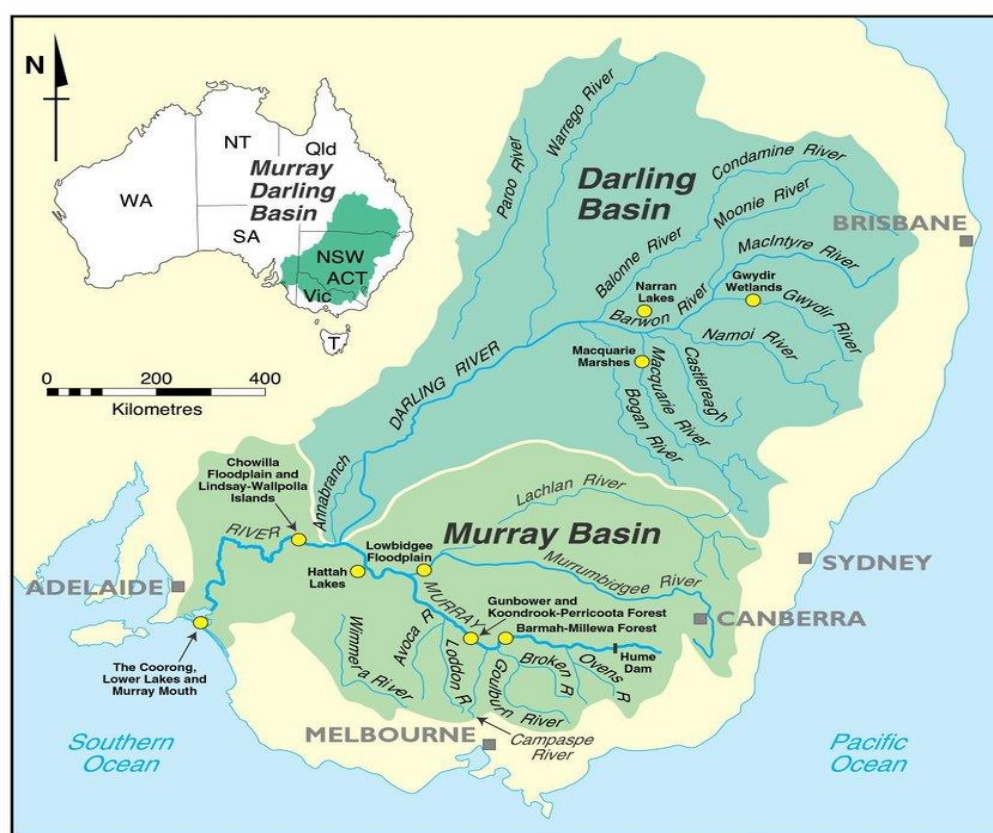
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Murray River (Australia)

I. Case Study Overview – Murray River

a. Project background and location

Murray River is the longest river in Australia, spanning a length of 2530 km, and is a major river system supporting Australia's life and economy. As it flows from the Snowy Mountains to the sea, it passes through several ecological–physiographic regions: Highlands, Riverine, Central Murray Mallee, Gorge, and the Coastal Lakes and Estuary sections (MacKay & Eastburn, 1990). For most of this course, the Murray flows roughly east to west until it reaches Morgan in South Australia, turning southward towards Lake Alexandrina and the sea. For the greater part of its course, the river moves from an area of higher rainfall (800 to 1200 mm per annum) in the Highlands to a much lower rainfall regime (200 to 400 mm per annum) on the



plains through a succession of vegetation zones (Littleton et al., 2023). The basin ends in South Australia, where the Murray Mouth meets the Southern Ocean (Murray Darling Basin Authority).

Figure 1: Murray Darling River Basin (Saintilan & Overton, 2010)

The MDB is home to more than two million Australians. As well as providing drinking water to over three million people (more than one-third of these people live outside the basin), the MDB provides for almost 45 per cent of the value of Australia's agricultural output, including its sheep and cattle industry and significant food and produce such as wheat, rice, cotton, vineyards, canola and soy. The MDB also generates approximately \$800 million annually in tourism and recreational industry income (Native Title Report, 2008). The MDB is immensely

biodiverse; among the native wildlife species of the basin are 98 kinds of bird, 31 frog species, 46 varieties of snake, 100 types of lizards, three species of freshwater turtle and over 50 species of fish (Murray Darling Basin, Authority).

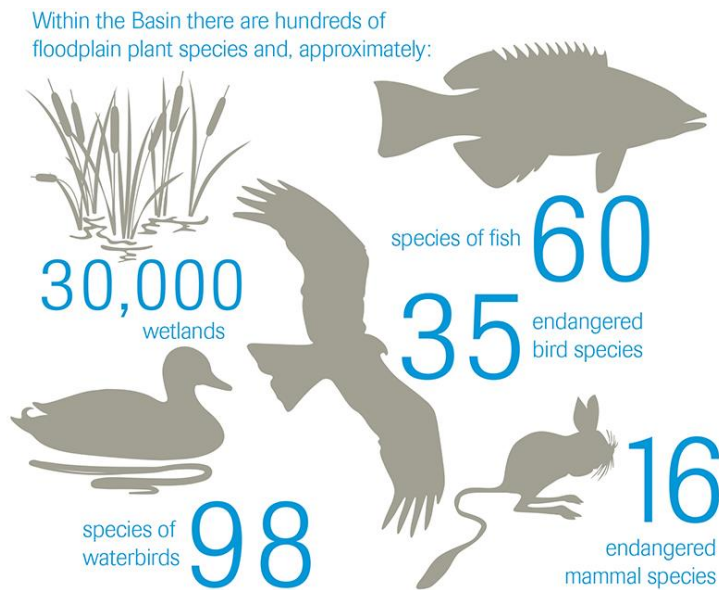


Figure 2: Biodiversity in the Murray Basin (Source: The Nature Conservancy Australia)

b. Problem statement: Management and environmental challenges

1. Over Extraction of Water

The Murray River is a lifeline for irrigation, drinking, industries and recreational activities. This has led to an overutilization of the river, and continuous extraction has led to serious consequences. There have been several notable droughts in the MDB: the Federation drought (1895-1902), the World War II drought (1937-1945), and the Millennium drought (1997-2009). The recent Millennium drought caused severe reductions in water runoff and water use in the MDB, resulting in water quality issues, biodiversity conservation loss and ecosystem function disruption (Wheeler, 2014). The level of water extraction from both groundwater and surface water resources for consumptive, industrial and agricultural purposes is a major contributor to the stress on this fragile river system. The consumptive water use across the MDB has reduced the average annual streamflow at the Murray Mouth by 61%. The river now ceases to flow through the mouth 40 per cent of the time compared to one per cent in the absence of water resource development (Native Title Report, 2008).

2. Groundwater Salinity

Much of the present salinity pattern in the MDB occurred before European settlement. This primary salinity is mainly associated with salt stored in groundwater systems, especially in the

regional sedimentary groundwater systems, where it is estimated that more than 1011 tons of salt is stored in the groundwaters of the Murray Basin (Simpson et al., 1994). This salt has accumulated through a combination of atmospheric fallout of marine and continentally derived solutes, weathering of rocks, ancient marine sediments, and removal of water by evapotranspiration over tens and thousands of years in this flat, low rainfall and high evaporation landscape (Herczeg et al., 2001). Since the European settlement, two significant land use changes and river regulations have resulted in the mobilization of the large primary groundwater salt stores to the land surface and river systems, which has impacted agriculture, water quality, ecological health, and built infrastructure. This resultant groundwater salinity is called secondary salinity (Barry et al., 2020).

3. Climate Issues

The change in climate and rise in global temperature are becoming major threats to the fragile ecosystem of MDB. So, in addition to more extreme droughts, there may also be more extreme floods and other events like bushfires and water quality issues. Climate models by the CSIRO predict that by mid-century, the basin may experience a 5% reduction in average annual rainfall, leading to a 20% reduction in average annual runoff. In an extreme scenario, the reduction in average annual rainfall could be as much as 15%, resulting in a 40% reduction in average annual runoff. The models also suggest that droughts could occur twice as frequently. These predictions are based on limiting global average warming to 2°C, but current warming trends indicate that warming could reach 2.5 to 3.5°C by the end of the century (Murray Darling Basin Authority). Along with these other major issues like Blackwater incidents, Lower DO, sediment deposition, and algal and cyanobacterial bloom are also closely related to changes in climate.

4. Loss of Biodiversity

The trajectory of Basin ecosystem decline is significant, with many key wetlands and floodplains approaching a threshold point of no return (Overton, 2012). Since European settlement, changes to the river system have resulted in many species living in the basin becoming endangered. Despite conservation efforts:

- At least 20 mammal species which lived in the basin have become extinct since European settlement, and 16 are endangered
- 35 bird species are endangered
- 5 species of snake and one lizard species are endangered (Murray Darling River Basin Authority).

II. Project Description

To overcome the challenges in the Murray River Basin, comprehensive strategies with well-defined objectives and actionable plans have been developed.

The Major objectives of Murray River Basin Management are:

- Healthy rivers that support resilient and thriving communities
- Protecting key environmental systems and cultural assets
- Protecting and promoting First Nations peoples' rights, interests, and role as custodians for the Country
- Productive agricultural communities and confident industries

Different measures and interventions, including legislation, have been implemented to achieve these objectives. By the Water Act 2007, the Basin Plan was brought into Commonwealth law in 2012. It resulted from a joint and agreed vision of the Australian government and state and territory governments to manage the rivers and groundwater at the Basin scale in the national interest (Basin Plan Review, 2024). In Figure 2, the timeline of Major Institutional and Management Arrangements in the Murray Basin is enlisted

Table 1: The Major Institutional and Management arrangements in Murray Basin

Year	Institutional And Managerial Developments
1992	Murray-Darling Basin Agreement replaces 1914 River Murray Waters Agreement
1995	Introduction of interim cap on Murray-Darling Basin surface water diversions
2002	Basin Salinity Management Strategy adopted
2004	National Water Initiative signed by all basin governments
2007	Water Act 2007 introduced
2008	Murray-Darling Basin Authority formed; 1992 agreement becomes part of Water Act 2007

2012	Murray-Darling Basin Plan becomes law
2017	Five-year report on the effectiveness of the Basin Plan
2019	State water resource plans revised in-line with the Basin Plan: sustainable diversion limits come into effect

Some key projects for the Murray Basin Management and the goals, strategies and key stakeholders are as mentioned:

1. Basin Plan Implementation

- The Basin Plan involves the management of the environment, boosting the economy while protecting the communities.
- The Plan functions on:
 - Limiting the amount of water extracted to prevent over-extraction
 - Giving back the extracted water back to rivers through structures and water trades to ensure the health of rivers and wetlands
 - Tackle the threat of Global Warming and climate change
- The Basin Plan Implementation is majorly presided over by the Australian government; other key players include state and local governments, the Murray Darling Basin Authority, and various other bodies.

2. Constraints Management Strategy (CMS)

- The CMS strategy ensures the maximum environmental benefits of water being returned into the river system by having a neutral or minimal effect on the community.
- The Key Contributors to CMS are landholders, irrigators, peak groups, Landcare and environmental groups, Indigenous leaders, catchment management authorities, state water agencies and local councils.

3. Environmental Watering

- Environmental watering, or Water for Environment, is a practice by which the health of rivers, wetlands and floodplains are maintained in the Murray Basin.
- The water is allocated to the water holders across the basin, who then decide on how, when and where the water should be released keeping a measurable environmental outcome. The water is then delivered in various ways depending

on the site and the desired outcomes. For example, water can be released from a dam into a river or transferred to a wetland via pumps, gates, and other purpose-built structures, which are known as environmental work.

- The Key Stakeholders include the Murray Darling Basin Authority, Commonwealth Environmental Water Holder, Basin State Governments, Australian Government, First Nation people and local communities.

4. Sustainable Diversion Limit Adjustment Mechanism (SDLAM)

- MDP has set limits on the amount of water that can be withdrawn from the river system, which is called the Sustainable Diversion Limit.
- The Goal of this mechanism is to recover 605 Giga Liters (GL)/y to enhance the environmental outcomes with the combined effect of 36 SDLAMs.
- The process works by adopting interventions that reduce evaporation at storage, better environmental water management using infrastructure, and changing river operating rules.
- Basin state governments are responsible for delivering SDLAM projects, overseen by the Basin Officials Committee (BOC).

5. Water Trades

- Water trades are another measure introduced to improve water redistribution as a resource. Water is allocated to each user depending on rainfall, inflows into storage and how much water is already stored. Allocations can increase throughout the year in response to changes in the system (Murray Darling River Basin Authority).
- Its main aim is to redress the over-allocation of water licenses and to return 2750 GL of water from irrigated agricultural land to the river system (Water and Land Resource Vertical, 2023).
- The stakeholders involve people living in the Basin, First Nations, state and local governments and institutions, Irrigation Infrastructure Operator (IIO) rules, Murray–Darling Basin Authority, Inspector-General of Water Compliance, and the Australian Competition and Consumer Commission (ACCC).

III. Outcomes and Impact

A. Social Impact

- The use of various Litigation like “The Declaration on the Rights of Indigenous Peoples” and bodies like Murray Lower Darling Rivers Indigenous Nations (Aboriginal Corporation) (MLDRIN) provides them access to indulge in the dialogue along with protection of rights that includes the right to a healthy environment, right to water and right to culture.
- Use and Occupancy Mapping is now being done to record Indigenous people's cultural, environmental, social and economic interests for each site. This approach focuses on the relationship of the Indigenous Community with the land and can be considered in creating the icon site management activity.

B. Economic Impact

- Irrigated agriculture is responsible for around 30% of the gross value of agriculture production (MDBA, 2020b) despite representing only 3% of the agricultural land (Hart et al., 2021), contributing more than \$20 billion per year in gross value.
- Tourism accounts for over \$7 billion in gross value added in 2017-18 and 2018-19 (Aither, 2022).



Image 1: Image of Kayaking in River Murray (Source: State of Environment, 2023)

C. Environmental Impact

- The basin is a breeding ground for native fish species like Golden Perch and Silver Perch in the river channel and black bream in the Northern Coorong.

- Increase in the number of Juvenile Coongli, migratory fish migrating from Coorong to Lake Alexandrina through summer.
- 99.92% of daily salinity measurement sites recorded levels well within the acceptable 800 micro-Siemens/sec limit.

IV. Lessons Learned and Recommendations

a. Key takeaways from the project

- Coordination among various stakeholders poses a huge challenge. However, there is still a need for trust to build among the central government, state governments, and local governments to achieve the goals of the Basin Management Plan.
- The rights of First Nation people are required to be ensured, and the emphasis on the protection of social, cultural and economic rights on the river as a resource by First Nation Inhabitants.
- Climate change and induced effects pose a considerable challenge, being a semiarid region, and with the rise in temperature, it is estimated that water scarcity across the Murray Basin is a huge threat.

b. Best strategies for adoption

- The First Nations' inhabitants' knowledge has been passed through generations; this knowledge helps them make better decisions and management practices.
- Updated River Models are used under the River Modeling Uplift Program, increasing transparency in assumptions and avoiding Black box decision-making.
- Water Trade is a common practice in the region. The Entitlement can be sold, and sometimes, governments are even involved in buying the Entitlement right from the free market.

c. Areas for Further Research

- A major focus of further Research is climate change-induced effects over the basin and timely interference to curb the effects like water scarcity.

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Danube River
[Not received]

Rhine River
Rhine River Basin: Case Study – I

I. Case Study Overview

a. Project Background and Location

The Rhine River (Figure 1), a crucial European waterway, traverses Switzerland, France, Germany, and the Netherlands, with its basin encompassing parts of Austria, Liechtenstein, Italy, and Belgium. Serving as a historical artery for transport, industry, and agriculture, the Rhine has faced significant ecological pressures [3]. The International Commission for the Protection of the Rhine (ICPR), established in 1950 with the initial aim of improving water quality, plays a pivotal role in coordinating efforts to mitigate these challenges.

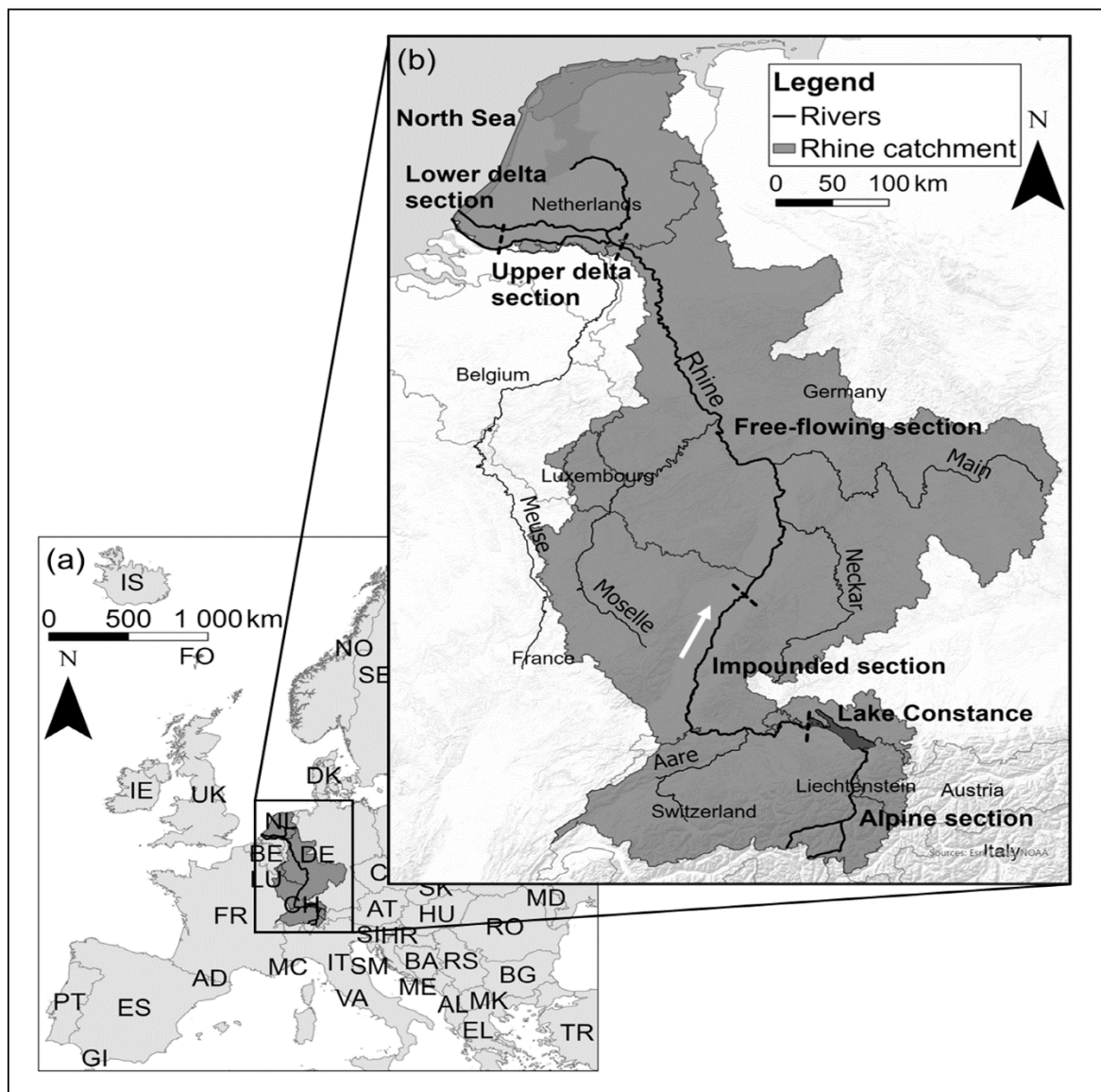


Figure 2. The Rhine River is located in central Europe [1].

Launched in 2001 at the 13th Conference of Rhine Ministers in Strasbourg, the "Rhine 2020" programme focused on the further improvement of the Rhine ecosystem, the reduction of flood risks and groundwater protection. This initiative built upon previous efforts, notably the Rhine Action Programme launched after the catastrophic Sandoz accident on 1 November 1986, in which several tonnes of toxic pesticides were released into the Rhine killing the aquatic communities for hundreds of

kilometres. The Rhine 2020 programme was supplemented by the resolutions of the Rhine Ministerial Conferences of 2007 and 2013 regarding climate change impacts, low water issues and plastic waste. The Water Framework Directive (WFD - Directive 2000/60/EC) and the Flood Risk Management Directive (FD Directive 2007/60/EC) have contributed significantly to the implementation of the ICPR programme. The goals that have not been achieved require further efforts as part of the implementation of the ICPR's "Rhine 2040" programme.

b. Problem Statement: Management or Environmental Challenge

The Rhine River confronts a complex array of environmental and management issues:

Ecological Degradation: Channelization, pollution, and habitat loss have historically impacted biodiversity and ecological integrity.

Water Quality Issues: Industrial, agricultural, and municipal discharges have contributed to pollution from nutrients, heavy metals, pharmaceuticals, and pesticides.

Flood Risk: Urbanization and land use changes in the Rhine basin have increased the potential for severe floods.

Low Water: Climate change and water extraction put stress on the river during dry periods.

Climate Change: Climate change exacerbates existing problems and introduces new challenges, such as altered water flows and temperatures.

Addressing these interconnected challenges demands coordinated international cooperation and integrated management approaches.

II. Project Description

a. Goals and Objectives

The ICPR's "Rhine 2020" programme set concrete targets for 2020 with a view to sustainable improvement of the ecosystem, including:

Ecological Improvement:

the reactivation of 160 km² of floodplains along the mainstream of the Rhine.

the connection of at least 100 oxbow lakes or lateral water bodies to the dynamics of the Rhine.

increasing the structural diversity of 800 km of riverbanks along the Rhine.

restoring the ecological continuity of the Rhine to Basel and in the tributaries from the Migratory Fish Programme for upstream and downstream migrating fish (specified in the Rhine Ministerial Conferences 2007 and 2013).

Water Quality Improvement:

Reducing nutrient loads (nitrogen, phosphorus) entering the Rhine and North Sea.

Reducing pollution from heavy metals, pharmaceuticals, and pesticides.

Flood Risk Reduction:

Reducing flood damage risks by 25% by 2020 (compared to 1995 levels).

Reducing extreme flood levels downstream of the impounded Upper Rhine by up to 70 cm.

Groundwater Protection:

Ensuring good quantitative status of groundwater bodies.

Improving the chemical status of groundwater bodies, particularly regarding nitrogen contamination.

b. Strategies and Interventions

The ICPR employed a range of strategies and interventions to achieve the "Rhine 2020" objectives:

Ecological Restoration:

Floodplain Reactivation: Dyke relocation, ecological flooding of retention areas, and the more natural design of estuaries of Rhine tributaries.

Habitat Connectivity: Connecting oxbow lakes, improving riverbank structure, and removing or modifying migration obstacles (weirs, dams) to restore fish passage.

Migratory Fish Programme: Implementing measures to support the return of migratory species like salmon, including habitat restoration and fish passage construction. The "Master Plan Migratory Fish Rhine", updated in 2018, shows how migratory fish species can be preserved and permanently reintroduced in the Rhine area.

Water Quality Management:

Wastewater Treatment Upgrades: Optimizing and expanding municipal and industrial sewage treatment plants to reduce nutrient and pollutant discharges.

Diffuse Source Pollution Control: Implementing measures to reduce nutrient runoff from agricultural and urban areas.

Micropollutant Reduction: Developing and implementing strategies to reduce the discharge of pharmaceuticals, pesticides, and other micropollutants. The ICPR issued recommendations in 2019 on how to further reduce micropollutant discharges into water bodies.

Sediment Management: Remediating contaminated sediment sites.

Flood Risk Management:

Flood Action Plan (APF): Implementing a comprehensive plan including retention basins, dike improvements, and floodplain restoration to reduce flood peaks.

Flood Forecasting and Warning Systems: Improving the accuracy and timeliness of flood forecasts and warnings. Since 2005, the forecast periods have been extended by 100 % compared to 1995.

Public Awareness: Raising public awareness of flood risks through flood risk maps and other communication tools.

Low Water Management:

Establishing a uniform low water monitoring system.

Communicating information on low water events and potential consequences.

Climate Change Adaptation:

Developing and implementing a climate change adaptation strategy based on discharge scenarios and projections. The ICPR issued in 2015 its climate change adaptation strategy, which will be updated shortly.

Promoting integrated approaches that synergize flood protection, water protection and nature conservation.

c. Key Stakeholders and Partnerships

The success of the "Rhine 2020" programme depended on effective collaboration among a diverse range of stakeholders:

ICPR Member States: Switzerland, France, Germany, the Netherlands, Luxembourg, and the European Union.

Other Rhine Basin States: Austria, Liechtenstein, Italy, and the Belgian Walloon region.

Government Agencies: National, regional, and local authorities responsible for water management, environmental protection, and flood control.

Industry: Companies from various sectors (e.g., chemical, agriculture) that discharge pollutants into the Rhine.

Non-Governmental Organizations (NGOs): Environmental groups advocating for Rhine protection and ecological restoration.

Research Institutions: Universities and research centers conducting scientific studies on the Rhine ecosystem.

Local Communities: Residents and businesses in the Rhine basin who are affected by water quality, flood risk, and ecological changes.

The ICPR provided a crucial platform for these stakeholders to coordinate their efforts, share information, and develop joint strategies. The states in the Rhine catchment area have been working together successfully for 70 years to align the diverse uses and protection of water bodies. In 2013 the ICPR was awarded the European River Prize and in 2014 the International Thiess River Prize for its successful work since 1950.

III. Outcomes and Impact

a. Environmental Benefits

The "Rhine 2020" programme has demonstrably improved the ecological health of the Rhine River. However, the assessment clearly shows that many objectives of the "Rhine 2020" programme have been achieved or set in motion, but not all the objectives set at that time have been achieved in full. Specific improvements in key areas include:

Ecology:

Floodplain Reactivation: Since 2000, around 140 km² of floodplains have been reactivated. By the end of 2018, more than 130 km² of floodplains in the Rhine had been reactivated (Figure 2). Considerable progress has also been made in protecting valuable floodplain ecosystems. The ICPR is examining whether it will be possible to carry out complete monitoring of success based on satellite data throughout the Rhine floodplain in the future.

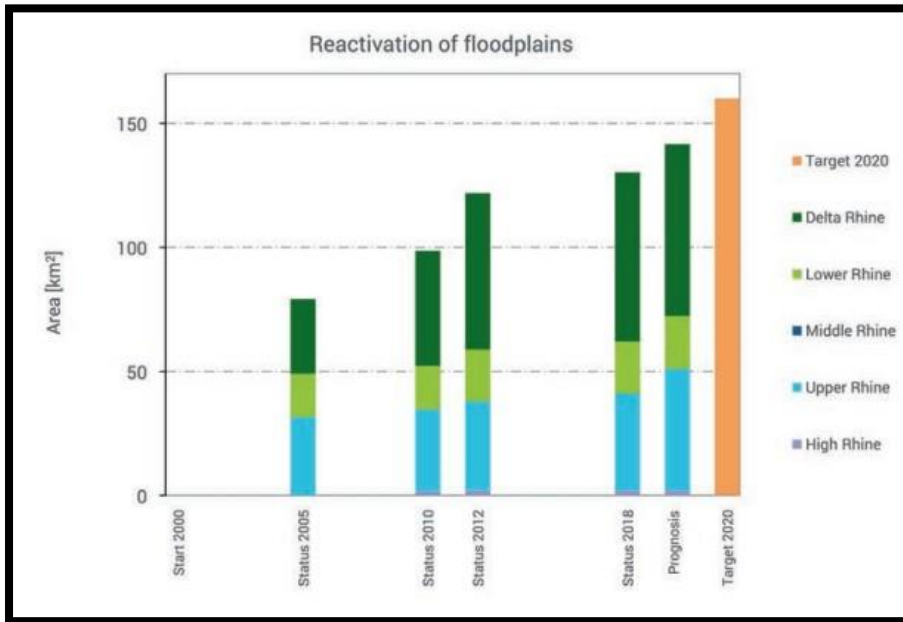


Figure 2. Reactivation of floodplains in Rhine River Basin.

Habitat Connectivity: Since 2000, 124 alluvial waters have been reconnected to the main Rhine River, exceeding the target set for 2020 of reconnecting 100 oxbow lakes and lateral water bodies to the Rhine (Figure 3).

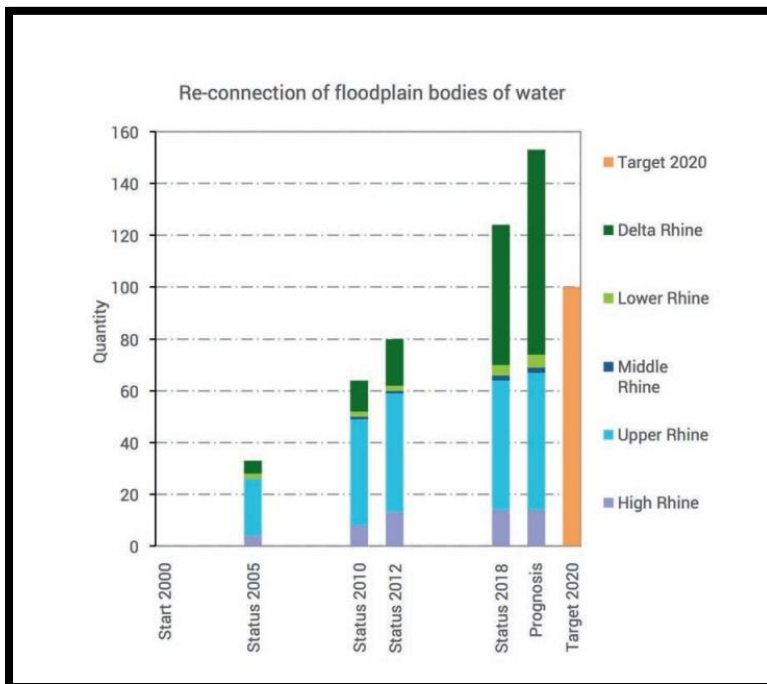


Figure 3. Reconnection of floodplain bodies of water [2].

Structural Diversity: Increasing the structural diversity of the banks of the Rhine and its arms. Structural diversity promotes biological diversity (Figure 4). This is because a varied design of the banks and riverbed creates new habitats for typical Rhine flora and fauna. Naturally overgrown and shallow riverbank areas can also strengthen the self-purifying property of a water body and increase the attractiveness of a water landscape as a local recreation area. In many places, concrete or monotonous rock-bed banks have been replaced by near-natural shallow and gravel-rich banks. Newly created gravel

islands, areas protected from wave impact and the introduction of deadwood have created a variety of new habitats along the Rhine for young fish, aquatic plants and invertebrates such as crabs and insect larvae.

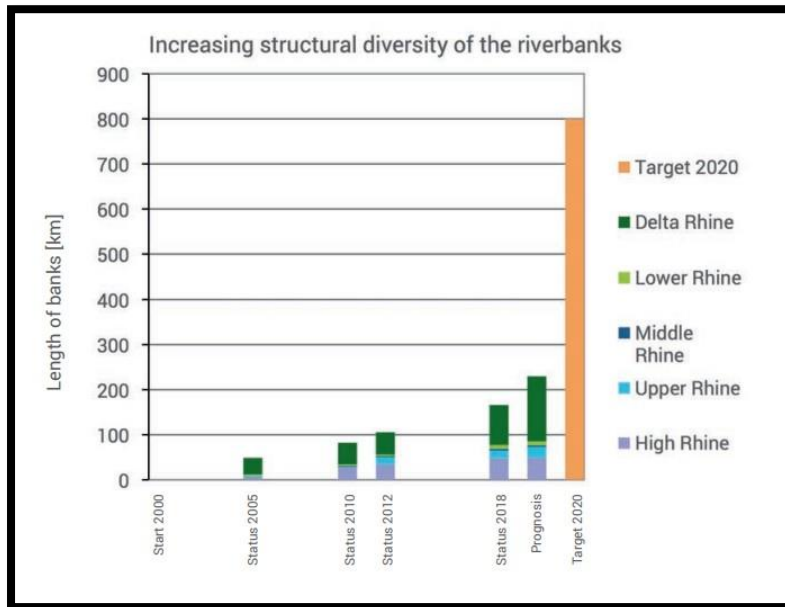


Figure 4. Structural diversity of the river banks [2].

However, the implementation of this goal is progressing slowly, as it is both economically and socially challenging. Ambitious projects require the acquisition of large areas along the banks, and in some places, users and residents are critical of measures. The transformation of the riverbank areas to a near-natural state is being prevented or at least delayed by the lack of clarity regarding responsibility for action and costs for large sections of the Rhine. In many places, it also conflicts with the use of the Rhine as a shipping lane. The importance of increasing the diversity of bank structures has now been recognised and the framework conditions for implementing the corresponding measures are continually improving. The European Commission is providing financial support for projects to create a blue-green infrastructure.

River Continuity: Almost 600 migration obstacles in the Rhine and the tributaries important for the reintroduction of migratory fish have been removed or equipped with fish passages. More than 28 % of the valuable salmon habitat areas have thus been reconnected to the Rhine. Today, several hundred salmon from the North Sea return to the accessible tributaries of the Rhine every year and reproduce naturally. A milestone for the restoration of the return of migratory fish from the sea to the Rhine and Meuse systems was achieved at the end of 2018 with the partial opening of the Haringvliet dam south of Rotterdam. With the construction of fish passages at four large weirs in the Upper Rhine, the goal of reopening the Rhine from the North Sea to Switzerland for fish migration is drawing closer, even if it has not yet been fully attained. Further obstacles to migration must be removed and habitats must be upgraded (Figure 5).

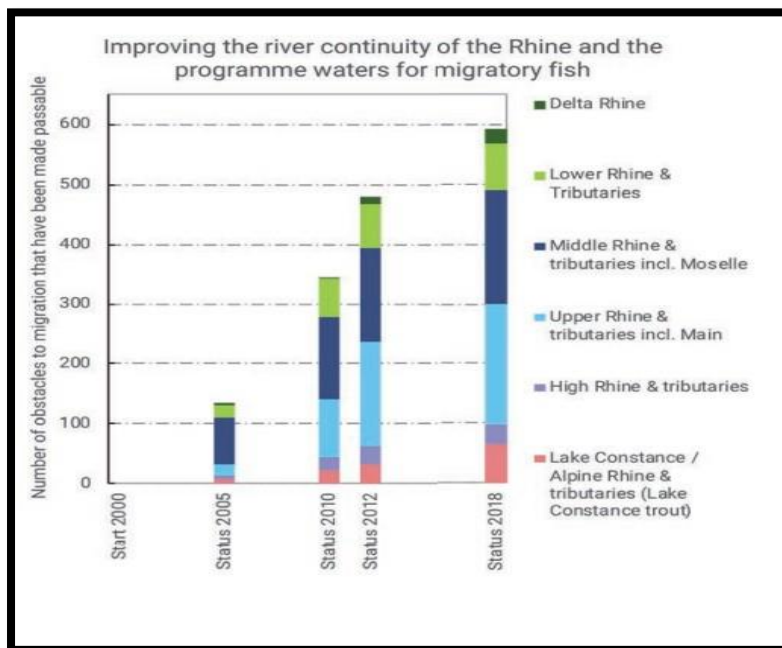


Figure 5. River continuity.

Migratory Fish Restoration: While the salmon was considered lost in the Rhine in 1958, today several hundred salmon from the North Sea return to the accessible tributaries of the Rhine every year and reproduce naturally there. Other previously widespread migratory fish such as allis shad, sea trout and sea lamprey also swim in the Rhine once again. The populations of salmon, shad, and sea trout are not yet self-sustaining and have to be supported by stocking measures in most of the programme waters and the Rhine [4]. On the other hand, the houting, a migratory fish species originally native to the Lower Rhine and the Delta Rhine, which had become extinct in the meantime, has been reintroduced so successfully that the population has now established itself, even without stocking measures (Figure 6).

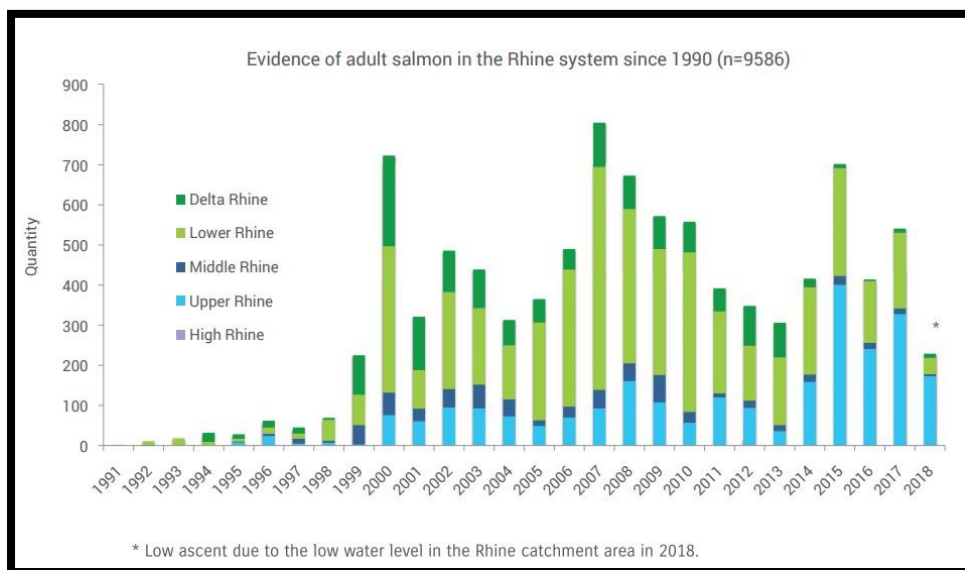


Figure 6. Migratory Fish Restoration.

Riverbanks: It has only been possible to ecologically upgrade 166 km of the Rhine bank since 2000. Due to the river's intensive use as a shipping lane, this target falls far short of the 800 km target. Every

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six years, the Rhine Monitoring Programme Biology investigates fish stocks, macrozoobenthos (invertebrates), macrophytes (aquatic plants), phytobenthos (fixed algae) and plankton in the mainstream. A further objective of the “Rhine 2020” programme is to restore the former network of biotopes typical of the Rhine, the habitat patch connectivity.

Water Quality:

The nitrogen load from the Rhine catchment area into the North Sea and the Wadden Sea was reduced by 15 - 20 % by 2015 because of continuous upgrading, optimization and expansion of municipal and industrial sewage treatment plants [5]. It has not yet been possible to significantly reduce the contamination by nutrients from diffuse sources (with a focus on agriculture, but also on urban areas). Contamination from metals was already significantly reduced between 1987 and 2000. It has been further reduced since 2000 by the construction, optimisation and modernisation of municipal and industrial sewage treatment plants. The causes of pollution must continue to be monitored and measures must continue unabated.

According to the 2017 assessment, active pharmaceutical substances and their degradation and transformation products are detectable in the entire catchment area of the Rhine. The ICPR issued in 2019 recommendations on how to further reduce micropollutant discharges into water bodies. It also explicitly dealt with active pharmaceutical substances and X-ray contrast agents.

Emissions of pesticides have been significantly reduced by new legal regulations on substances, bans on use and approvals, and new application techniques. However, peak loads can still occur at times, particularly in smaller bodies of water. The ICPR recommendations of 2019 for the reduction of micropollutants are also aimed at agriculture. The quantitative status of groundwater bodies is largely good (96 %). However, the chemical status of 33 % of groundwater bodies is poor, due to excessive nitrogen contamination.

Of the 22 risk areas identified in the 2009 Sediment Management Plan, remediation work was completed at ten sites. Some substances, including mercury, exceed the specified environmental quality standards everywhere. The biota investigations in 2014/15 provide an overview of the contamination of biota (fish) with pollutants in the Rhine catchment area.

Communication via the International Warning and Alarm Plan (IWAP) for the Rhine works well, reliably and via the Internet across states and countries.

Floods:

The states in the Rhine catchment area successfully implemented the Flood Action Plan on Floods (APF) between 1995 and 2020 at a cost of more than 14 billion euros.

The most important objective of the APF (1998), the “reduction of flood damage risks by 25 % by 2020”, has been achieved.

In 2020, a retention volume of around 340 million m³ for major floods will be available on the Rhine. By 2030, the planned volume will be around 540 million m³. The APF target of “reducing extreme flood levels downstream the impounded section of the Upper Rhine by up to 70 cm by 2020” has not been achieved. Numerous measures to lower water levels have been implemented since 1995. However, the

reduction of 70 cm will only be achieved in some places in 2020 and only for a few floods.

The flood announcement system has been improved. Since 2005, the forecast periods have been extended by 100 % compared to 1995. The awareness of flood risk among the population has been strengthened.

Low Water:

Based on an inventory carried out in 2018, the ICPR has set up a uniform low water monitoring system throughout the Rhine. In the future, it will communicate more intensively on low water events, their consequences, and measures.

Climate Change:

There are ICPR studies on the effects of climate change on the water balance, water temperature and ecology.

Based on discharge scenarios for the near (by 2050) and remote (by 2100) future, the ICPR issued in 2015 its climate change adaptation strategy, which will be updated shortly.

The Rhine catchment area already has many examples, including cross-border ones, showing synergies between flood protection, water protection and nature conservation.

b. Social Benefits

The programme also generated important social benefits:

Enhanced Community Engagement: Public participation in restoration projects and increased awareness of environmental issues has fostered a sense of stewardship and community engagement.

Improved Recreation: Restored floodplains and improved water quality have enhanced recreational opportunities, such as hiking, biking, and fishing.

Reduced Flood Risk: The Flood Action Plan has reduced flood damage risks, protecting communities and infrastructure.

c. Economic Benefits

The economic benefits of the "Rhine 2020" programme include:

Cost Savings: The states in the Rhine catchment area successfully implemented the Flood Action Plan on Floods (APF) between 1995 and 2020 at a cost of more than 14 billion euros. Reduced flood damage translates into significant cost savings for governments, businesses, and individuals.

Ecosystem Services: Restored floodplains provide valuable ecosystem services, such as water purification and carbon sequestration, which have economic value.

Tourism: Improved water quality and restored landscapes can attract tourists, boosting local economies.

Property Values: Reduced flood risk can increase property values in flood-prone areas.

IV. Lessons Learned and Recommendations

a. Key Takeaways from the Project

Several key takeaways emerged from the "Rhine 2020" programme:

International Cooperation is Essential: The Rhine River is a shared resource, and its effective management requires close collaboration among all basin states.

Integrated Approaches are More Effective: Addressing multiple challenges (e.g., flood risk, water

quality, ecological degradation) through integrated, multi-objective projects yields better outcomes.

Long-Term Commitment is Necessary: Restoring a large and complex ecosystem like the Rhine requires sustained effort and investment over decades.

Adaptive Management is Crucial: The programme needed to adapt to new challenges, such as climate change and emerging pollutants, adjusting strategies as needed.

Stakeholder Engagement is Key: Involving all stakeholders in the planning and implementation process ensures that projects are effective, equitable, and sustainable.

b. Best Practices and Strategies for Replication

The "Rhine 2020" programme offers several best practices and strategies that can be replicated in other river basins:

Establish Clear Goals and Targets: Setting specific, measurable, achievable, relevant, and time-bound (SMART) goals provides a clear direction for management efforts.

Develop Comprehensive Action Plans: A well-defined action plan outlining specific measures, timelines, and responsibilities is essential for effective implementation.

Invest in Monitoring and Assessment: Regular monitoring of water quality, ecological conditions, and flood risk is crucial for tracking progress and identifying emerging problems.

Promote Knowledge Sharing: Sharing experiences, lessons learned, and best practices among river basin organizations can accelerate progress and avoid duplication of effort.

Secure Sustainable Funding: Long-term funding commitments are essential for sustaining management efforts and achieving lasting results.

c. Areas for Further Improvement or Research

While the "Rhine 2020" programme achieved significant progress, some areas require further attention:

Diffuse Source Pollution: It has not yet been possible to significantly reduce the contamination by nutrients from diffuse sources (with a focus on agriculture, but also on urban areas).

Micropollutant Management: Active pharmaceutical substances and their degradation and transformation products are detectable in the entire catchment area of the Rhine.

Climate Change Adaptation: More research is needed to assess the long-term impacts of climate change on the Rhine and to develop robust adaptation strategies.

Integrated Sediment Management: Some substances, including mercury, exceed the specified environmental quality standards everywhere.

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Rhine River Basin: Case Study – II

Case Study: Rhine River Basin Management: Lessons for the Yangtze River

I. Case Study Overview

a. Project Background and Location

The Rhine River is the longest in Western Europe, stretching approximately 1,233 kilometers, flowing through Switzerland, Liechtenstein, Austria, Germany, France, and the Netherlands [1]. Historically, it has been one of Europe's most important waterways, serving as a major trade route and a source of drinking water, irrigation, and hydroelectric power for millions of people. However, industrialization and urbanization in the 19th and 20th centuries led to severe pollution problems. Rapid industrial development along the river introduced heavy metals, synthetic chemicals, and untreated wastewater into the Rhine [1].

The turning point came with a major pollution incident where 5–8 tons of highly toxic pesticides and more than 100 tons of fire extinguishing agents were released into the river. This contamination caused severe ecological damage, including the death of most fish within a range of about 160 km and affecting drinking water sources up to 480 km. Furthermore, pollutants like PCBs had a huge impact on the river's ecology, contributing to the decline of species such as the European [1]. By the mid-20th century, the Rhine became one of the most polluted rivers in Europe, endangering aquatic biodiversity and water quality. Pollution accumulation led to the near-extinction of migratory fish like the Atlantic salmon [2]. The river was often referred to as the “sewer of Europe” [1].

The Rhine River passes through multiple countries, and they had different monitoring priorities and governance schemes in the past. Given the transboundary nature of the river, effective international cooperation was necessary for restoration. In response, various countries established agreements to combat pollution, culminating in the International Commission for

the Protection of the Rhine (ICPR) and a series of large-scale environmental action programs. The previous co-operations didn't produce significant governance effects until ICPR was established for unified management.

b. Problem Statement: Management or Environmental Challenge

River Basin is a complex and sensitive ecosystem that requires meticulous management plans covering the key aspects, including environmental issues, flow, biodiversity, etc. (Figure 1). The Rhine River faced severe pollution due to industrial discharge, agricultural runoff, and inadequate wastewater treatment, threatening aquatic life, water quality, and ecosystem health [1]. The lack of coordinated environmental management among Rhine-bordering countries worsened the problem, turning the river into a convenient sewage disposal site over the last century [1]. As Shi et al. (2021) [1] note, the Rhine became the most convenient sewage disposal place due to accumulated pollution and diffused impact in the last century. Addressing this issue required a comprehensive international approach to pollution reduction, ecological restoration, and sustainable river basin management.

Other persistent issues included high levels of heavy metals, persistent organic pollutants (PCBs, dioxins), and sewage overflow, rendering the Rhine unsuitable for drinking water without advanced treatment [3]. Flood risk management was another challenge. The Rhine has historically been prone to devastating floods, exacerbated by urban expansion, land-use changes, and climate change [4]. Growing pressure on water resources and ecosystem degradation highlighted the inadequacy of traditional pollution control measures. A comprehensive, cross-border management strategy was essential to restore the Rhine's ecological health while balancing economic development and industrial activities.



Figure 1. Rhine River Management Challenges.

II. Project Description

a. Goals and Objectives

The overarching goal of the Rhine River management project was to restore the river's water quality and ecological health, ensuring its sustainable use for future generations [1]. Key objectives included:

Reducing pollution from various sources, including chemical, heavy metal, and organic pollutants.

Improving water quality to levels that support aquatic life and human use.

Restoring natural habitats and promoting biodiversity.

Establishing a comprehensive and coordinated management framework involving all stakeholders.

Implementing long-term monitoring and adaptive management strategies to address emerging challenges.

Returning key species, such as salmon, to their original habitats [1].

Addressing broader ecological issues such as rebuilding natural habitats and implementing flood protection measures [1].

b. Strategies and Interventions

The Rhine River management project employed a range of strategies and interventions, including:

International Cooperation: Establishing the International Commission for the Protection of the Rhine (ICPR) in 1950 to facilitate collaboration among countries in the basin [1]. The ICPR was reconstituted by a formal treaty among the nine riparian states in 1963.

Rhine Action Program (RAP): Implementing comprehensive action plans with specific targets for pollution reduction and ecosystem restoration.

Policy and Regulation: Enacting and enforcing regulations to control pollution from point and non-point sources. This included the Convention for the Protection of the Rhine against Chemical Pollution.

Investment in Infrastructure: Upgrading wastewater treatment plants and implementing best management practices in agriculture.

Monitoring and Assessment: Regularly monitoring water quality and ecological health to track progress and identify emerging issues.

Ecological Restoration: Implementing measures to restore natural habitats, such as wetlands and floodplains, and improve fish passage.

Sediment Management: Addressing pollution from contaminated sediments through targeted removal and remediation efforts.

Rhine 2020: Implementing ecological issues such as rebuilding natural habitats and flood protection measures [1].

c. Key Stakeholders and Partnerships

The success of the Rhine River management project relied on the engagement and collaboration of various stakeholders and partnerships:

International Commission for the Protection of the Rhine (ICPR): The central coordinating body, responsible for developing and implementing management plans [1].

National Governments: The governments of countries within the Rhine River Basin, responsible for enacting and enforcing regulations.

Local Authorities: Regional and municipal governments responsible for implementing local management measures.

Industry: Industrial sectors that discharge pollutants into the river, required to adopt cleaner production practices.

Agricultural Sector: Farmers and agricultural organizations, encouraged to implement best management practices to reduce agricultural runoff.

Non-Governmental Organizations (NGOs): Environmental groups that advocate for river protection and participate in monitoring and restoration efforts.

Research Institutions: Universities and research organizations that conduct scientific studies to inform management decisions.

The European Union: The EU has played an increasing role, particularly through the Water Framework Directive, in setting environmental standards and promoting cooperation [1].

III. Outcomes and Impact

To visually reflect the outcomes of the interventions, changes in the basin conditions, and illustrate the implications and focus of the series of policy implementations in a more macro perspective, the time framework of the Rhine River is presented. With the time stage of the Rhine River governance as the horizontal axis and pollution-phase goals-policy measures as the vertical axis, an analysis framework for changing-governance measures was established as depicted in Figure 2.

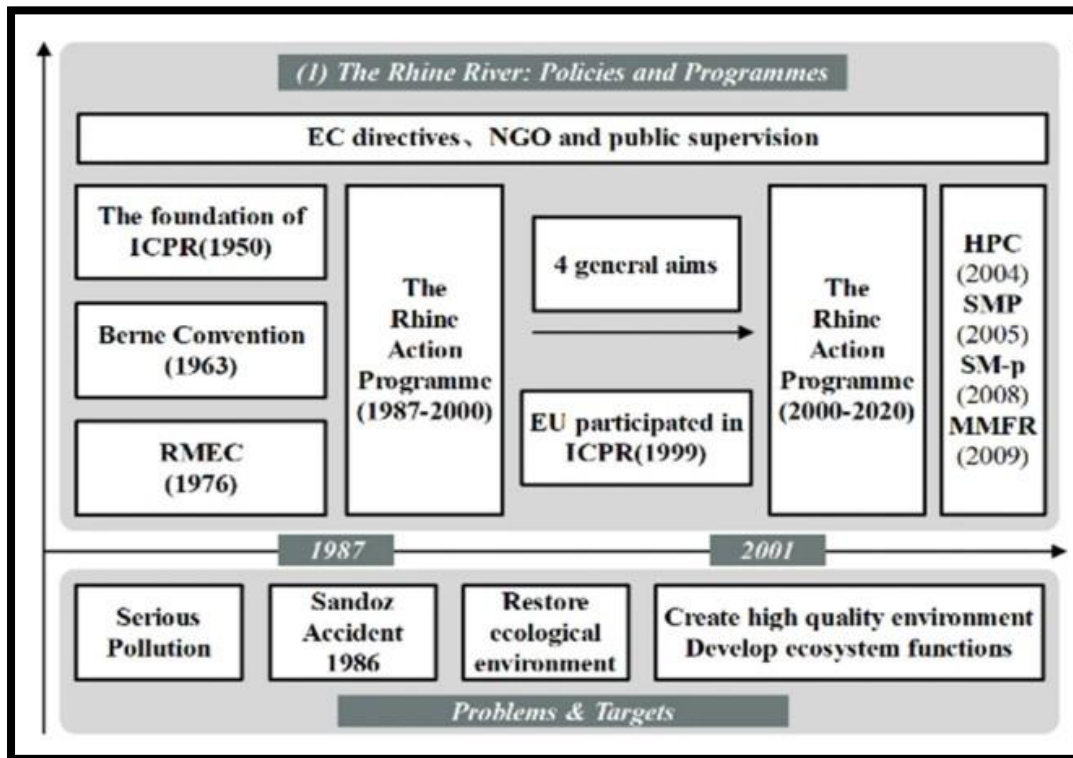


Figure 2. Time-framework of Rhine River Basin Management [1].

During the initial remediation stage, cooperation among Rhine-bordering countries began with the establishment of the International Commission for the Protection of the Rhine (ICPR) in 1950. In 1963, the ICPR was formally reconstituted through a treaty among nine riparian states: Austria, Switzerland, Belgium, France, Germany, Italy, Liechtenstein, Luxembourg, and the Netherlands [5]. The 1970s saw significant progress with the efforts of the Rhine Environmental Ministers Conference (REMC), a high-level political forum addressing water quality issues. In 1976, two key treaties were signed: the Convention for the Protection of the Rhine against Pollution by Chlorides and the Bonn Convention, which set pollution reduction targets and regulated hazardous substances. However, environmental management remained in its early stages until the 1986 Sandoz chemical spill catalyzed more systematic action. In response, the ICPR introduced the Rhine Action Program (RAP) in 1987, committing basin countries to substantial financial investments to cut pollution levels by 50% by 1995 and implement long-term restoration measures [3].

By the late twentieth and early twenty-first centuries, Rhine governance transitioned to an advanced ecological restoration phase. The ICPR formally joined the European Union in 1999, revising and signing a new Rhine Protection Convention. Building on prior efforts, the "Rhine 2020" program, launched in 2000, expanded beyond pollution control to broader ecological goals such as habitat restoration and flood protection. Key initiatives, including the Habitat Patch Connectivity Plan (2004), Sediment Management Plan (2005), and Masterplan Migratory

Fish Rhine (2009), focused on improving biodiversity and ecosystem functions. The environmental, social, and economic benefits of these initiatives are outlined below -

a. Environmental Benefits

The Rhine River management project has demonstrably improved the river's environmental condition [1]. Key benefits include:

Improved Water Quality: Dissolved oxygen levels have increased significantly, from approximately 4 mg/L in the 1970s to around 10 mg/L in the twenty-first century [1]. This improvement is crucial for supporting aquatic life.

Reduced Pollution: Total phosphorus levels have decreased by 78.8% over the past decades [1]. The organic pollution AOX (Comprehensive Index of Absorbable Organic Halogen) had dropped by 82%.

Ecological Restoration: Species sensitive to pollution, such as salmon, have returned to the Rhine, indicating improved water quality and habitat conditions [1]. Since the 1990s, the number of migratory salmon was increasing and reached a stable high level in the twenty-first century [1].

Habitat Improvement: Restoration of wetlands and floodplains has enhanced biodiversity and ecosystem resilience.

b. Social Benefits

The Rhine River management project has also delivered substantial social benefits to communities along the river:

Improved Public Health: Cleaner water reduces the risk of waterborne diseases, leading to better public health outcomes.

Enhanced Recreational Opportunities: Improved water quality has allowed for increased recreational activities like swimming, fishing, and boating, improving the quality of life for residents.

Increased Aesthetic Value: A cleaner, healthier river enhances the aesthetic appeal of the surrounding landscape, positively impacting the well-being of communities.

Community Engagement: The project has promoted community engagement and a sense of stewardship towards the river [1].

c. Economic Benefits

The economic benefits of the Rhine River management project are multifaceted:

Cost Savings: Reduced pollution leads to decreased costs associated with water treatment and healthcare [1].

Increased Tourism: A healthier river attracts more tourists, boosting the local economy.

Enhanced Property Values: Properties near a healthy river tend to have higher values, benefiting homeowners and local governments.

Sustainable Fisheries: Restoring fish populations supports sustainable fisheries, providing economic opportunities for local communities.

Reduced Flood Risk: Flood management and ecological restoration have contributed to reduced flood risk, though specific economic data would require further research.

IV. Lessons Learned and Recommendations

a. Key Takeaways from the Project

Several key takeaways can be drawn from the Rhine River management project:

International Cooperation is Essential: Effective River basin management requires strong international cooperation and coordination [1].

Comprehensive Action Plans are Necessary: Implementing comprehensive action plans with clear targets and timelines is crucial for achieving measurable results.

Policy and Regulation are Important: Strong policies and regulations are needed to control pollution from various sources.

Stakeholder Engagement is Key: Engaging all stakeholders, including governments, industry, agriculture, and communities, is essential for building support and ensuring effective implementation.

Monitoring and Adaptive Management are Critical: Continuous monitoring and adaptive management are necessary to track progress, identify emerging challenges, and adjust management strategies accordingly.

Long-Term Vision is Required: Successful River basin management requires a long-term vision and commitment to sustainability.

b. Best Practices and Strategies for Replication

The Rhine River management project offers several best practices and strategies that can be replicated in other river basins, as emphasized by Shi et al. (2021) [1]:

Establish an International Commission: Create an international commission or similar body to facilitate cooperation and coordination among countries or regions within the basin [1].

Develop a Comprehensive Action Plan: Develop a comprehensive action plan with specific targets, timelines, and measurable indicators.

Implement Polluter Pays Principle: Enforce the "polluter pays" principle, requiring polluters to bear the costs of pollution control and remediation.

Promote Best Management Practices: Promote the adoption of best management practices in agriculture, industry, and other sectors to reduce pollution.

Invest in Green Infrastructure: Invest in green infrastructure, such as wetlands and floodplains,

to enhance ecosystem services and reduce flood risk.

Engage Local Communities: Engage local communities in monitoring, restoration, and decision-making.

c. Areas for Further Improvement or Research

While the Rhine River management project has been successful, there are areas for further improvement or research:

Addressing Emerging Pollutants: Further research is needed to address emerging pollutants, such as microplastics and pharmaceuticals, and their impacts on river ecosystems.

Climate Change Adaptation: Developing strategies to adapt to the impacts of climate change, such as increased flooding and droughts, is essential for long-term sustainability.

Integrated Water Resources Management: Implementing integrated water resources management approaches that consider the interactions between surface water, groundwater, and land use is crucial.

Economic Valuation of Ecosystem Services: Conducting economic valuations of ecosystem services to better understand the benefits of river restoration and inform decision-making.

Public Awareness and Education: Enhancing public awareness and education about the importance of river protection and sustainable water use is needed to foster stewardship and support for management efforts.

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Rhine River Basin: Case Study – III

Governance Conditions for a Successful Restoration of Riverine Ecosystems, Lessons from the Rhine River Basin

I. Case Study Overview

a. Project Background and Location

The Rhine River, a vital European waterway, traverses through Switzerland, Germany, France, Luxembourg, and the Netherlands, serving as a crucial economic and ecological corridor [1]. Over centuries, human activities, including industrialization, urbanization, and intensive agriculture, have significantly impacted the river's ecosystem, leading to biodiversity loss and degradation of habitats. Recognizing the transboundary nature of the river and the shared responsibility for its health, the riparian states initiated collaborative efforts in the early 1950s [1]. These initial efforts primarily focused on addressing water quality issues stemming from industrial pollution and agricultural runoff. In 1986, the scope of cooperation broadened to include comprehensive riverine ecosystem restoration, aiming to revive the river's ecological integrity and restore its natural functions [1]. The International Commission for the Protection of the Rhine (ICPR) was established as the central coordinating body for these international efforts, providing a platform for collaboration, policy development, and the implementation of restoration measures.

b. Problem Statement: Management or Environmental Challenge

The primary challenge addressed is the degradation of the Rhine River ecosystem, resulting in a decline in biodiversity, including the near extirpation of the Atlantic salmon [1]. The management challenge lies in coordinating the restoration efforts across multiple sovereign states with differing priorities and legal frameworks. It requires navigating complex governance structures, integrating ecological objectives with socio-economic activities, and ensuring long-term commitment from all stakeholders. Despite efforts to reintroduce the Atlantic salmon, a self-sustaining population has not been established. This highlights the complexities involved in restoring a large, heavily impacted river ecosystem and the need for adaptive management strategies that address both ecological and socio-economic factors. The success of the restoration efforts depends not only on ecological factors but also on effective governance conditions that facilitate the implementation of restoration measures and ensure the long-term sustainability of the restored ecosystem.

II. Project Description

a. Goals and Objectives

The overarching goal is to restore the ecological integrity of the Rhine River basin, enabling

the return of key indicator species like the Atlantic salmon and enhancing overall biodiversity (ICPR, 2015) [2]. This goal is aligned with international agreements and conventions, such as the EU Water Framework Directive and the Convention on Biological Diversity, which promote the protection and restoration of aquatic ecosystems. Specific objectives include:

- Improving water quality to meet the needs of target species, reducing pollution from point and non-point sources, and ensuring compliance with water quality standards (ICPR, 2015) [2].
- Restoring riverine habitats, such as floodplains and spawning grounds, to provide suitable conditions for fish and other aquatic organisms (ICPR, 2015) [2].
- Enhancing fish migration by removing barriers and constructing fish passages, allowing migratory species to access their historical spawning grounds and complete their life cycles.
- Establishing a self-sustaining population of Atlantic salmon, indicating the successful restoration of the river's ecological health and the functionality of its ecosystem (ICPR, 2015) [2].
- Fostering international cooperation and integrated river basin management, ensuring the coordinated and sustainable use of the Rhine River's resources (ICPR, 2015) [2].

b. Strategies and Interventions

The ICPR employs a range of strategies and interventions to achieve its goals, including:

International Coordination: The ICPR serves as a platform for coordinating restoration efforts among the Rhine basin states, setting common goals, and developing joint action plans. This involves harmonizing policies, sharing information, and promoting best practices in river basin management (ICPR, 2020).

Policy Development: Development and implementation of policies and regulations aimed at reducing pollution, protecting habitats, and promoting sustainable water management (ICPR, 2020). This includes setting emission limits for industries, regulating agricultural practices, and establishing protected areas along the river.

Ecological Restoration Measures: Implementation of concrete restoration measures, such as the reconnection of floodplains, construction of fish passages, and improvement of spawning habitats (ICPR, 2020). These measures aim to restore the natural functions of the river ecosystem and enhance its resilience to future disturbances.

Monitoring and Research: Continuous monitoring of water quality, fish populations, and habitat conditions to assess the effectiveness of restoration measures and adapt management strategies (ICPR, 2020). This involves collecting data on various ecological indicators, analyzing trends, and using the information to inform decision-making.

Stakeholder Engagement: Engaging with stakeholders, including governments, industries, NGOs, and local communities, to ensure broad support for the restoration efforts. This involves

raising awareness, building partnerships, and promoting participatory decision-making.

c. Key Stakeholders and Partnerships

Key stakeholders include:

International Commission for the Protection of the Rhine (ICPR): The central coordinating body responsible for setting goals, developing policies, and monitoring progress [1].

National Governments: The governments of Switzerland, Germany, France, Luxembourg, and the Netherlands, responsible for implementing restoration measures within their respective territories.

European Union: The EU plays a role through its environmental directives, such as the Water Framework Directive and the Habitats Directive, which provide a framework for river basin management and biodiversity conservation.

Environmental NGOs: Organizations such as WWF and nature conservation groups, advocating for the protection of the Rhine River ecosystem and participating in restoration projects.

Industry: Sectors such as agriculture, navigation, and energy production, which have a significant impact on the river and are involved in implementing sustainable practices.

Local Communities: Residents and municipalities along the Rhine River, who are affected by the river's health and are involved in local restoration initiatives [1].

Scientific Community: Research institutions and universities, providing scientific expertise and conducting research on the Rhine River ecosystem.

Partnerships are crucial for the success of the project, fostering collaboration and knowledge sharing among the diverse stakeholders [1]. The ICPR facilitates partnerships by organizing meetings, workshops, and conferences, and by promoting joint projects and initiatives.

III. Outcomes and Impact

a. Environmental Benefits

The restoration efforts have yielded several environmental benefits, although the full ecological recovery of the Rhine River is still an ongoing process. Specific outcomes include:

Water Quality Improvement: Significant reductions in concentrations of several pollutants, including heavy metals and organic compounds, have been achieved through stricter regulations and improved wastewater treatment technologies. The levels of oxygen have increased, and the overall chemical status of the Rhine has improved, benefiting aquatic life (ICPR, 2020).

Habitat Restoration: Reconnection of over 500 kilometers of floodplains, providing increased habitat for various species and enhancing the river's natural flood control capacity. These restored floodplains serve as spawning grounds for fish, breeding areas for birds, and habitats for a variety of plant and animal species (ICPR, 2020).

Fish Migration: Construction of over 200 fish passages at dams and weirs, enhancing the ability

of migratory species to access spawning grounds and complete their life cycles. These fish passages allow fish to bypass obstacles and migrate upstream to their spawning areas (ICPR, 2020).

Increased Biodiversity: While the Atlantic salmon has not yet established a self-sustaining population, other fish species have shown signs of recovery, and the overall biodiversity of the Rhine River ecosystem has increased (ICPR, 2020).

b. Social Benefits

Enhanced Recreational Opportunities: Improved water quality and restored ecosystems have created opportunities for recreation, such as fishing, swimming, and boating. This has increased the value of the Rhine River for local communities and tourists.

Increased Awareness: Increased public awareness of the importance of riverine ecosystems and the need for their protection, leading to greater support for conservation efforts.

Community Engagement: Fostering a sense of stewardship and community involvement in the restoration efforts, with residents participating in river clean-up events and conservation initiatives [1].

c. Economic Benefits

Flood Damage Reduction: Floodplain restoration has contributed to an estimated reduction in potential flood damage by 15% in certain areas, reducing the need for expensive infrastructure and protecting communities from the impacts of floods (ICPR, 2015).

Increased Tourism: Enhanced recreational opportunities can boost tourism and local economies, generating revenue for businesses and creating jobs.

Sustainable Fisheries: Potential for sustainable fisheries, providing economic benefits for local communities while ensuring the long-term health of fish populations.

IV. Lessons Learned and Recommendations

a. Key Takeaways from the Project

International cooperation is essential for transboundary river restoration, as the Rhine River case demonstrates the importance of collaboration among multiple countries to achieve common goals [1].

Long-term commitment and sustained investment are crucial for success, as ecosystem restoration is a long-term process that requires consistent effort and resources.

Stakeholder engagement builds support and ensures effective implementation, as involving diverse stakeholders in the decision-making process leads to more sustainable and equitable outcomes [1].

Adaptive management allows for adjustments based on monitoring and evaluation, as continuous monitoring and evaluation are needed to adapt management strategies to changing

conditions and new information.

Governance challenges related to decision-making and financial incentives remain, as the decision-making processes can be slow, responsibilities are sometimes ambiguous, and financial incentives may be limited [1].

b. Best Practices and Strategies for Replication

Establish strong international coordinating bodies, like the ICPR, to facilitate collaboration and coordination among riparian states.

Develop shared visions and common goals among stakeholders, aligning the interests of different stakeholders to ensure a unified approach to river basin management.

Implement integrated management approaches considering ecological, social, and economic aspects, addressing the complex interactions between human activities and the environment.

Invest in monitoring and research to inform decision-making, generating knowledge to support evidence-based policies and adaptive management strategies (ICPR, 2020) [3].

Promote stakeholder participation through engagement and capacity-building initiatives, empowering local communities and other stakeholders to participate in the restoration process.

c. Areas for Further Improvement or Research

Addressing governance gaps related to decision-making and financial incentives, streamlining decision-making processes and providing financial incentives for stakeholders to participate in restoration efforts [1].

Enhancing ecological monitoring to better assess the effectiveness of restoration measures, using advanced monitoring technologies and developing more comprehensive ecological indicators (ICPR, 2020) [3].

Investigating the socio-economic impacts of river restoration to understand community benefits better, assessing the economic, social, and cultural benefits of river restoration for local communities.

Integrating climate change considerations into river basin management, developing strategies to mitigate the impacts of climate change on the Rhine River ecosystem and ensure the long-term sustainability of restoration efforts (ICPR, 2015) [2].

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Rhine River Basin: Case Study – IV

Case Study: Adaptation Turning Points in River Restoration? The Rhine Salmon Case

I. Case Study Overview

a. Project Background and Location

The Rhine River, a crucial European waterway, has been the centre of considerable restoration initiatives, especially the ambitious reintroduction of the Atlantic salmon (*Salmo salar*). This effort was initiated after the species vanished from the Rhine in the 1950s due to the deadly mix of pollution, habitat destruction, and overfishing. Conceived in 1987, the Rhine Action Plan (RAP) had the ambitious objective of revitalizing the Rhine ecosystem to a point where it could sustain higher species like salmon and sea trout. This undertaking requires the active involvement of numerous stakeholders, including national governments, regional authorities, and NGOs. Spanning the entirety of the Rhine River basin, from its source in the Swiss Alps to its delta in the Netherlands, the project aims to improve water quality, connectivity, and habitat morphology. While the return of salmon is often touted as an inspiration for public and private initiatives along the Rhine, a fundamental question remains: Can this project realistically succeed given the growing threats, particularly from climate change, that are already undermining its progress? "Numbers of observed migrating salmon are low and we cannot speak of a sustainable population yet," which is why reintroduction efforts continue to be high on the policy agenda.

b. Problem Statement: Management or Environmental Challenge

Despite the reported progress in improving water quality and habitat restoration, the long-term success of salmon reintroduction is increasingly compromised by the escalating impacts of climate change. The Rhine Action Plan was built on the assumption of relatively stable hydrological and temperature conditions, a notion that is becoming less realistic with each passing year. Projections now indicate a greater likelihood of extreme weather events and significant changes in the river's hydrological and temperature regimes. Alarming, rising water temperatures present a direct and potentially insurmountable threat to salmon survival and reproduction. This case study critically examines whether climate change will ultimately negate the attempts to reintroduce salmon to the Rhine and, more importantly, whether adaptation strategies can effectively mitigate these risks.

II. Project Description

a. Goals and Objectives

The Rhine Salmon 2020 action plan's overarching goal to re-establish a self-sustaining, wild Atlantic salmon population in the Rhine River by 2020 now seems overly optimistic, if not entirely unattainable. Supporting objectives include:

Achieving an upstream migration of 7,000 to 21,000 individual salmon per year.

Ensuring undisrupted migration possibilities up to Basel, Switzerland.

Establishing salmon stocking practices that lead to self-sustaining populations, reducing reliance on artificial propagation.

These objectives, while seemingly reasonable on paper, are increasingly jeopardized by the likelihood of conditions becoming uninhabitable due to climate change. The underlying flaw is the pursuit of these goals without fully accounting for the detrimental effects of rising water temperatures, which can have cascading effects on the entire ecosystem. The paper by Bolscher et al. (2013) [1] emphasized that the "analysis finds a significant risk of failure of salmon reintroduction because of projected increases in water temperatures in a changing climate."

b. Strategies and Interventions

The Rhine restoration efforts, while extensive, risk becoming futile due to the overriding impact of climate change. The strategies and interventions include:

Water Quality Improvement: Reducing pollution from industrial and agricultural sources to meet the necessary conditions for salmon.

Habitat Restoration: Restoring spawning grounds and other crucial habitats to provide safe havens.

Connectivity Enhancement: Constructing fish passages at weirs and dams to improve migration routes.

Stocking Programs: Releasing hatchery-raised juvenile salmon into the Rhine and its tributaries to supplement natural populations.

Monitoring and Research: Ongoing scientific studies to track progress and adapt strategies.

Policy and Governance: Integrating salmon restoration objectives into broader water management policies.

Since 1990, a significant €50 million has been invested in the project, with additional investments of €528 million planned for infrastructure adaptation and habitat restoration until 2015 [3]. However, this financial commitment may prove inadequate if rising water temperatures surpass the tolerance levels for salmon, negating the benefits of improved water quality, habitat, and connectivity. As Bolscher et al. (2013) [1] pointed out, the action plan "implicitly assumes that hydrological and temperature regimes of the river do not significantly change in the future," a dangerous oversight given current climate projections.

c. Key Stakeholders and Partnerships

The Rhine salmon restoration project involves a wide array of stakeholders, including:

International Commission for the Protection of the Rhine (ICPR): Coordinates restoration efforts among the Rhine riparian states.

National and Regional Governments: Implement restoration measures within their jurisdictions.

Non-Governmental Organizations (NGOs): Advocate for salmon restoration and implement local projects.

Fishery Associations: Represent the interests of anglers and promote sustainable fisheries management.

Farmers and Land Users: Involved in habitat restoration projects that may affect land use practices.

Research Institutions: Conduct scientific research to support restoration efforts.

III. Outcomes and Impact

a. Environmental Benefits

While the Rhine salmon restoration project has seemingly produced some environmental benefits, their significance is undermined by the overarching threat of climate change:

Improved Water Quality: Reduced pollution levels enhancing river health.

Habitat Restoration: Increased availability of suitable environments for salmon and other species.

Increased Biodiversity: Contribution to greater biodiversity and ecosystem resilience.

Ecosystem Services: Restored floodplains and wetlands providing ecosystem services.

Connectivity: Facilitated fish movement through the construction of fish passage facilities.

However, the potential impacts of climate change, especially rising water temperatures, threaten to negate these achievements. Simulations have indicated that temperature increases can lead to critical water temperature limits for salmon being exceeded, particularly during the summer months, which could drastically affect their survival and reproduction [2]. "This suggests a need to rethink the current salmon reintroduction ambitions or to start developing adaptive action," as noted by Bolscher et al. (2013) [1], highlighting the urgent need to adapt to changing climate conditions. The paper highlights specific temperature thresholds, noting that prolonged exposure to water temperatures above 25°C can be lethal for adult salmon, and temperatures exceeding 20°C can impair spawning success.

b. Social Benefits

The Rhine salmon restoration project has been promoted as generating social benefits; however, these benefits are tenuous and may prove short-lived:

Recreational Opportunities: New recreational fishing opportunities.

Community Engagement: Local communities engaged in environmental stewardship.

Educational Opportunities: Educational opportunities for students and the public.

Cultural Value: Restoring a species that was once an integral part of the Rhine's natural and cultural heritage.

c. Economic Benefits

The claimed economic benefits of the Rhine salmon restoration project are speculative and possibly misleading:

Tourism: Potential for attracting tourists interested in fishing and wildlife viewing.

Fisheries: Development of sustainable salmon fisheries.

Ecosystem Services: The economic value of services provided by restored floodplains and wetlands.

Job Creation: Opportunities in construction, engineering, and environmental management.

The economic viability of these benefits is contingent on the long-term survival of salmon in the Rhine. If the salmon population declines due to climate change, the projected tourism revenue, fisheries income, and increased property values will fail to materialize, rendering the substantial investments in restoration efforts wasteful. The paper discusses the potential for "adaptation turning points," where climate change impacts become so severe that the current management strategy is no longer effective, leading to significant economic losses.

IV. Lessons Learned and Recommendations

a. Key Takeaways from the Project

The Rhine salmon restoration project provides several sobering lessons:

Climate Change Imperative: Climate change can undermine even the most ambitious restoration efforts if not adequately addressed.

Stakeholder Conflicts: Conflicting interests among stakeholders can hinder the effectiveness of restoration efforts.

Adaptive Management Limitations: Adaptive management alone may not be sufficient to overcome the challenges posed by climate change.

Connectivity Isn't Enough: Connectivity alone cannot ensure salmon restoration success if other factors are not within acceptable limits.

b. Best Practices and Strategies for Replication

Based on the Rhine salmon restoration experience, the following "best practices" should be regarded with caution:

Set clear and measurable goals: Ensure goals are realistic and account for climate change impacts.

Conduct thorough assessments: Include comprehensive climate vulnerability assessments.

Prioritize habitat restoration: Determine whether habitat restoration can effectively offset climate impacts.

Promote stakeholder engagement: Proactively address conflicting interests.

c. Areas for Further Improvement or Research

To salvage the Rhine salmon restoration effort and inform future projects, these areas require urgent attention:

Advanced Climate Modeling: Develop more precise climate models to predict regional impacts on river ecosystems.

Targeted Adaptation Strategies: Implement specific strategies to mitigate the impacts of rising water temperatures.

Effective Governance Mechanisms: Implement governance mechanisms to enforce climate-conscious policies and resolve stakeholder conflicts.

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Rhine River Basin: Case Study – V

Case Study: River Basin Approach in the Netherlands, an example of Good Multilevel Water Governance?

I. Case Study Overview

a. Project Background and Location

The Water Framework Directive (WFD), established by the European Commission in 2000, mandates that all water bodies within the European Union should achieve "good" chemical, ecological, and nutrient status. The Netherlands, as an EU member, is committed to fulfilling these requirements. This case study focuses on the Rhine West sub-basin within the Netherlands, examining the implementation of the WFD's River Basin Approach in this specific context. The Rhine West sub-basin is one of six regions in the Netherlands created to incorporate WFD plans into the existing Dutch water governance system [1].

b. Problem Statement: Management or Environmental Challenge

Despite the WFD's objectives and the deadline for achieving "good" status set for 2015 (with possible extensions to 2021 or 2027), studies indicate that the Netherlands is unlikely to meet this goal for all its water bodies by 2027. Factors hindering successful implementation include a lack of political will and an inability to address the root causes of water quality issues. As the WFD is a binding agreement, non-compliance could have financial and legal repercussions for the Netherlands. The challenge lies in effectively translating the WFD's goals into tangible improvements in water quality within the complex multi-level governance structure of the Netherlands. The research aims to assess the effectiveness of the River Basin Approach in the Rhine West sub-basin in addressing these challenges.

II. Project Description

a. Goals and Objectives

The overarching goal of the River Basin Approach, as mandated by the WFD, is to achieve "good" water status in all water bodies by set deadlines. This encompasses various objectives, including reducing pollution, restoring ecosystems, and ensuring sustainable water management. The research specifically aimed to assess the effectiveness of the governance arrangements in the Rhine West sub-basin in achieving these objectives, identifying factors that contribute to or hinder the successful implementation of the WFD's River Basin Approach. This involves examining the outputs, outcomes, and impacts of the implemented measures. The

study seeks to provide insights into the multilevel interactions and coordination mechanisms for the WFD at a basin level in the Netherlands [1].

b. Strategies and Interventions

The River Basin Approach in the Netherlands involves several strategies and interventions, primarily centered around the development and implementation of River Basin Management Plans (RBMPs). These plans outline specific measures to protect and improve water quality and are developed through a multi-stakeholder process.

The Dutch water governance system is characterized by multiple layers of authority:

National Level: Ministries responsible for national waters and regulations concerning pesticides and manure deposition.

Regional Level: Provinces oversee groundwater and project planning, while regional water authorities manage surface and waste waters.

Local Level: Municipalities handle wastewater treatment.

The implementation of the WFD in the Netherlands has involved dividing the country's four river basins into six regions, including the Rhine West sub-basin. Interventions include measures to reduce pollution from agriculture, industry, and urban areas, as well as efforts to restore natural habitats and improve water flow. Examples include:

Construction and upgrading of wastewater treatment plants to reduce the discharge of pollutants into surface waters.

Implementation of best management practices in agriculture to minimize nutrient runoff and pesticide contamination.

Restoration of riverbanks and floodplains to enhance ecological habitat and improve water retention.

c. Key Stakeholders and Partnerships

The implementation of the River Basin Approach in the Rhine West sub-basin involves a diverse range of stakeholders and partnerships. Key stakeholders include:

National Ministries: Responsible for overall water policy and regulation.

Provinces: Responsible for groundwater management and spatial planning.

Regional Water Authorities: Manage surface water and wastewater treatment.

Municipalities: Manage wastewater collection and treatment.

Farmers and Agricultural Organizations: Contribute to water pollution through agricultural runoff.

Industries: Can be significant sources of water pollution.

Environmental Organizations: Advocate for improved water quality and ecosystem protection.

Local Communities: Affected by water quality and have a stake in its improvement.

b. Methodology

The research adopts a case study methodology, focusing on the Rhine West sub-basin to evaluate the effectiveness of the River Basin Approach in the Netherlands as a model for multilevel governance. This specific sub-basin was chosen due to its complexity, involving multiple governing bodies with diverse and often conflicting interests. A qualitative approach was employed to gain deeper insights into the processes and interactions at the basin level, incorporating document analysis and interviews with key stakeholders. The study operationalized key variables based on theories of multilevel governance, policy integration, and the Water Framework Directive (WFD), developing an analytical framework to assess success factors in water management. A literature review was conducted to identify relevant success factors, with searches in Scopus focusing on terms like “success factors” and “effective” in combination with WFD governance themes.

Data collection involved policy document analysis and semi-structured interviews with 15 experts and policymakers from water authorities, provincial governments, the Ministry of Infrastructure and Water Management, and academic institutions. Policy documents were sourced from publicly available repositories, including advisory documents, annual updates, and reports from the Netherlands Environmental Assessment Agency. The interviews focused on governance processes, collaboration within the sub-basin, and the effectiveness of policy implementation. Transcripts were coded using NVivo software to identify patterns in experiences, challenges, and opportunities. To evaluate the presence and effectiveness of governance success factors, a traffic light assessment system was employed, categorizing factors as fully implemented (green), partially implemented (yellow), or largely absent (red). This structured approach provided a comprehensive assessment of the Rhine West sub-basin's governance performance under the WFD framework.

III. Outcomes and Impact

The Rhine West sub-basin has produced numerous reports, summaries, and advisory documents to guide water management efforts. The characterization of the region began in 2004, followed by an exploratory brief in 2006. In 2008, the *Clean Water Rhine West* advisory document was published, presenting the results of area-based processes where water authorities engaged in discussions with stakeholders to develop region-specific measures. These processes accounted for various functions of the water body, and while individual parties defined their measures, discussions within the Regional Water Authority (RBO) facilitated better coordination and implementation. The initial measures implemented between 2009 and 2015 focused primarily on redeveloping water flows, modifying banks, and adjusting water depth.

Other key initiatives during this period included improvements in bank management and efforts to limit emissions from wastewater treatment plants. Additionally, an extensive research agenda was launched to assess the impacts of these measures.

In 2012, the **Working Programme 2012-2015** provided a detailed action plan that concentrated on nutrient management in the peatlands, deep polders, and the bulb-growing regions of the basin. Runoff management also became a major focus. By 2013, the **Fish Migration Project** was initiated, and an **Essay on the Blue Economy** was published to highlight the economic benefits of improved water quality. The subsequent advisory document for the 2016-2021 planning period introduced a broader set of measures, including the reduction of point-source pollution, limitations on wastewater overflow, and upgrades to wastewater treatment plants. The plan also emphasized the sanitation of polluted soils and continuation of nutrient management projects that had already begun. Additionally, the implementation of the Delta Programme Agricultural Water Management was integrated into regional planning. Authorities in Rhine West also outlined expectations for the national government to introduce generic measures to limit nutrient runoff. Other priorities included expanding hydromorphological interventions, increasing fish migration routes, and launching public awareness campaigns on water quality. The report also stressed the importance of cost-effective strategies to maintain public support.

In the years following 2016, annual progress reports were published until 2019, after which no further updates were released. However, in 2021, the **Collaborative Agenda** was published, identifying nine key themes for future action: nutrients, harmful substances and pesticides, fish migration, habitat and management, groundwater, urban water, agriculture, wastewater treatment plants, and regulatory enforcement. For each of these themes, action plans were proposed, ranging from maintaining existing practices to increasing personnel, initiating pilot projects, and conducting further studies. The effectiveness of these strategies was to be evaluated later in the year, determining whether all themes would continue and how funding would be allocated.

The impact of these measures was evaluated in two major reports: one conducted by the Rhine West sub-basin itself in 2016 and another by the Netherlands Environmental Assessment Agency (NEAA) in 2020. The 2016 evaluation, which covered the period from 2009 to 2015, found that 70 percent of planned measures had been completed, with an additional 20 percent carried over into the next planning phase. Ecological improvements were observed, particularly in fish populations, which increased by 25 percent. In the bulb-growing region, nutrient management programs were developed to enhance the efficiency of organic fertilizers and prevent effluent pollution. Other agricultural projects tested sustainable farming methods such

as closed-loop systems. The *Fish Migration Project* resulted in the creation of a *Vision Paper* and the identification of 30 key fish migration barriers, along with plans to mitigate these obstacles.

Despite these achievements, the 2020 *National Analysis Water Quality* report by the NEAA indicated that the goal of achieving good water quality by 2027 remained out of reach. The report projected that only 60 percent of water bodies would meet nutrient standards under the existing measures, with significant regional variability. One major challenge in Rhine West was the high phosphorus content in the soil, which contributed to persistent nutrient pollution in the water. Researchers suggested that water quality targets should be adjusted to account for this background pollution. The effectiveness of hydrological interventions, dredging, and de-phosphorization measures remained uncertain, leading to low confidence in goal attainment.

Through the Delta Agricultural Water Programme (DAW), pollution reduction of several percent was achieved, with the potential to reach 35 percent if all farmers in the region participated. However, disparities in expected outcomes were linked to variations in goal-setting and financial planning. The NEAA report identified several areas where additional measures could be implemented. Regarding nutrient management, an additional round of filtration at wastewater treatment plants was proposed to further reduce runoff. In agriculture, voluntary participation in DAW was encouraged, but stricter regulations under the Common Agricultural Policy were also suggested.

The report also assessed ecological improvements using four key indicators: fish, algae, macrofauna, and aquatic plants. The projected success of reaching *Good Ecological Potential (GEP)* varied across these factors. Approximately 60 percent of water bodies were expected to meet GEP standards for fish and algae, while macrofauna compliance was projected at 40 percent and aquatic plants at only 25 percent. The widespread implementation of nature-friendly bank structures and reduced mowing was expected to benefit fish and macrofauna populations in the coming years. However, the high turbidity of water in some areas remained a barrier to achieving GEP for aquatic plants, which require clear water for growth. Addressing this issue could necessitate structural interventions such as phosphorus extraction from the waterbed or the isolation of certain lakes, but these measures could negatively impact other water uses.

The NEAA report also examined the presence of problematic and emerging pollutants, including chemicals from construction, agriculture, industry, and shipping. Due to the lack of comprehensive data on these substances, it was difficult to assess the effectiveness of mitigation measures. However, several strategies were proposed to limit their presence in water bodies, primarily through reductions in pesticide use and improved wastewater management.

a. Environmental Benefits

The study evaluates the environmental benefits of the River Basin Approach in the Rhine West sub-basin by analyzing the outputs and outcomes of implemented measures. While specific data on pollutant reduction is not provided, the study highlights a gap between planned measures and actual outcomes [1].

The thesis indicates that the goal of achieving "good" water status, as defined by the WFD, has not yet been met in the Rhine West sub-basin. The study found that while knowledge capacity and financial means were present, other factors important for the WFD realisation were missing. Especially political commitment, coordination, and integration were found to be missing. Therefore, it was concluded that the River Basin Approach in Rhine West cannot be seen as an example of good Multilevel Water Governance.

This suggests that the outputs (e.g., constructed treatment plants, implemented BMPs) have not translated into the desired environmental outcomes (e.g., improved water quality, reduced pollution levels). The thesis underscores the need for more effective and targeted interventions to achieve substantial environmental benefits. The lack of achievement in "good" water status indicates that the ecological and chemical parameters, such as nutrient levels, specific pollutants, and biodiversity indicators, are still not within the acceptable ranges defined by the WFD.

b. Social Benefits

Improved water quality can enhance recreational opportunities, such as swimming, fishing, and boating, potentially increasing tourism and economic activity in the region. Cleaner water sources can also improve public health by reducing the risk of waterborne diseases. While the study does not explicitly focus on these benefits, they are potential co-benefits of the River Basin Approach. Increased engagement of local communities in water management projects can foster a sense of ownership and promote social cohesion.

c. Economic Benefits

Investment in water treatment infrastructure and sustainable agricultural practices can stimulate economic activity and create jobs. Improved water quality can reduce the costs associated with treating drinking water and managing water-related diseases.

A healthy aquatic ecosystem can support fisheries and tourism, generating revenue and employment opportunities for local communities. More effective implementation of the River Basin Approach could unlock these economic benefits in the Rhine West sub-basin. Furthermore, avoiding legal and financial consequences of non-compliance with the WFD

represents a significant economic advantage. The study suggests that a more integrated approach to water management could lead to greater economic gains.

d. Outputs versus Outcomes & Impacts

The collaborative processes in the Rhine West sub-basin were primarily shaped by consultation and knowledge exchange rather than integrated goal-setting and joint implementation. While various stakeholders participated in discussions, decision-making remained somewhat fragmented, with individual water authorities implementing hydromorphological measures on a case-by-case basis. The primary focus of the sub-basin from the beginning was on fish migration and reducing agricultural nutrient pollution. Measures undertaken to achieve these objectives mainly involved working with the agricultural sector to reduce nutrient runoff and identifying and addressing key barriers to fish migration.

Up until 2021, these remained the central themes of action, reflecting the priorities set during the early phases of planning. However, despite these efforts, the 2020 *National Analysis on Water Quality* made it clear that even with the full implementation of planned measures and additional upgrades, the water quality goals set for 2027 would not be met in all water bodies. This shortfall was, in part, a consequence of the early processes and outputs in the sub-basin. In the initial phase, the primary focus was on assessing the state of the water system, which justified a limited scope of immediate measures. However, by the second phase, with a more developed understanding of the system, it would have been possible to implement more ambitious actions, particularly to mitigate nutrient runoff from wastewater treatment plants [1]. Additional interventions, such as increased dredging or removal of nutrient-rich sediments, could have been pursued to account for background pollution. However, financial constraints prevented the Regional Water Authority (RBO) from adopting more far-reaching measures. The RBO consistently maintained that without a national policy to reduce nutrient runoff, the 2027 goals would remain unattainable. Furthermore, the persistent turbidity in certain waters of Rhine West posed additional challenges to achieving targets for aquatic plants, as their growth requires clearer water conditions. The "one out, all out" principle used to assess ecological quality failed to account for these location-specific conditions, making it even more difficult to achieve overall compliance with water quality standards.

e. Critical analysis of the Rhine-West sub-basin WFD implementation challenges

Legal Aspects

The alignment of governance boundaries with watersheds is undermined by fragmented mandates and overlapping policies, fostering blame-shifting rather than collaboration. While the WFD's "good status by 2027" goal provides clarity, its complexity alienates non-specialists,

including politicians, weakening broader institutional buy-in. The binding nature of deadlines drives accountability but risks incentivizing bureaucratic compliance (e.g., provinces shifting responsibility via the NPLG) over meaningful action. Regulatory flexibility through “Good Ecological Potential” (GEP) is a strength, allowing tailored goals for modified water systems, but it also risks complacency by legitimizing lowered standards [1].

Knowledge & Monitoring

Technical knowledge of water systems is robust yet siloed. Water authorities and provinces disagree on sufficiency, reflecting gaps in understanding nutrient interactions and systemic pressures. Knowledge-sharing has improved within water-sector working groups but fails to engage critical non-water sectors like agriculture, limiting holistic solutions. Monitoring protocols are rigorous but vulnerable to budget cuts, risking data gaps that could derail adaptive management. Reliance on historical pollution data also overlooks emerging contaminants, leaving regulatory frameworks reactive rather than proactive.

Political Aspects

Political commitment is fractured: local water authorities prioritize WFD goals, but national policymakers sideline water quality for economic interests (e.g., agriculture, industry). Framing water quality as an ecological issue—rather than linking it to public benefits like drinking water—has stifled public and political engagement. While RBO/RAO meetings maintain internal focus, external attention relies on fear of litigation, not genuine urgency. The lack of media coverage and public awareness perpetuates inertia, allowing systemic drivers (e.g., chemical use, intensive farming) to persist unchallenged [1].

Governance Fragmentation: Interdependence without accountability mechanisms enables blame-shifting.

Communication Failures: Overly technical WFD messaging alienates stakeholders; side benefits (health, economy) are underused.

Political Short-Termism: National policies prioritize economic growth over long-term water security, undermining WFD goals.

Resource Constraints: Monitoring and enforcement are jeopardized by funding instability, risking regulatory capture by polluters.

IV. Lessons Learned and Recommendations

a. Key Takeaways from the Project

The research identifies several key takeaways regarding the implementation of the River Basin Approach in the Rhine West sub-basin. A major finding is that the necessary knowledge and financial resources are available, but critical factors such as political commitment, coordination, and integration are lacking (Figure 1).

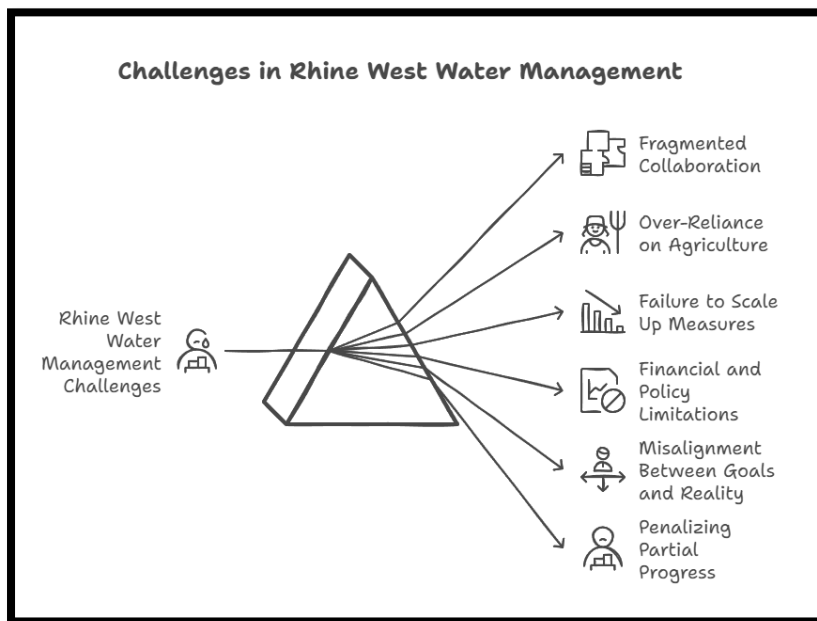


Figure 1. Challenges in Rhine River waste water management.

The analysis reveals a gap between the planned measures and the actual outcomes, indicating that the current governance arrangements are not effectively addressing the underlying causes of water quality problems [3]. The thesis also highlights the importance of addressing issues at their root, rather than focusing on short-term fixes. Overall, the study suggests that a more holistic and integrated approach is needed to achieve the WFD's objectives in the Rhine West sub-basin [1].

Some of the key takeaways from the Rhine West Sub-Basin Management Efforts are mentioned below –

Fragmented and Ineffective Collaboration

While the water management approach in Rhine West involved stakeholder consultations and knowledge exchange, it lacked true integration in goal setting and coordinated implementation. The reliance on individual water authorities to act led to fragmented and inconsistent efforts rather than a unified basin-wide strategy. This limited the overall impact of the measures taken.

Over-Reliance on Agricultural Partnerships with Limited Accountability

The focus on working with the agricultural sector to reduce nutrient pollution was a key priority, but it remained largely voluntary and lacked stringent enforcement mechanisms. Without stronger regulations and accountability measures, the reduction of agricultural runoff remained insufficient, undermining progress toward water quality goals.

Failure to Adapt and Scale Up Measures in Later Phases

The initial focus on research and data collection in the first phase was necessary, but by the second phase, the sub-basin had gained enough system understanding to take more aggressive measures. However, rather than scaling up interventions, financial and political constraints

prevented the adoption of more impactful actions, such as enhanced wastewater treatment and sediment removal. This failure to escalate efforts contributed to the shortfall in achieving the 2027 goals.

Persistent Financial and Policy Limitations Stalled Progress

The Rhine West sub-basin consistently cited financial constraints as a reason for not implementing stronger measures. While cost considerations are important, this argument highlights a broader issue: a lack of political will to prioritize water quality improvements. Additionally, the absence of national policy support to address nutrient runoff further weakened local efforts, showing a disconnect between local and national water management strategies.

Misalignment Between Goals and On-the-Ground Realities

The 2020 *National Analysis on Water Quality* confirmed that even with all planned measures, the sub-basin would fail to meet the 2027 water quality targets. High phosphorus levels in the soil and persistent turbidity made achieving ecological restoration for aquatic plants particularly difficult. Instead of adjusting the strategy to account for these challenges, Rhine West continued to operate within an unrealistic framework that did not sufficiently address these systemic issues.

The "One Out, All Out" Approach Penalized Partial Progress

The rigid application of the "one out, all out" principle in water quality assessment failed to recognize localized improvements in specific ecological factors, such as fish migration. This approach disregarded incremental progress and instead framed the entire effort as a failure, potentially discouraging further investment and action.

Despite some successes, particularly in fish migration improvements, the Rhine West sub-basin's water management efforts suffered from fragmented coordination, financial limitations, and an overly cautious approach to scaling up interventions. The reliance on voluntary agricultural cooperation without stronger regulatory enforcement further weakened pollution control measures [2]. Additionally, national policy gaps and a rigid assessment framework created additional barriers to achieving long-term water quality goals. Without stronger political commitment, increased funding, and more adaptive management strategies, Rhine West will likely continue struggling to meet its targets [1].

b. Best Practices and Strategies for Replication

While the study identifies shortcomings in the implementation of the River Basin Approach in the Rhine West sub-basin, it also suggests several best practices and strategies that could be replicated in other contexts.

Raising Awareness: Increasing awareness among policymakers and the public about the importance of water quality and the benefits of the WFD.

Structured Stakeholder Collaboration: Engage all stakeholders with legally binding commitments, cross-sectoral governance, and transparent reporting to ensure accountability.

Adaptive and Ambitious Planning: Shift quickly from research to action with flexible management, proactive policies, and periodic reassessments of strategies [1].

Stronger Nutrient Management: Implement advanced wastewater treatment, enforce precision farming, and introduce market-based incentives for pollution control.

Emphasizing Co-benefits: Highlighting the side benefits of improved water quality, such as enhanced recreation opportunities and improved public health.

Resource Redistribution: Reallocating resources to the sub-basin level to ensure that local authorities have the capacity to implement effective measures.

Project Ownership: Appointing a project owner for specific issues that need to be addressed to ensure accountability and coordination.

Strengthening Coordination and Integration: Improving coordination among different government agencies and stakeholders, and integrating water management with other policy areas, such as agriculture and spatial planning.

Promoting Political Commitment: Securing strong political commitment to the WFD at all levels of government through campaigns and lobbying.

c. Areas for Further Improvement or Research

The study identifies several areas for further improvement or research. One area is to develop a more comprehensive and integrated analytical framework that captures the complexities of multi-level water governance. This framework should consider not only the environmental outcomes of water management policies but also the social and economic impacts.

Another area for further research is to examine the role of stakeholder participation in the implementation of the WFD. The study suggests that greater community involvement could lead to more effective and sustainable water management outcomes. Additionally, further research is needed to identify the most effective strategies for promoting political commitment to the WFD and overcoming the barriers to implementation. Generalising these conclusions to the national level would require further research.

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Rhine River Basin: Case Study – VI

Case Study: Governance Conditions for Successful Restoration of Riverine Ecosystems - **Lessons Learned from the Rhine River Basin**

I. Case Study Overview

a. Project Background and Location

The Rhine River Basin, shared by nine European nations, is a vital European waterway that faced severe ecological degradation following the Industrial Revolution. By the 1980s, this once-thriving ecosystem was plagued by chemical pollution, habitat fragmentation from hydroelectric dams, and a significant loss of floodplains. The International Commission for the Protection of the Rhine (ICPR), established in 1950, launched coordinated restoration efforts in 1987 following the Sandoz chemical spill disaster. One prominent focus of these efforts was the reintroduction of the Atlantic salmon (*Salmo salar*), a keystone species that had virtually disappeared from the Rhine. However, despite decades of interventions, the establishment of a self-sustaining salmon population remains elusive, underscoring the complexities of riverine ecosystem restoration and the critical role of governance.

b. Problem Statement

While considerable progress has been made, the ICPR's governance structure faces persistent challenges that hinder the full realization of ecosystem restoration goals. These challenges include:

Decision-Making Inefficiencies: The ICPR's reliance on soft-law agreements, requiring unanimous approval from all member states, often leads to slow and cumbersome decision-making processes. This can delay the implementation of critical restoration measures, such as dam removals and pollution control initiatives.

Fragmented Responsibilities: Ambiguity in the distribution of responsibilities within national political systems poses a significant obstacle. The lack of clear lines of accountability can result in fragmented implementation, with restoration efforts being undermined by conflicting sectoral policies and priorities.

Inadequate Financial Incentives: Securing sufficient financial support from riparian states remains a persistent challenge. Despite the long-term economic benefits associated with ecosystem restoration, such as avoided flood damage costs and improved water quality, these benefits are often undervalued in political and financial considerations. Only 38% of required €12B secured for 2040 targets due to compartmentalized national budgets.

Transferring Insights to National Politics: Translating interdisciplinary insights into compartmentalized national politics is challenging.

Policy-science disconnect: Difficulty translating interdisciplinary restoration needs into sectoral policymaking.

These shortcomings highlight gaps in key governance conditions necessary for achieving long-term sustainability and resilience in riverine ecosystems.

II. Project Description

a. Goals and Objectives

The ICPR's overarching goal is to restore the ecological integrity of the Rhine River Basin, with a particular focus on re-establishing a self-sustaining population of Atlantic salmon and enhancing overall biodiversity. Specific objectives include:

Removing migration barriers to reconnect spawning habitats for salmon.

Reducing chemical pollution to comply with EU Water Framework Directive (WFD) standards.

Restoring floodplains to enhance ecological resilience and mitigate climate-related risks.

b. Governance Framework and Strategies

To assess governance conditions for successful riverine ecosystem restoration, the ICPR implemented a framework derived from scientific literature and refined through expert interviews and policy analysis. This framework identified 24 governance conditions categorized into institutional, financial, legal, and stakeholder dimensions (Tables 1 and 2):

Table 1. Governance Framework and Strategies [1].

Governance Dimension	Key Conditions Implemented
Institutional	Transboundary coordination, scientific consensus-building
Financial	Cost-benefit analysis protocols
Legal	EU Water Framework Directive alignment
Stakeholder	Industry partnerships (CHEM-Pact), NGO collaborations

14 out of 24 conditions were fully operationalized, while 10 remained partially/wholly absent.

Table 2. Critical Governance Gaps in Rhine Restoration [1].

Critical Governance Gaps in Rhine Restoration	
Absent/Partial Conditions	Impact
Binding enforcement mechanisms	Delayed dam removals & pollution controls

Critical Governance Gaps in Rhine Restoration	
Absent/Partial Conditions	Impact
Cross-sectoral funding pools	62% budget shortfall for fish passes
Political expertise integration	Poor translation of ecological needs to policy

Key Governance Strategies:

Institutional Coordination: The ICPR serves as a crucial transboundary body, facilitating cooperation and policy harmonization among the nine riparian states. This coordination is essential for aligning restoration goals and implementing coherent measures across the entire basin.

Legal Frameworks: Restoration efforts are guided by the EU Water Framework Directive, which mandates "good ecological status" for European water bodies by 2027. However, the effectiveness of this legal framework is constrained by the ICPR's reliance on soft-law agreements and limited enforcement powers.

Financial Mechanisms: Restoration projects are primarily funded through national budgets, leading to fragmented financial commitments and a persistent funding gap. Innovative financing mechanisms are needed to mobilize additional resources and ensure the long-term sustainability of restoration efforts.

Stakeholder Engagement: The ICPR actively engages with various stakeholders, including NGOs, industries, and local communities, to foster collaboration and build support for restoration initiatives [4]. These partnerships have facilitated voluntary pollution reduction measures, habitat restoration projects, and public awareness campaigns.

c. Key Stakeholders and Partnerships

The governance of river restoration involves multiple stakeholders. The ICPR ensures transboundary coordination and policy alignment, while riparian states implement national restoration efforts. EU institutions provide legal oversight through enforcement mechanisms. NGOs advocate for ecological restoration and public awareness, and industries contribute by adopting cleaner technologies to reduce pollution impacts. Table 3, shows the key stakeholders and partnerships.

Table 3. Key Stakeholders and Partnerships [1].

Stakeholder Group	Role in Governance	Contribution to Restoration Efforts
ICPR	Coordinating transboundary governance	Policy harmonization; monitoring progress
Riparian States	National implementation	Funding, execution of restoration measures
EU Institutions	Legal oversight	Enforcement of Water Framework Directive
NGOs (e.g., WWF)	Advocacy	Habitat restoration; public engagement
Industry (e.g., BASF)	Pollution control	Adoption of cleaner technologies

III. Outcomes and Impact

a. Governance Successes (14 Present Conditions)

The Rhine River restoration initiative has achieved notable successes in several governance areas, particularly in fostering transboundary alignment. By 2023, 93% of the riparian states had adopted the ICPR's monitoring standards, demonstrating a strong commitment to unified data collection and assessment practices [1]. This alignment facilitates effective comparison and synthesis of information across the basin, enabling more informed decision-making. Furthermore, the establishment of an 18-university consortium has significantly improved climate resilience planning [1]. This collaborative effort leverages diverse expertise to develop comprehensive models and strategies for mitigating the impacts of climate change on the Rhine ecosystem. Lastly, strong public engagement, evidenced by 82% citizen approval, has enabled faster policy adoption [1]. This high level of public support underscores the importance of transparency and participatory processes in building consensus and accelerating the implementation of restoration measures.

b. Governance Gaps (10 Absent/Partial Conditions)

Despite these successes, significant governance gaps persist, hindering the full realization of restoration goals. Financial shortfalls remain a critical challenge, as evidenced by the fact that only 23 of 58 migration barriers had been removed by 2023, falling far short of the 40% target [1]. This limited progress highlights the need for increased financial investment and more efficient allocation of resources. Enforcement deficits also pose a substantial obstacle, with 45% of industries remaining non-compliant with the CHEM-Pact, a voluntary agreement aimed at reducing chemical pollution [1]. This lack of compliance underscores the limitations of relying solely on voluntary measures and the need for stronger regulatory mechanisms. Moreover,

political bottlenecks impede progress, as 14 of 24 governance conditions lack legislative anchoring [1]. This lack of formal legal backing weakens the enforceability of restoration policies and makes them vulnerable to political changes.

The combined effects of these governance successes and gaps are reflected in the benefits as discussed below:

a. Environmental Benefits

Despite significant investments and dedicated efforts, ecological outcomes have been mixed, with some successes but also notable shortcomings.

Salmon Returns: While Atlantic salmon returns have increased from zero in 1986 to approximately 2,300 individuals in 2023, this number remains far below the target needed for a self-sustaining population [3]. This shortfall is attributed to incomplete removal of migration barriers and ongoing habitat degradation.

Pollution Reduction: Chemical pollution levels have decreased by 68% since 1990, but this still falls short of the EU directive's compliance target of 95%. Moreover, emerging contaminants such as pharmaceuticals and microplastics pose new challenges that require urgent attention.

However, floodplain restoration has yielded significant co-benefits, including increased biodiversity (recolonization by 27 indicator species) and improved carbon sequestration capacity (+20%).

b. Social Benefits

Governance measures have promoted greater public participation in restoration efforts, enhancing awareness and fostering a sense of stewardship among local communities.

Community Engagement: Community-led River stewardship programs have been instrumental in raising public awareness about the ecological challenges facing the Rhine basin and empowering citizens to act.

Recreational Opportunities: Improved water quality and enhanced fish populations have increased recreational opportunities such as fishing, contributing significantly to local economies.

However, the distribution of social benefits remains uneven across riparian states due to disparities in funding and implementation, leading to concerns about environmental justice.

c. Economic Benefits

Economic outcomes highlight the potential for ecosystem restoration to generate significant financial returns, but also underscore the need for more effective valuation and communication of these benefits [2].

Flood Damage Prevention: Floodplain restoration has demonstrated its effectiveness in

preventing flood damage, saving an estimated €650 million annually.

Water Treatment Savings: Improved water quality has reduced water treatment costs by 30%, resulting in annual savings of €140 million.

Despite these clear economic advantages, limited financial support from riparian states continues to hinder long-term investments in ecosystem restoration, highlighting the need for innovative financing mechanisms and improved economic valuation methods.

IV. Lessons Learned and Recommendations

a. Strengths in Governance Conditions

The analysis revealed that 14 out of 24 governance conditions were fully present in the ICPR's framework, contributing significantly to the progress made to date:

Transboundary Coordination: The ICPR's ability to harmonize policies and coordinate actions across nine states has been critical for aligning restoration goals and implementing coherent measures across the entire basin.

Scientific Integration: Collaborative research initiatives involving universities and scientific institutions have provided valuable insights into ecosystem dynamics, sediment transport modeling, and climate resilience planning.

Public Engagement: Citizen science programs, NGO partnerships, and public awareness campaigns have enhanced community involvement in monitoring water quality, restoring habitats, and advocating for policy changes.

b. Weaknesses in Governance Conditions

However, the absence or partial implementation of 10 governance conditions has significantly limited the effectiveness of the ICPR's efforts, hindering the achievement of long-term sustainability and resilience:

Legal Enforcement Mechanisms: The reliance on soft-law agreements undermines accountability among riparian states, delaying critical measures such as dam removal and pollution control initiatives. Without binding enforcement mechanisms, there is a risk that restoration efforts will be undermined by non-compliance and inadequate implementation.

Financial Fragmentation: The lack of integrated funding mechanisms has resulted in significant budget shortfalls for key projects such as fish passes and habitat restoration. This financial fragmentation stems from the fact that restoration projects are primarily funded through national budgets, leading to competition for resources and a lack of coordinated investment.

Political Expertise Integration: The absence of political science experts within the ICPR's advisory structure has hindered the effective translation of interdisciplinary insights into actionable policies. This lack of political expertise can result in policies that are not politically

feasible or that fail to address the underlying power dynamics that shape environmental decision-making.

c. Recommendations for Improvement

Strengthening Legal Frameworks:

Introduce binding enforcement mechanisms within ICPR agreements to ensure timely implementation of restoration measures and hold riparian states accountable for meeting their commitments.

Establish majority voting procedures for urgent decisions rather than requiring unanimous approval, which can lead to paralysis and delays.

Enhancing Financial Mechanisms:

Develop innovative financing tools such as "Rhine Restoration Bonds" that leverage avoided flood damage costs and other economic benefits to attract private investment.

Implement an "Eco-Contribution" system requiring commercial river users to fund ecological restoration projects, ensuring that those who benefit from the river's resources contribute to its sustainable management.

Building Political Capacity:

Create an ICPR Political Advisory Board composed of experts with legislative experience to improve policy negotiation processes, build political support for restoration initiatives, and ensure that policies are politically feasible and effective.

Increase collaboration with political science researchers to refine governance strategies based on empirical evidence, improve understanding of the political dynamics shaping environmental decision-making, and develop more effective approaches for navigating complex governance challenges.

Addressing Emerging Challenges:

Expand monitoring frameworks to include emerging contaminants such as pharmaceuticals and microplastics, which pose new threats to ecosystem health and require innovative management strategies.

Improve climate resilience modelling beyond current projections limited to 2050 to better anticipate and prepare for the long-term impacts of climate change on the Rhine River Basin.

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Thwake River

I. Case Study Overview

a. Background & location

The Athi basin is Kenya's second largest river basin after the Tana basin, with an area of 69,930 km². The basin is surrounded by Indian Ocean in the East, the Rift Valley basin to the West, Tanzania to the South and Tana Basin to the North (Kitheka et al., 2022). The Athi River originates from the Ngong Hills, flows through vast semi-arid parts of Kenya, and discharges into the Indian Ocean. The topography varies from sea level to 2400 m above MSL (Kithilia, 2007). The Thwake River is a tributary of the Athi River system, and it originates from Iveti Hills in Machakos County. The Thwake sub-basin has an area of 5,724 km². The Thwake river is seasonal with very turbid water during rainy seasons (Kitheka et al., 2022). The location of Thwake River in the Upper Athi basin is shown in Fig. 1.

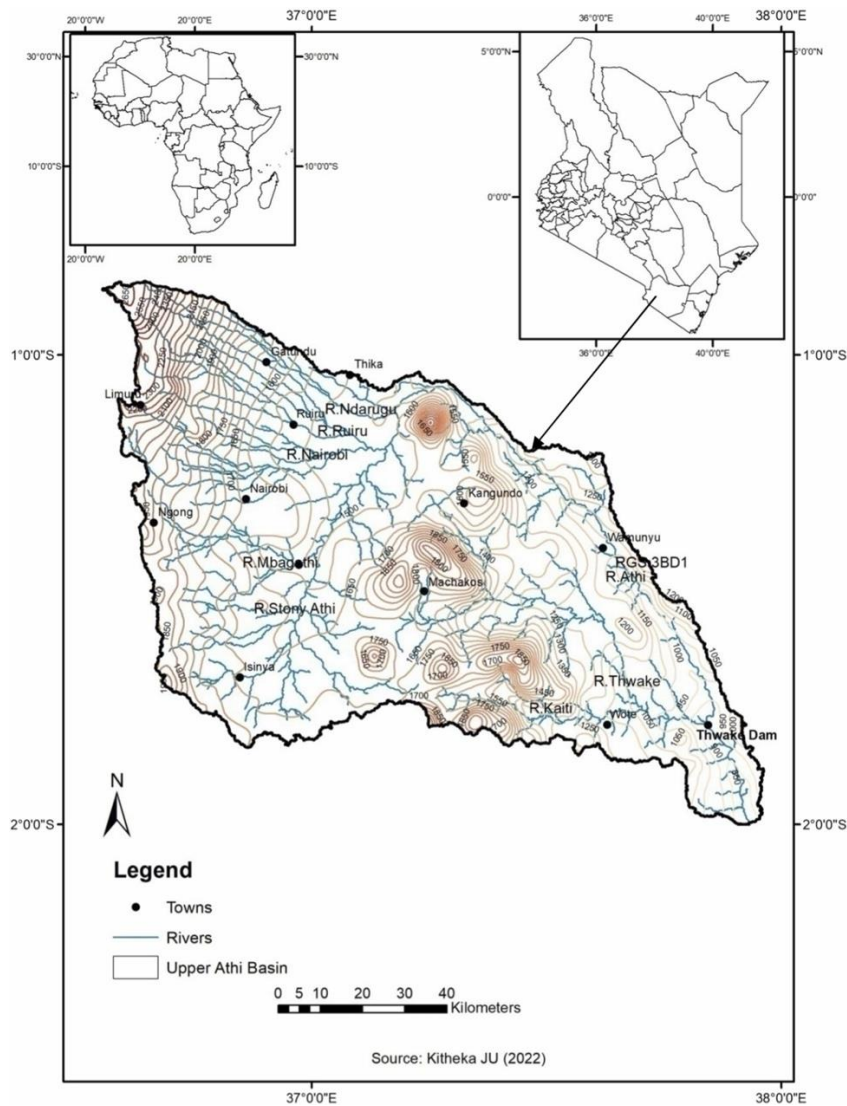


Fig. 1 Thwake River in the Upper Athi Basin (Kitheka et al., 2022)

b. Problem statement

The significant problems and environmental challenges faced in the basin are listed below:

1. Degradation of River Water Quality

High levels of toxic elements, heavy metals and carcinogens were reported in various stretches of the river, posing health risks to communities relying on its water (Chebii et al., 2024).

2. Sand Mining

Sand mining is found to be a common economic activity in Africa, mainly for construction purposes. The unsustainable sand harvesting has created concerns among the community as well as the government. Illegal and unchecked sand harvesting is often found in many countries of Kenya. In-stream sand harvesting is a preferred method of sand extraction as the deposit sites are easily accessible, and the sand is already well sorted from silt and clay compared to other

–

sand sources, such as land (Mwaura, 2013). The sand harvesting influenced water quality parameters such as Colour, turbidity, BOD, DO and Fe concentrations in Thwake River. The change in water quality parameters makes it unfit for consumptive uses and also effects the aquatic life in the river.

3. Sediment deposition in reservoirs

The Thwake River basin experiences high soil erosion due to its semi-arid climate, steep slopes, and lack of vegetation (Maiyo et al., 2024). Thwake River exhibits a consistent trend where bed-load transport increases with rising flow. The mass cumulative sediment inflow from the sub-basin into the reservoir was estimated as between 14 and 26.3 metric tons per annum, representing reservoir loss and useful life under 50 years (Maiyo et al., 2024).

4. Salinity and salt fluxes

High levels of TDS and salinity were reported in the river during dry seasons, which were reduced relatively when the flow increased. Studies also established that the river transports a relatively large volume of dissolved salts that range between 29×10^3 and 261×10^3 tons year⁻¹. The relatively high salt fluxes in the river were attributed to the discharge of wastewater into the river, seepage of groundwater from saline basement complex rocks, and entry of irrigation return flows from the basin (Kitheka, 2019).

5. Social impacts of Dam construction

Thwake Multipurpose dam is approximately 1 km downstream of Thwake and Athi River confluence at about 840 m above MSL. It was found that both displaced and non-displaced women experienced the impacts of dam construction in four areas, i.e., economic (income loss), health (hearing damage), social (disrupted social networks), and environmental (flooding) domains. The displaced women perceived worse economic and social outcomes than non-displaced ones. They also faced issues such as loss of cultural identity, land ownership and access to culturally significant sites (Owour et al., 2023).

II Project description

Some of the significant projects undertaken in the Thwake River Basin are listed below with their goals, strategies and partnerships.

1. Thwake Multipurpose Water Development Program (TMWDP):

- TMWDP is an initiative by the Government of Kenya (GoK) through the Ministry of Water and Irrigation. The project involves the construction of a multipurpose dam on the Athi River, near the confluence with the Thwake River.
- The project includes the construction of a 77m high multipurpose dam, installing 20 MW of hydropower capacity, developing a water supply system for 150,000 m³/day and developing 40,000 hectares of irrigation systems.
- Purpose: water supply, hydropower generation, irrigation development in Kitui and Makueni Counties, and flow regulation for flood and drought mitigation.

2. Thwake Reservoir Modelling:

- Hydrologic & Hydraulic modelling studies to estimate the safe yield and develop operational rules were conducted by various consultancies for the Thwake reservoir as a part of TMWD as Decision Support.
- The model estimates the monthly reservoir balance and analyzes the sensitivity of different components of the reservoir water balance.
- The consultancy works were done for the Ministry for Water and Irrigation, Kenya

3. Soil Conservation Measures by Thwake Kalawa Water Resource Users Association (WRUA)

- The Thwake Kalawa WRUA has been working on terrace farming and soil conservation practices to address soil erosion and sedimentation issues in the basin
- The funding is provided by the Water Resources Authority - Kenya.



Fig. 2 Terracing activities by Thwake Kalawa WRUA in Thwake Dam catchment area (Water Resources Authority, Kenya)

4. **Environmental Impact Assessments for the Thwake Dam Project:**

- The sustainability of the project in terms of water quality, impacts on biodiversity and local communities were carried out.
- The EIA was carried out by Environment and Climate Change Division, African Development Bank (ADB).

5. **Ondiri Wetland Conservation Efforts:**

- Located near Kikuyu in Kiambu County, Ondiri Wetland is a significant source of the Nairobi River.
- Conservation initiatives aim to reduce pollution entering major waterways that feed into the Thwake Dam, thereby improving water quality and supporting biodiversity.
- Ondiri Wetland conservation efforts were done by National Environmental Management Authority (NEMA) of Kenya along with other NGO's.



Fig. 3 Long-tailed window birds in Ondiri Wetlands, post conservation efforts
(Source: <https://www.atlasobscura.com>)

III Outcomes and Impact

The various benefits that have been achieved after implementing various projects in the Thwake Basin are as follows:

a. Environmental Benefits:

1. Soil Conservation – The soil erosion issues have been addressed in the basin by adopting soil conservation measures like contour and bench terraces, agroforestry, cover cropping, mulching and training the farmers.
2. Flood Control - The dam helps in flood control, as it stores the excess rainfall and protects the downstream from the risk of flooding.
3. Conservation of Biodiversity- Through the **Ondiri Wetland Conservation, initiatives are taken to control the pollutants entering the waterways, improve the water quality, and conserve biodiversity.**

b. Social Benefits:

1. Access to Potable water - The dam improves access to clean water for local communities, reducing the risk of waterborne diseases, which is critical in arid and semi-arid regions where access to clean water is limited.
2. Agricultural Productivity and Food Security - The irrigation systems powered by the dam enable year-round farming, which increases food security for local populations. Availability of irrigation supply allows cultivation of crops which require water

throughout the growing period, thereby ensuring stable food supply even when rainfall is uncertain.

3. Infrastructure Development - The introduction of new projects supports the development of infrastructure, such as roads, schools, and health facilities, which improve the overall quality of life for the residents in the region. Improved infrastructure promotes local businesses by increasing access to markets.
4. Energy Access - Hydroelectric power generated from the dam provides energy to nearby communities, contributing to overall living standards.

c. Economic Benefits:

1. An increase in Agricultural Production through irrigation increases the farmers' income. It also ensures a consistent supply of agricultural products for local markets and exports. The increase in agricultural productivity helps local economies and contributes to national GDP. A more stable agricultural sector means Kenya can reduce its reliance on food imports, potentially saving foreign exchange and improving trade balances.
2. Employment opportunities - The construction and operation of the dam create direct and indirect job opportunities. Opportunities are developed in construction, agriculture, tourism, and local services, benefiting surrounding communities. These jobs can help reduce poverty and increase the standard of living in the region.
3. Improved Infrastructure - Better transportation networks make it easier for local businesses to reach larger national or regional markets.
4. Tourism Opportunities – The reservoir development provides opportunities to tourism. Activities such as water sports, fishing, and eco-tourism create additional revenue for the region.

IV Lessons Learned & Recommendations

a. Key takeaways from the project

1. Through the Thwake River Basin projects, irrigation was achieved throughout the year from the water stored in the dam. South-East Kenya is a semi-arid region. Therefore, the developments in irrigation & agriculture could bring food security to semi-arid countries.
2. Agriculture focuses more on drought-resistant crop varieties, thus reducing the risk of damage and loss during drought. Sorghum, millets (especially finger millet & pearl

millet), cowpeas, sweet potato, and cassava are some of the drought-resistant crop varieties grown in Kenya.

3. In the Thwake projects, a strong partnership between the government, private sector, and local communities has been observed, indicating that the strong participation of stakeholders is essential in successfully implementing any project.
4. Displacement and relocation as a part of any project can disrupt traditions, social structure and cultural ties. Displaced communities might face challenges in accessing health services during the relocation process. Furthermore, settling in new areas without proper infrastructure can lead to poor sanitation and health outcomes.
5. Large-scale projects often bring challenges related to waste management. Construction activities generate waste that could pollute nearby water bodies if improperly handled.
6. **Long-Term Maintenance and Operation Costs** - Beyond initial construction, the ongoing maintenance and operation of the dam and associated infrastructure can strain national and local budgets, mainly if expected revenue does not materialize as planned.

b. Best strategies for adoption

Sustainable Agriculture

- With the introduction of TMWD, the dependency on seasonal rainfall for agriculture has reduced. This ensures food security and economic stability for farmers.
- Adoption: Countries in arid or semi-arid regions can adopt irrigation infrastructure supported by water storage systems to reduce vulnerability to droughts and ensure more reliable food production.

Community Participation and Stakeholder Engagement

- In the Thwake Basin project, local farmers were included in the planning and implementation phases of the project. Communities were actively involved in decision-making processes related to water management.
- Adoption: The participation of vulnerable communities should be ensured in the initial phases of any project. Their involvement enhances cooperation and reduces conflicts in

later stages of the project. Their traditional ideas will also help in sustainable resource utilization.

1. Education and Awareness Campaigns

- Community members, farmers, and other stakeholders are educated on sustainable water use. The TMWDP has involved local schools in afforestation programs and creating awareness about Climate change by creating groups that works on 3R's.
- Adoption: Promoting water conservation education at the community level can empower people to take proactive steps in sustainable resource utilization.

c. Areas for further improvement

The areas that need focus with regard to River Basin Management Projects (as observed in the case of Thwake Basin):

1. Solutions to problems due to relocation: With the TMWDP, communities were forced to relocate. Families who rely on land for their livelihoods are forced to relocate, potentially losing their homes and traditional sources of income.
2. Cultural Disruption: Displacement can result in the disruption of social structures, traditions, and cultural ties to the land, leading to challenges in maintaining social cohesion in relocated communities.

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James River
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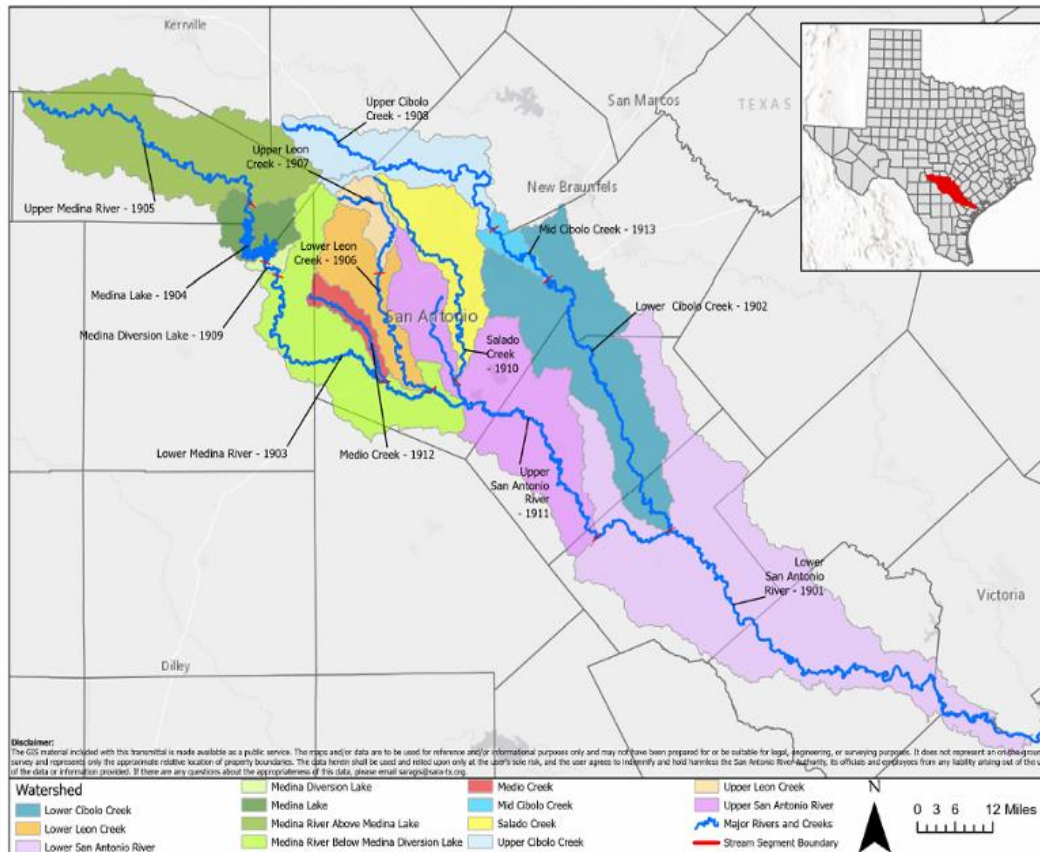
San Antonio River

Case Study Overview

Basin Overview

The San Antonio River basin is in south central Texas. While the San Antonio River Authority's (River Authority) political jurisdiction is comprised of four counties (Bexar, Wilson, Karnes and Goliad), the actual basin consists of all or part of 14 counties. The basin extends north into the Texas Hill Country in the lower portion of Kerr County and continues southeast to the Guadalupe River about 10 miles from San Antonio Bay. Most of the basin is rural, except Bexar County, which is in the center of the basin and consists of the City of San Antonio and various smaller municipalities. Five major perennial streams contributing to the San Antonio River are the Cibolo Creek, Leon Creek, Medina River, Medio Creek, and Salado Creek (*[San Antonio River 2022 Basin Highlight Update Report](#)*).

The basin originates in the northeast corner of Bandera County forming the headwaters of Medina River. Medina River, Helotes Creek, Upper Leon Creek, Olmos Creek, Upper Salado Creek, Upper Cibolo Creek and numerous ephemeral streams traverse the Edwards Aquifer Recharge Zone in northwest Bexar and Medina Counties. As these streams cross the recharge zone, their water flows into the Edwards Aquifer. Most of these streams become intermittent as they cross the recharge zone and emerge as perennial downstream of the recharge zone. Texas Commission on Environmental Quality (TCEQ) identifies five major perennial streams: Medina River, Cibolo Creek, Salado Creek, Leon Creek, and Medio Creek which all flow directly or indirectly into the San Antonio River. The San Antonio River, which originates on the grounds of the University of the Incarnate Word just north of downtown San Antonio, flows in a southeast direction through Bexar, Wilson, Karnes, and Goliad counties. The river then becomes the county line separating Refugio and Victoria counties before converging with the Guadalupe River about ten miles from San Antonio Bay (*[San Antonio River 2024 Basin Highlight Final Report](#)*).



Figure

1. Index Map of San Antonio river Basin

Source: San Antonio River 2024 Basin Highlight Final Report

Problem Statement

The **San Antonio River** faces multiple management and environmental challenges due to rapid urbanization, industrial expansion, and agricultural activities. Issues such as water pollution, declining groundwater levels, habitat degradation, and seasonal water scarcity have significantly impacted the basin's ecological health and water security. Effective management strategies are essential to address these challenges and ensure the sustainable use of water resources in the region.

1. Flood: In 1724, severe flooding from the San Antonio River prompted the relocation of the Alamo to its present-day home. Subsequent floods wreaked havoc on San Antonio until significant flood control measures were implemented. The first major improvement was the construction of Olmos Dam in 1928, north of downtown San Antonio and just above the Blue Hole (*Upper San Antonio River Watershed Master Plan*).

2. Weather: During fiscal year 2023 (September 1, 2022, to August 31, 2023), weather was a key factor affecting water quality, flow, and aquatic communities, particularly in the San Antonio River Basin. A La Niña weather pattern resulted in warmer and drier conditions in Texas. For San Antonio, it was the hottest summer on record, with an average temperature of

88.7°F. There were 75 days of triple-digit temperatures, with five days reaching as high as 106°F between June 16 and September 24, 2023 (*San Antonio River 2024 Basin Highlight Final Report*)

3. Rainfall: Rainfall varied significantly across the San Antonio River Basin during fiscal year 2023. The town of Medina, in the northwest, received only 19.48 inches of rain, well below the average annual rainfall of 34.97 inches (1966-2023). Conversely, Falls City in the southern basin saw higher-than-average rainfall, with 35.28 inches compared to the historical average of 27.58 inches (1946-2023) (*San Antonio River 2024 Basin Highlight Final Report*).

Project Description

Goals and Objectives

The San Antonio River Basin Management focuses on:

Promote clean urban waters.

Reconnect the citizens to their waterways.

Promote water conservation.

Promote economic revitalization and prosperity through existing networks of urban water resources.

Identify the major flooding reaches within the San Antonio River main stem and major tributary channel areas.

Select flood mitigation targets and evaluate appropriate projects for consideration as alternative solutions.

Strategies and Interventions

Detention: Detention options are widely utilized to detain storm water for a period of time, allowing for more controlled release, which can help to minimize flash flooding (*Upper San Antonio River Watershed Master Plan*).

Channelization: Channelization can also be useful in mitigating the effects of flooding. The feasibility of modifying existing channels to accommodate additional flows was explored, with the intent of lowering the depth of water anticipated during the 10%, 2%, 1% and 0.2% storm events (*Upper San Antonio River Watershed Master Plan*)

Olmos Basin/San Antonio Zoo Water Quality and Ecosystem Restoration: The San Antonio Zoo is constructing an ultraviolet treatment facility to disinfect water before releasing it into the San Antonio River. This project aims to reduce bacteria levels and eliminate point source pollution, improving overall water quality (*San Antonio/Bexar County, Texas Urban Waters Project 2014 Work Plan*)

East side Promise Neighbourhood/Choice/Promise Zone & (B) Salado Creek Greenway:

The Wheatley Choice Neighborhood aims to implement low impact development (LID)

strategies to manage stormwater, reduce environmental impact, and support natural water movement (*San Antonio/Bexar County, Texas Urban Waters Project 2014 Work Plan*)

World Heritage and Cultural Connections: These missions, featuring over fifty structures, archaeological sites, and irrigation systems (acequias), reflect the cultural blending that led to the founding of San Antonio, El Camino Real de los Tejas with the San Antonio Missions National Historical Park (*San Antonio/Bexar County, Texas Urban Waters Project 2014 Work Plan*).

Key stakeholders and Partnerships

Several government and community-led initiatives have been implemented in response to the need to protect the river's environment:

Federal agency partnerships

- **Department of Agriculture:**

U.S. Forest Services

Natural Resource Conservation Service

- **Department of Commerce**

Economic Development Administration

National Weather Service

- **Department of Defense**

U.S. Army Corps of Engineers

Joint Base San Antonio

State Agency Partnerships

- Texas Commission of Environmental Quality

- Texas General Land Office

- Texas Parks and Wildlife

- Texas State Forestry Division

- Texas Water Development Board

Local Government Agency Partnerships

- Bexar County

- Edwards Aquifer Authority

- San Antonio Housing Authority

- San Antonio Independent School District

- San Antonio River Authority

- San Antonio Water System

Outcomes and Impact

The successful implementation of strategic interventions in the San Antonio River Basin will lead to transformative environmental, social, and economic benefits. By improving water management, reducing pollution, and enhancing infrastructure, the basin will witness a revitalized ecosystem, improved quality of life for local communities, and sustainable economic growth. The key outcomes and impacts can be categorized into three major areas: environmental, social, and economic benefits.

Environmental benefits

Improved water quality: Ultraviolet treatment and stormwater management strategies reduce pollution, enhancing overall water quality in the San Antonio River.

Ecosystem restoration: Habitat restoration efforts, including bank stabilization and tree planting, improve biodiversity, benefiting aquatic and terrestrial species.

Reduced erosion: Erosion control techniques, such as root wad installation, prevent sedimentation, protecting the riverbed and contributing to long-term ecosystem health.

Riparian zone rehabilitation: The evaluation and restoration of riparian areas like Oso Creek help filter pollutants and reduce bacteria levels, improving water quality

Social Benefits

Enhanced public safety: Flood mitigation and water management reduce the risks to communities, enhancing public safety during extreme weather events.

Increased public engagement: Projects like the San Antonio Zoo's ultraviolet treatment facility and the restoration of waterways reconnect citizens with their natural resources, raising environmental awareness and community involvement.

Cultural heritage preservation: The restoration of irrigation systems and other historical structures in the World Heritage site preserves cultural heritage while promoting educational opportunities.

Health and well-being: Cleaner water and improved green spaces support public health by providing safe recreational areas and reducing pollution-related health risk.

Economic Benefits

Flood damage reduction: Effective flood mitigation measures like detention and channelization reduce the risk of property damage, lowering repair costs and economic losses in flood-prone areas.

Increased tourism and recreation: Improvements to the river's ecosystem, such as water quality and wildlife habitat restoration, enhance recreational opportunities (e.g., fishing, boating, tourism), boosting local businesses.

Revitalization of urban areas: The restoration projects and improved water management

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promote economic revitalization by attracting investment and fostering community development.

Lessons Learned and Recommendations

Key Takeaways

- **Integrated Flood Management:** Combining flood mitigation strategies such as detention and channelization can effectively reduce flood risks. Customizing these measures for each basin's topography and hydrology is essential for success.
- **Ecosystem Restoration with Infrastructure:** Projects like the San Antonio Zoo's ultraviolet treatment facility show that integrating infrastructure upgrades with environmental restoration enhances water quality while supporting both ecological and public health goals.
- **Community Engagement and Cultural Connections:** Engaging the public and reconnecting communities with their waterways through heritage preservation and recreational opportunities fosters environmental stewardship and local support.
- **Water Quality Improvement:** Targeted interventions like riparian zone restoration, pollution control, and water disinfection are effective in improving water quality, and these approaches can be adapted to different basins based on specific pollution sources.
- **Erosion Control through Natural Methods:** Using natural materials like root wads for erosion control, combined with planting fast-growing vegetation, can reduce sedimentation and create habitat for wildlife, serving as a low-cost and environmentally friendly erosion control solution.
- **Holistic Urban Water Management:** Coordinating efforts to manage stormwater, restore ecosystems, and promote economic development through urban water networks can lead to long-term sustainability for river basins in urbanized areas.
- **Long-term Monitoring and Adaptive Management:** Regular evaluations of riparian zones, stream health, and flood risks allow for adaptive management, ensuring that interventions continue to meet environmental and social needs over time.

Best Practices and Strategies for Replication

Flood Management and River Reconfiguration: Restoring River curves (sinuosity) and planting native vegetation balances flood control with ecological restoration, improving habitats and reducing erosion.

Managing Urban Stormwater Pollution: Solutions like rain gardens, rainwater capture, and responsible waste management reduce pollutants in stormwater, preventing fish kills.

Water Quality and Ecosystem Restoration: Removing invasive species and planting native

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vegetation restores ecosystems and improves water quality by filtering runoff and reducing pollution.

Low Impact Development (LID): Sustainable urban development strategies, such as permeable surfaces and green spaces, manage stormwater, reduce environmental impact, and revitalize communities.

Creek Restoration for Multiple Benefits: Restoring creeks enhances flood control, provides habitats for migratory species, and creates recreational spaces for communities.

Cultural and Historical Integration: Incorporating historical and cultural sites in restoration projects increases public engagement, tourism, and economic development, fostering a connection to the environment.

Conclusion

The San Antonio River Improvement Project serves as a multi-faceted restoration and sustainability initiative that integrates ecological restoration, cultural preservation, flood management, and community engagement. This project aims to enhance both the ecological and social health of the river basin while addressing modern challenges such as pollution, stormwater management, and habitat degradation.

The key strategies include flood management with ecosystem restoration, reducing pollution from urban stormwater, promoting water supply diversification through brackish groundwater desalination, and conducting extensive riparian and aquatic species restoration efforts. These strategies are tailored to not only preserve the river's natural functions but also to reconnect local communities with their waterways. Furthermore, the project highlights the importance of cultural integration by restoring and promoting historical sites along the San Antonio River.

Ultimately, the San Antonio River Improvement Project showcases a balanced approach to river restoration by addressing environmental, social, and economic objectives. Through continuous monitoring, adaptive management, and community involvement, the project provides a model for future urban waterway restoration initiatives aimed at creating a sustainable and resilient environment for future generations.

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Upper San Antonio River Master Plan (USRMP) Final Report

Niagara River

Sha River

Sha River Basin: Case Study – I

Response of Water Quality and Macroinvertebrate to Landscape at Multiple Lateral Spatial Scales in the Sha River Basin, China

Case Study Overview

Project backgrounds and location

The Sha River Basin (Figure 1), a significant sub-basin of the Huai River Basin in China, spans 317 km with a basin area of 28,800 km². Despite covering only 13% of the Huai River Basin, it accounts for over 30% of serious pollution incidents, underscoring its environmental vulnerability [1]. Since 2004, the basin has been a focal point of the "Rise of Central Part of China" strategy, leading to rapid urbanization and increased threats to the river's ecosystem [2][3]. Historically, the Sha River provided clean water to surrounding communities, but economic growth and urban expansion have resulted in substantial human disturbances, particularly in the middle and downstream areas [4]. This study analyzed land use and cover at multiple spatial scales (60, 120, 240, 480, and 960 meters) to assess their impact on water quality and macroinvertebrate populations, categorizing land into agriculture, urban, forest, wetlands, and grassland [5][6]. The findings indicate that agriculture and urban land are primary predictors of water quality at the catchment scale. At the same time, increased forest cover could improve water quality and macroinvertebrate biodiversity, emphasizing the need for effective

management and restoration strategies [7]. With urbanization continuing to exert pressure on the ecosystem, urgent environmental management measures are necessary to mitigate the adverse effects of human activities on the Sha River Basin [3][8].

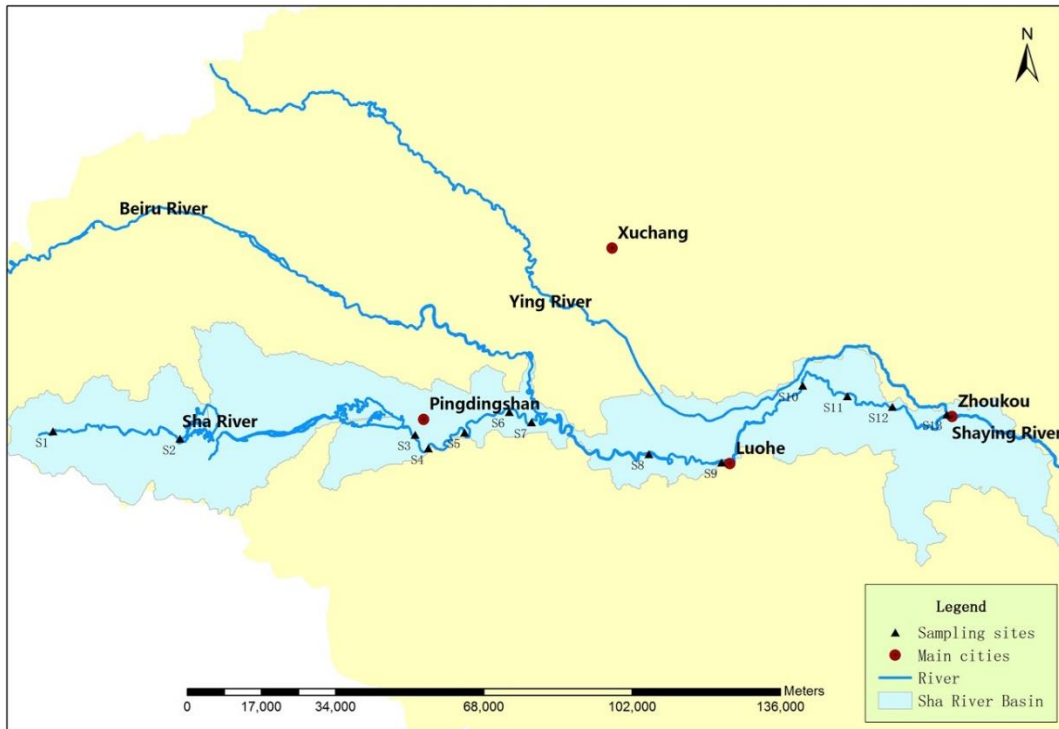


Figure 1. Location of the Sha River Basin and sampling sites [1].

Problem statement

The Sha River Basin faces significant environmental and management challenges primarily driven by human activities and urbanization (Figure 2). Fluvial ecosystem degradation has led to declining water quality and biodiversity, necessitating urgent restoration efforts [1]. However, many restoration projects are implemented without a solid understanding of ecological processes, leading to suboptimal outcomes that fail to meet ecological restoration goals [1][2]. Urbanization is a major contributor to water eutrophication in the basin, with the extent and intensity of urban land cover playing a crucial role in water quality deterioration [3]. Additionally, spatial autocorrelation and collinearity among land cover classes present challenges in analyzing relationships between land cover and stream response variables, potentially leading to misleading conclusions [4][5]. The study also emphasizes the importance of scale in management strategies, as ecosystem responses to landscape factors vary depending on the spatial scale considered [6]. Furthermore, in-stream habitat conservation is vital for macroinvertebrate biodiversity, and enhancing habitat complexity and heterogeneity is crucial for maintaining ecological.

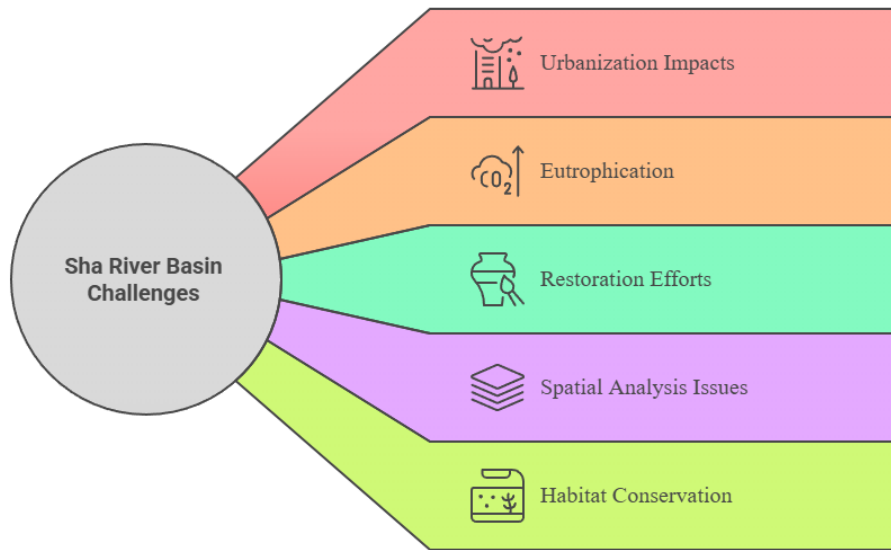


Figure 2. Challenges in the Sha River Basin.

Project Description

Goals and objectives

Determine key factors affecting stream conditions, focusing on water quality and macroinvertebrate populations.

Identify lateral scales where ecosystems respond best to landscape factors for targeted management.

Use empirical models and independence tests to analyze relationships between stream response and landscape variables.

Apply findings to improve stream restoration strategies and ecological conditions in the Sha River Basin.

Strategies and interventions

The study on the Sha River Basin highlights several strategies and interventions aimed at improving water quality and macroinvertebrate biodiversity in stream ecosystems, emphasizing the importance of considering landscape factors and spatial scales. Targeted restoration projects should be planned with a clear understanding of ecological processes, ensuring that restoration efforts are not arbitrary but based on specific landscape predictors and ecological response variables at various spatial scales [1][2]. A multiple scale approach is crucial for understanding

stream ecosystems, as analyzing ecological variables across different spatial levels (local, regional, and catchment) allows managers to identify the most effective intervention scales [3][4]. Enhancing forest cover is another key strategy, as increasing afforestation and reforestation in the catchment area can significantly improve water quality and support macroinvertebrate biodiversity [5]. Given that urban land use is a major predictor of water quality issues, strategies should focus on managing urban development impacts by implementing green infrastructure, such as permeable surfaces and green roofs, to reduce runoff and improve water quality [5]. Additionally, continuous monitoring of water quality and macroinvertebrate populations is essential for assessing the effectiveness of restoration efforts. An adaptive management approach, which allows for adjustments based on ongoing research and monitoring results, ensures that restoration goals are met effectively [6]. These strategies provide a comprehensive framework for enhancing the ecological condition of the Sha River Basin and managing stream ecosystems in the face of anthropogenic disturbances (Figure 3).

Outcomes and Impact

Environmental benefits

The study on the Sha River Basin highlights several environmental benefits associated with improved water quality and macroinvertebrate biodiversity, which are essential for maintaining ecological balance and supporting ecosystem services. Increased forest cover significantly enhances water quality by reducing pollutants such as total nitrogen (TN), ammonia nitrogen (NH₃-N), chemical oxygen demand (CODMn), total phosphorus (TP), and phosphate (PO₄-P) across all spatial scales, emphasizing the importance of preserving and expanding forested areas [1]. Additionally, urban land use is a primary contributor to water eutrophication, and managing urban development while promoting green spaces can help mitigate its negative effects, leading to healthier aquatic ecosystems [2]. The study also found that higher forest cover and specific river geomorphological features, such as sinuosity and channel depth, positively influence macroinvertebrate diversity, which is crucial for maintaining ecosystem resilience and functionality [3]. Furthermore, enhancing in-stream physical habitats by increasing habitat complexity and heterogeneity supports diverse macroinvertebrate communities, benefiting overall aquatic ecosystem health [4]. Lastly, the relationship between improved water quality and increased biodiversity creates positive feedback loops, as healthy water quality sustains diverse biological communities that further enhance water quality through natural processes like filtration and nutrient uptake [5].

Significant Findings

Primary Predictors of Water Quality: Agriculture and urban land were the dominant land cover classes affecting water quality at the catchment scale. Urban land was identified as the main driver of water eutrophication, significantly degrading water quality in the basin [1].

Correlation Analysis: Partial Mantel tests indicated that the relationship between agriculture and water quality was influenced by urban land and spatial covariates, highlighting urbanization's major impact on water quality metrics [2].

Macroinvertebrate Associations: Macroinvertebrate populations showed no direct association with most land cover percentages but were significantly related to in-stream physical variables, emphasizing the importance of habitat quality [2].

Effective Scales for Assessment: The catchment scale was most effective for detecting water eutrophication, while the in-stream habitat scale was best for macroinvertebrate restoration, underscoring the role of scale in ecological assessments [2].

Forest Cover Impact: Increasing forest cover was linked to improved water quality and macroinvertebrate biodiversity, suggesting that forest expansion could enhance stream health [3].

Statistical Analysis: Stepwise multiple regression analysis ($p < 0.05$) was used to assess the impact of predictive variables on river ecosystem health, providing a rigorous evaluation of land use effects [4].

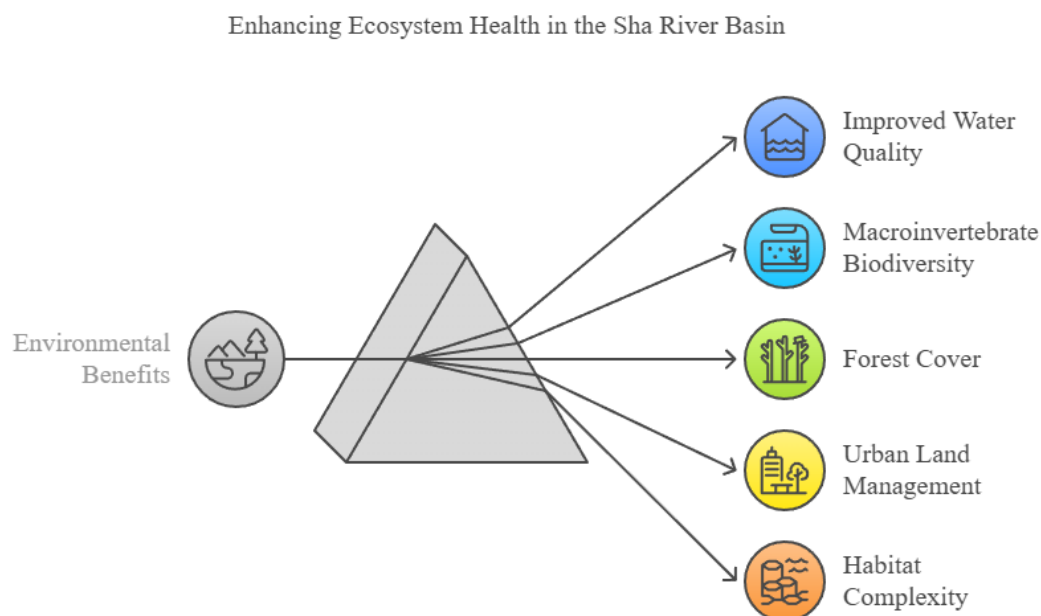


Figure 3. Environmental benefits of the Sha River Basin.
Lessons Learned and Recommendations

Key takeaways from the project

Land Use and Water Quality: Agricultural and urban land significantly impact water quality in the Sha River Basin. Multivariate regression analysis identified these as primary predictors, emphasizing the need for careful land management to reduce pollution [1].

Urbanization and Eutrophication: Urban land use contributes significantly to water eutrophication, increasing pressure on water resources. The study highlights the necessity of urban planning and pollution control measures to protect water quality [1].

Macroinvertebrate Biodiversity: Macroinvertebrate diversity was more closely linked to in-stream physical variables rather than land cover percentages. This suggests that enhancing in-stream habitats may be more effective for their restoration than focusing solely on land cover changes [1].

Forest Cover Benefits: Increasing forest cover improves both water quality and macroinvertebrate biodiversity. Forests act as natural buffers, reducing runoff and filtering pollutants before they reach water bodies [1].

Effective Management Strategies: The study supports using empirical models and independence tests to clarify how landscape changes affect disturbed stream ecosystems, ensuring scientifically informed management and restoration efforts [1].

Multi-Scale Approach: The catchment scale was the most effective for detecting water quality issues, while the in-stream habitat scale was crucial for macroinvertebrate restoration, emphasizing the need for a multi-scale approach in environmental management [1].

Practical implications

Urban Planning and Management: Urban land significantly impacts water quality, particularly through eutrophication (Figure 4). Planners should incorporate green infrastructure, storm water management, and low-impact development to reduce runoff and pollution [1].

Land Use Policies: Both agricultural and urban land use affect water quality. Policymakers should implement zoning laws to protect sensitive areas and promote sustainable agricultural practices to limit nutrient runoff [2].

Habitat Restoration Efforts: Enhancing in-stream habitat complexity with natural structures like logs and rocks can support macroinvertebrate conservation [3].

Forest Conservation Initiatives: Expanding forest cover near water bodies can improve water quality and biodiversity by filtering pollutants and stabilizing stream banks [4].

Multi-Scale Management Approaches: Addressing water quality and biodiversity requires scale-specific strategies, such as catchment-level interventions for water quality and in-stream habitat improvements for biodiversity [2].

Research and Monitoring: Ongoing research and monitoring are crucial to assess land use impacts, track management effectiveness, and guide future conservation efforts [2].

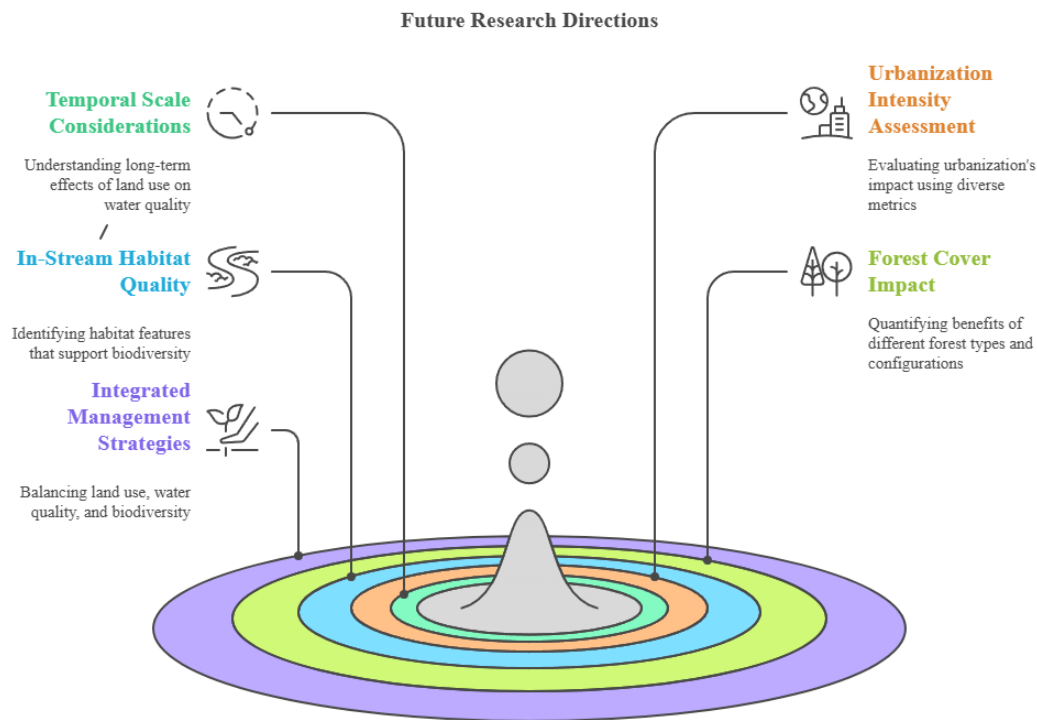


Figure 4. Areas for further improvement or research.

Areas for further improvement or research

Temporal Scale Considerations: Historic land use legacy significantly influences water quality. Future research should incorporate temporal scales to understand long-term effects and inform restoration efforts [1].

Urbanization Intensity Assessment: The study only considered land use percentage, limiting insights into urbanization's impact. Future studies should include metrics like population density, industrial activity, and infrastructure development [1].

In-Stream Habitat Quality: Significant relationships exist between macroinvertebrates and in-stream variables. Further research is needed to identify habitat features that support biodiversity and inform restoration efforts [2].

Forest Cover Impact: Increasing forest cover improves water quality and biodiversity. Future studies should quantify the benefits of different forest types and configurations to guide reforestation efforts.

Integrated Management Strategies: Research should explore strategies that balance land use, water quality, and biodiversity to minimize negative impacts while promoting sustainable development in the Sha River Basin (Figure 3).

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Sha River Basin: Case Study – II

Longitudinal Changes in Water Quality to Landscape Gradients Along Sha River Basin

Case Study Overview

Project backgrounds and location

The research focuses on the Sha River Basin, a hydrologically diverse region with 13 probabilistically selected sampling sites ensuring representative analysis. Field surveys were conducted in August and September of 2009 and 2010, chosen for moderate temperatures and base flow conditions ideal for water quality assessment. The Sha River is a meandering large river with sinuosity values exceeding 1 at all sites, reaching over 1.5 in some areas, particularly at the headwaters. Channel widths mostly exceed 100 meters, with six sites reaching 200 meters, and depths varying from under 1.5 meters to nearly 6 meters at sites S11 and S12. Water temperatures ranged from 20 to 24°C, aligning with the seasonal conditions of July and August. A land use analysis, based on 2008 Landsat TM and ETM imagery, categorized land cover into agriculture, urban, forest, wetlands, and others, essential for evaluating the impact of land use on water quality. The primary objective of the study is to examine how landscape changes influence water quality in the Sha River Basin, particularly the effects of urbanization on

indicators such as total nitrogen and ammonium.

Problem statement

The Sha River Basin faces significant environmental challenges due to rapid urbanization, which negatively impacts water quality. Expanding urban areas introduce various pollutants, with point source pollution from industrial and municipal wastewater treatment plants directly contaminating the river, while nonpoint source pollution from residential areas contributes through diffuse runoff. The loss of riparian vegetation and wetlands further exacerbates the situation by reducing the natural capacity to filter pollutants and protect aquatic habitats. Research indicates that urbanization becomes particularly detrimental when urban land exceeds 20% of the total area, making it essential to maintain urban development below this threshold to mitigate water quality degradation. Although agriculture remains the dominant land use in the basin, the adverse effects of concentrated urbanization surpass agricultural impacts. Additionally, longitudinal changes in water quality reveal that nutrient loads peak in middle-order reaches before declining downstream due to both natural processes and human activities.

Project Description

Goals and objectives

The goals and objectives of the Sha River Basin case study are shown below (Figure 1):

Investigate the spatial variability of water quality across different reaches of the Sha River Basin, focusing on differences between headwater, mid-reach, and downstream areas to understand the impact of urbanization.

Examine the relationship between water quality and landscape characteristics along the longitudinal scale of the basin, identifying critical reaches that explain water quality changes. Determine the critical threshold for urban land percentage (not exceeding 20%) necessary to maintain acceptable water quality levels according to Chinese State Standards for surface and drinking water.

Construct dose-response curves for key water quality indicators, such as total nitrogen and ammonium, to predict how urbanization affects water quality.

Provide recommendations for land use management and urban planning to minimize water quality degradation by maintaining lower urban land percentages.

Advocate for restoration projects in mid-reach and lower-reach areas to enhance stream health and biodiversity, addressing the negative impacts of urbanization.

Contribute to the broader understanding of how urbanization and land use changes affect river ecosystems, providing a framework for future research and management practices.

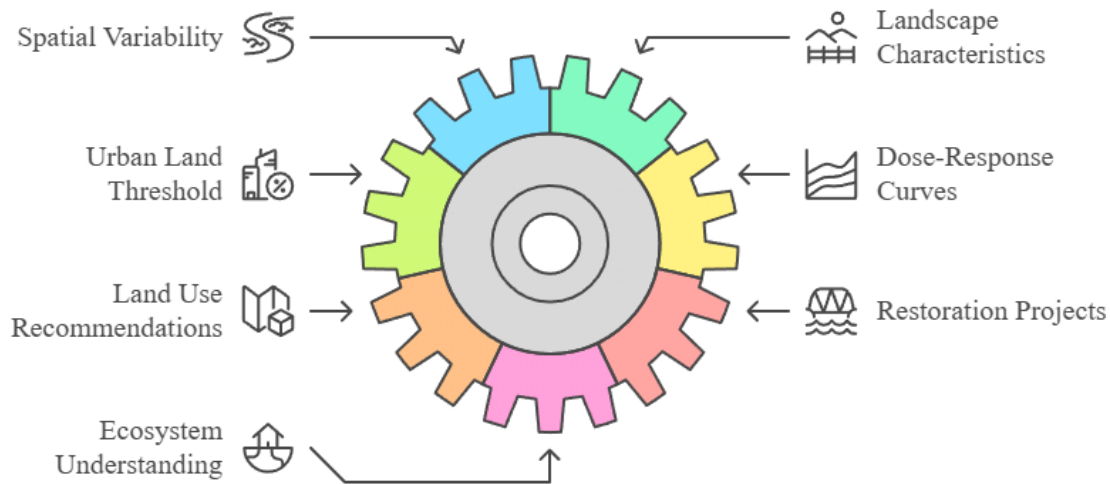


Figure 1. Goals and objectives

Strategies and interventions

To enhance water quality in the Sha River Basin, several strategies can be implemented. Restoration projects in the mid-reach and lower-reach areas should focus on improving stream health and biodiversity, particularly in urbanized regions where water quality has significantly degraded. Effective land use management is also essential, with urban land percentages recommended to remain below 20% to prevent further degradation. Implementing green infrastructure, such as vegetated buffers, wetland restoration, and permeable surfaces, can help mitigate urban runoff and nonpoint source pollution. Public awareness campaigns can educate local communities on the importance of protecting water quality and encourage participation in conservation efforts like tree planting and clean-up activities. Additionally, continuous monitoring of water quality indicators, such as total nitrogen and ammonium levels, is necessary to assess the effectiveness of these interventions and adjust strategies as needed. By employing these comprehensive measures, the Sha River Basin can achieve improved water quality and a healthier ecosystem.

Outcomes and Impact

Environmental benefits

Land Use & Water Quality: Urbanization negatively affects water nutrient levels. The study identifies urban land percentage thresholds to maintain water quality, aiding sustainable land management.

Role of Forests: Forested areas mitigate water eutrophication by acting as natural filters, reducing nutrient runoff. Findings support conservation efforts to restore and protect forest

regions.

Methodological Approach: The use of generalized additive models (GAMs) provides a robust tool for analyzing environmental stressors and stream ecosystem responses, enabling targeted interventions.

Monitoring & Management: Continuous water quality monitoring supports timely interventions and adaptive management. The study informs effective restoration strategies to enhance river resilience.

Policy Implications: Insights help policymakers and conservationists improve water quality and protect the Sha River Basin's ecological integrity.

Significant Findings

The study on the Sha River Basin provided significant findings on the relationship between water quality and landscape gradients, supported by statistical data. One key finding is that water quality deteriorates significantly from the headwaters to downstream areas. Specifically, total nitrogen (TN) and ammonium (NH₃-N) levels exhibited a clear positive correlation with urbanization, with TN levels increasing as urban land use exceeded 5% of the total area and showing marked impacts when urban land surpassed 20%. The research identified the middle reach of the river as the most critical area for explaining water quality degradation, with urbanization being the primary driver of this decline. To meet the Chinese State Standard (CSS) for surface and drinking water, it is crucial to maintain urban land at or below 20% of the total area. Exceeding this threshold leads to significant increases in pollution levels. Moreover, response curves for TN and NH₃-N demonstrated a parabolic relationship with urbanization, indicating that as urban land increases, its impact on water quality becomes more pronounced. The study noted that maintaining urban land below 20% could effectively keep TN levels under the CSS maximum permissible limit of 2 mg/L for drinking water. Overall, the findings emphasize the need for effective land management strategies to mitigate the adverse effects of urbanization on water quality in the Sha River Basin, highlighting the importance of understanding both lateral and longitudinal scales in assessing stream health and ecosystem responses.

Lessons Learned and Recommendations

Key takeaways from the project

Spatial Variation: Water quality in the Sha River Basin declines from headwater to downstream areas, with better quality in headwater reaches and worse in middle and lower reaches [1].

Impact of Urbanization: Urbanization is the primary cause of water quality degradation,

especially in mid-reach areas. Downstream urbanization worsens water quality [2][3].

Urban Land Threshold: To meet the Chinese State Standard (CSS) for surface and drinking water, urban land must remain below 20%. Exceeding this threshold significantly increases pollutants [2][4].

Response Curves: Total nitrogen (TN) and ammonium (NH₃-N) show a parabolic relationship with urbanization, with greater impacts as urban land increases [4].

RDA Analysis: Redundancy Analysis (RDA) indicates urban land positively affects water nutrient values, while forest land mitigates water eutrophication [5][6].

Geological Influence: Geological factors, such as water velocity, correlate positively with most water quality metrics, affecting water quality [5].

Restoration Needs: Restoration projects are recommended in mid-reach and lower-reach areas to protect stream health and biodiversity from urbanization impacts [7].

Practical implications

The findings of this study on the Sha River Basin have significant practical implications for water resource management and urban planning. Firstly, identifying urbanization as a primary driver of water quality degradation emphasizes the need for effective land-use policies that limit urban expansion, particularly in sensitive areas. Maintaining urban land below 20% of the total area is crucial to preventing further deterioration of water quality, as indicated by the response curves for total nitrogen and ammonium, which show a strong correlation with urbanization levels [1][2]. Additionally, the study highlights the importance of preserving forested areas, which can mitigate eutrophication effects and improve water quality in headwater regions [3]. Implementing restoration projects in the mid and lower reaches of the river, where urbanization impacts are most pronounced, can enhance ecosystem health and biodiversity [4]. Overall, the study provides a framework for policymakers to develop strategies that balance urban development with environmental protection, ensuring sustainable water quality in the Sha River Basin.

Areas for further improvement or research

The study on the Sha River Basin opens several avenues for further research and improvement in understanding water quality dynamics (Figure 2). Firstly, there is a need for more detailed investigations into the specific sources of nonpoint source pollution, particularly from residential areas, as these have been identified as significant contributors to water quality degradation [1]. Additionally, future studies could explore the long-term effects of urbanization

on aquatic ecosystems, particularly in relation to biodiversity loss and habitat alteration, which were not extensively covered in this research. The role of riparian vegetation in buffering water quality impacts should also be examined more closely, as the study noted its reduction due to urban expansion [1]. Furthermore, expanding the research to include seasonal variations in water quality could provide insights into how different land use types affect water quality throughout the year. Lastly, comparative studies with other river basins experiencing similar urbanization pressures could enhance the understanding of universal patterns and effective management strategies for maintaining water quality in urbanizing landscapes.

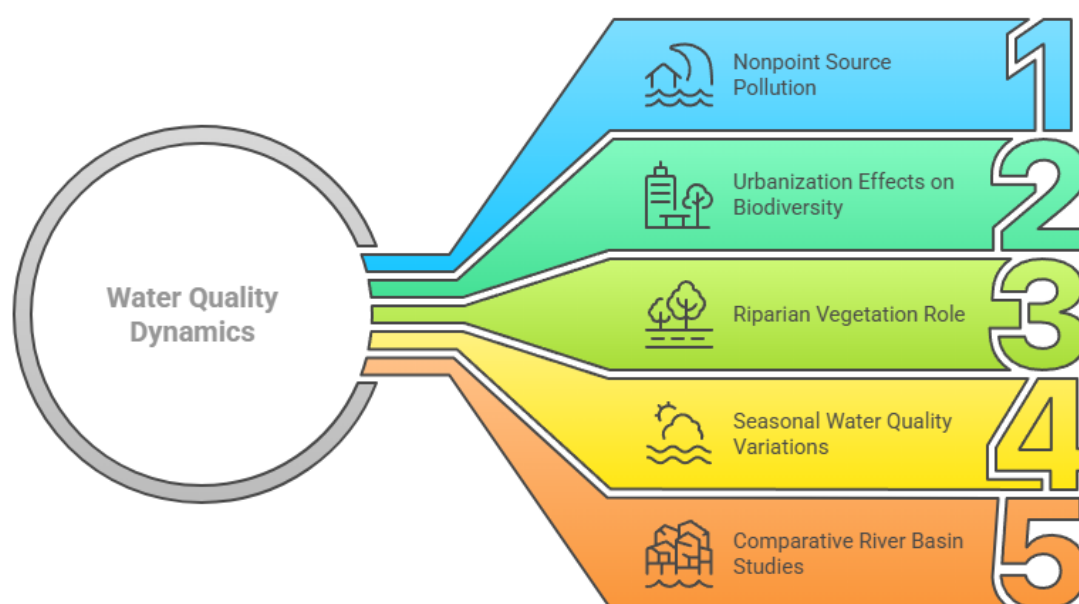


Figure 2. Areas for further improvement or research in the Sha River Basin

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Geostatistical and geoarchaeological study of Holocene floodplains and site distributions on the Sha-Ying River Basin, Central China

Case Study Overview

Project location and background

The study focuses on the Holocene floodplains of the Sha-Ying River Plain (SYRP) in eastern Central China. It examines how alluvial processes and environmental changes influenced human settlement patterns throughout 9000–2500 B.P. The research integrates geological, pedological, and archaeological data with geostatistical methods like variograms and kriging to reconstruct landform evolution and human adaptation.

Problem Statement: Management and Environmental Challenges

The floodplains in the region are characterized by prolonged alluvial aggradation, making it difficult to obtain clear records of long-term human-environment interactions.

Continuous sediment deposition buries archaeological sites, complicating their study.

Flooding and hydrodynamic changes create unstable environmental conditions, posing challenges for settlement sustainability.

Project description

a. Goals and Objectives

To reconstruct the environmental history of the Holocene period in the SYRP.

To apply geostatistical methods for analyzing spatial and temporal variations in landform evolution.

To integrate environmental and archaeological data for understanding long-term human adaptations to floodplain changes.

b. Strategies and Interventions

A systematic geoarchaeological drilling project covering 300 km² was conducted.

A total of 361 boreholes were analyzed for sedimentation patterns and landform changes.

Variogram modeling and kriging interpolation were used to generate spatial reconstructions of past floodplain conditions.

Outcome and Impacts

a. Environmental Benefits

Enhanced understanding of floodplain evolution aids in better management of present-day hydrological risks.

Insights into prehistoric human responses to environmental challenges can inform modern land-use strategies.

Identification of stable and unstable regions in the floodplain supports archaeological site preservation.

b. Significant Findings

The study revealed multiple phases of alluvial aggradation and sedimentation changes over thousands of years.

Spatial analysis indicated that hydrological factors had significant control over settlement patterns.

Human settlements exhibited adaptability strategies such as shifting occupations in response to environmental fluctuations.

Lesson Learned and Recommendations

a. Key Takeaways from the Study

The integration of geo-statistics with archaeology provides a powerful tool for understanding floodplain evolution.

Human settlements in dynamic environments are heavily influenced by hydrological stability.

Floodplain environments require adaptive strategies for long-term human habitation.

b. Practical Implications

Modern floodplain management can benefit from historical data on landform evolution.

Archaeological survey techniques should incorporate geostatistical methods for more precise site identification.

Future urban and agricultural planning in flood-prone areas can leverage insights from past human adaptations.

c. Areas for Further Improvement or Research

More detailed chronological studies using improved dating methods.

Expansion of research to cover more regions and compare floodplain environments globally.

Investigation into micro-scale human adaptation strategies in response to local hydrological changes

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Drôme River

The Drôme River Basin is located in southeastern France, covering an area within the Auvergne-Rhône-Alpes region, encompassing a diverse landscape of mountains, valleys, and floodplains. Originating from the Vercors Massif near La Bâtie-des-Fonds at approximately 1,200 meters elevation, the Drôme River traverses roughly 110 kilometres through varied topography, eventually joining the Rhône River near Lorient-sur-Drôme. Geographically, the basin extends between latitudes 44°30'N to 45°10'N and longitudes 4°30'E to 5°30'E, encompassing significant ecological diversity.

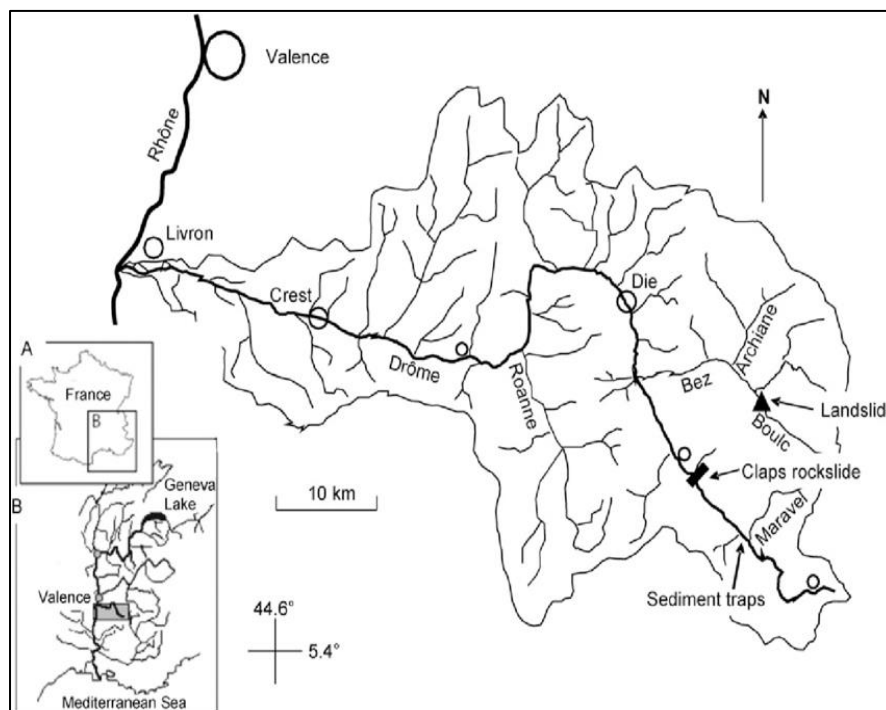


Figure 3. Index Map of Drôme River (Image Source: <https://link.springer.com/article/10.1007/s00027-009-9201-7>)

Climate Change

The GICC-DECLIC (Gestion et Impacts du Changement Climatique-Drôme : Eau, Climat et Impacts liés aux Changements) project, conducted from 2010 to 2012, extensively examined climate variability and associated impacts on the Drôme River Basin in southeastern France.

Focusing on water resources, agriculture productivity, and forestry management, this collaborative initiative integrated expertise from academic institutions (three research laboratories LTHE, PACTE and ESPACE) and regional territorial agencies. Utilising comprehensive climatic data over the past 60 years, the study revealed significant climatic shifts, particularly rising temperatures and altered precipitation patterns and atmospheric pressure. For instance, Montélimar recorded an increase in mean temperature of approximately 1°C since 1984, alongside notable shifts in seasonal dynamics such as rising nocturnal temperatures and altered precipitation patterns, intensifying agro-climatic stress. These alterations have profound implications on water-sensitive sectors, significantly affecting vineyards, fruit production, forestry sustainability, and regional tourism viability. Consequently, researchers highlighted a persistent declining trend in precipitation from 1989 onwards, underscoring urgent adaptation needs. The study aimed to deliver a comprehensive "green paper" to guide decision-makers towards informed, adaptive strategies addressing climate-induced challenges.

Stella et al. (2013) examined the decline of *Populus nigra* trees along the Drôme River, attributing it primarily to the combined impacts of climate change and channel incision resulting from extensive gravel mining. Employing dendrochronological analyses, the study demonstrated a significant correlation between declining tree growth rates and reduced water availability. These impacts were worsened by local geomorphic factors like bedrock depth, intensifying the drought-induced stress on riparian forests. The study thus underscored how riparian forests remain highly vulnerable to hydrological and geomorphological alterations intensified by changing climate patterns.

Similarly, Borgniet et al. (2013) evaluated forest management strategies in Aosta Valley and Drôme region, particularly focusing on erosion control and mitigation of rockfalls hazards through afforestation efforts. Historically, Austrian Black Pine forests successfully stabilized vulnerable slopes following severe floods in the 19th-century. However, recent rise in temperatures and frequency of drought events have progressively weakened them over time, leading to forest decline. Due to limited Monitoring infrastructure, tracking the precise impacts of climate change on forest health remained challenging. Researchers employed remote sensing, including NDVI indices, and modelling tools such as RockforLIN to monitor forest dieback and assess environmental risks. High-resolution satellite imagery mapped vegetation losses, guiding adaptive strategies, including eco-engineering and selective thinning to enhance forest resilience effectively.

Sediment Transport and River Morphology

Liébault et al. (1999) investigated bedload delivery from tributaries to the Drôme River to assess

the potential for reversing bed degradation trends. They used Principal Component Analysis, aerial photography, and field surveys to compare sediment supply from different tributaries. Their findings showed that active tributaries had well-developed gravel bars, while inactive ones experienced bed incision, channel narrowing, and vegetation encroachment. Human interventions, such as erosion control measures and afforestation, played a secondary role in sediment transport. The study highlighted the importance of understanding sediment dynamics for sustainable river management.

Kondolf et al. (2002) investigated how land use changes influenced sediment supply and channel morphology in Pine Creek, Idaho, and the Drôme River, France. They found that historical mining and deforestation in Pine Creek increased sediment loads, leading to channel widening and instability. In contrast, reforestation and erosion control in the Drôme reduced sediment supply, causing channel incision and narrowing. Both cases resulted in negative environmental impacts, such as flood risks, infrastructure damage, and groundwater loss. The study highlighted the importance of understanding sediment dynamics for sustainable river management and restoration strategies.

Piégay et al. (2004) assessed changes in sediment yield in the upper Drôme River basin due to afforestation. Using archival data, dendrogeomorphology, and radionuclide analysis, they found that sedimentation rates declined after the 1960s, linked to planned afforestation and reduced grazing following World War II. Bedload transport remained stable, but sediment sources shifted due to channel degradation. Hydrological changes, including lower peak flows and increased water retention, further influenced sediment dynamics. The study highlighted the long-term impacts of land use change on sediment transport and emphasized the role of afforestation in stabilizing river systems.

Toone (2009) investigated geomorphological discontinuities and their influence on macroinvertebrate community organization in the Drôme River. Using historical aerial imagery, GIS analysis, and field surveys, she examined changes in channel morphology from 1948 to 2006. The study found that channel degradation followed a non-linear trajectory, influenced by sediment transport and flood events. Macroinvertebrate distribution was shaped by variations in sediment composition, hydrology, and channel structure. The research emphasized the role of geomorphic processes in maintaining biodiversity and highlighted the need for sediment management strategies to preserve ecological integrity.

Toone et al. (2014) investigated the geomorphological evolution of a 5 km reach of the Drôme River, France, focusing on the role of alternating alluvial and bedrock zones in channel development. Using aerial photographs (1948–2006) and bed elevation profiles (1928, 2003, 2005), it was found that bedrock exposures-controlled sediment connectivity and channel

zonation. A moderate 1978 flood triggered significant changes, while long-term trends showed incision (up to 2.1 m), narrowing (zone 2 by 7% and zone 4 by 12%), and sediment redistribution. Between 1948 and 2001, zone 4 widened (61% increase in active width) due to sediment accumulation, whereas zone 2 narrowed (19% reduction) and increased up to 1.6 m, acting as a sediment source. Bedrock bottlenecks constrained sediment transfer, influencing overall channel dynamics. These findings underscored the importance of long-term perspectives in river management, as contemporary observations alone may be misleading.

Roux et al. (2014) developed the Fluvial Corridor GIS toolbox to automate riverscape characterization and biogeomorphologic analysis. Applied to the Drôme River in France, the tool effectively extracted and analysed fluvial corridor features, despite some spatial limitations. The results demonstrated its usefulness in geomorphologic studies and river management by enabling spatial aggregation and integration of external data. Various metrics, such as fluvial widths and ecotones, were successfully assessed to support environmental planning. The toolbox was concluded to be a valuable resource for scientists and river basin managers in assessing riverscape dynamics and informing decision-making processes.

Ruiz-Villanueva et al. (2016) reviewed large wood dynamics in river systems, examining its role in morphology, ecosystems, and associated risks. The study analysed measurement and modelling approaches across various regions, highlighting large wood's impact on sediment transport and habitat formation while posing flood risks. Results emphasized advancements in quantification techniques, offering insights for river management. Future research needs were identified to improve predictive models and sustainable management strategies.

Marmonier et al. (2019) examined the impact of natural and artificial floodplain constrictions on hyporheic fauna in the Drôme River. The study found that natural valley narrowing reduced alluvium thickness, increased groundwater inflow, and boosted stygobite abundance, while an artificial embankment reduced the spatial heterogeneity of benthic fauna without affecting stygofauna. Sampling across nine stations revealed greater faunal heterogeneity near riverbanks. The findings emphasized that natural constrictions shape stygofauna distribution through groundwater interactions, whereas artificial modifications mainly alter benthic fauna patterns. This research aids river management by highlighting ecological effects of human-induced changes.

Fernandez et al. (2020) investigated the impact of flood sequences on braided river morphodynamics under varying vegetation strengths in a laboratory setting. Using alfalfa as a proxy, it was found that vegetation increased channel formation, width, and topographic irregularity, especially during low flows. Vegetation life stages influenced morphodynamic sensitivity, with younger and decaying plants responding more to floods, while mature

vegetation stabilized channels. Deficit floods reduced plant-morphology interactions, mimicking larger floods without sediment deficits. These findings enhance flood impact predictions, improving long-term river modelling and management amid climate change.

Water Pollution

Châtelliers et al. ([Not received]

[2021](#)) conducted a study to evaluate nitrate and pesticide contamination in groundwater and agricultural soil in the Mnasra region, Morocco, an area known for intensive farming. 108 water samples and 68 soil samples were collected from ten selected sites between May 2010 and September 2012. It was found that 89.7% of groundwater samples exceeded the standard nitrate limit of 50 mg/L, with 50.9% surpassing 100 mg/L. This contamination was attributed to the sandy soil, frequent fertiliser application, and shallow groundwater levels, facilitating nitrate leaching. Conversely, pesticide residues were below the quantification limit in all samples, likely due to the rapid degradation of pesticide molecules and the predominance of foliar pesticide applications. The study highlighted the need for improved water management practices, such as optimised fertigation systems and balanced manure application, to reduce nitrate pollution. Furthermore, monitoring pesticide residues and their metabolites was recommended to enhance environmental protection efforts.

Ecological and environment studies

Pieâgay et al., (1997) examined the ecological significance and management challenges of riparian forests along the Drôme River. Researchers analysed forest evolution since 1948, identifying issues such as reduced sediment transport, channel incision, and vegetation fragmentation. They proposed management strategies, including legal conservation measures, replanting vegetation corridors, and selective intervention to balance flood risk and ecosystem health. The study supported adaptive strategies to maintain riparian dynamics, prevent erosion, and enhance biodiversity, aligning with France's Water Law of 1992 and the Rhône watershed management plan.

Dufour et al. (~~2009~~[2007](#)) examined how river embankments influenced riparian vegetation. Researchers compared an embanked and an unconstrained reach, finding that channel confinement reduced active channel width, altered sediment composition, and created drier conditions. These changes led to a decrease in species diversity, a homogenization of vegetation structure, and a dominance of drought-tolerant species like *Populus nigra*. The study noted the long-term ecological impacts of embankments and emphasized the need for sustainable river management to preserve riparian biodiversity.

Gal et al. (2010) investigated CO₂ emissions from a natural underground reservoir. Researchers conducted gas sampling in 2006 and 2007 to assess soil CO₂ fluxes and isotopic compositions.

They found elevated CO₂ concentrations that exceeded biological activity levels, suggesting deep gas migration. However, no evidence of leakage from the reservoir was detected. The study emphasized the need for further monitoring to understand seasonal gas variations and assess the safety of underground CO₂ storage.

Hervouet et al. (2011) analysed post-flood vegetation recruitment in braided rivers using UAV, ultra-light aerial vehicles, and satellite imagery. They examined vegetation development along the Drôme River from 2005 to 2011, finding that asexual reproduction dominated but sexual reproduction played a role during low-flow periods after major floods. Their findings showed that vegetation encroachment contributed to channel narrowing, influenced by climatic conditions, water table levels, and local topography. The study highlighted the importance of remote sensing for monitoring riverine vegetation dynamics and emphasized the role of hydro-geomorphic factors in shaping riparian ecosystems.

Janssen et al. (2020) examined the impact of human-induced stressors on riparian forest succession along the Rhône and Drôme rivers. Using a chronosequence modelling approach, they found that channelization and flow regulation accelerated forest transition, favouring non-native species along the Rhône. These changes disrupted natural succession, altering forest composition and structure. The study highlighted the long-term ecological consequences of river modifications and the need for sustainable management.

Watershed Management

Bertrand et al. (2013) conducted a study to implement and test a conceptual framework for the sustainable management of gravel-bed rivers in the Drôme River Basin, France. The functional sector concept was applied to assess environmental change risks, particularly the impacts of sediment replenishment on functional sector diversity, used as a proxy for habitat diversity, and on brown trout distribution. Remote sensing and Geographic Information System (GIS) methods were utilized to generate original datasets, and a functional sector typology was established using cluster analysis on principal component analysis results. A comparison of present and 1948 functional sector diversity indices revealed past evolutionary trends in the channel network, while sensitivity analysis predicted potential changes resulting from planned sediment reintroduction and forest removal. Similarly, alterations in brown trout distribution were projected based on changes in canopy cover and summer water temperature. The findings indicated that the functional sector approach could effectively evaluate management actions to improve aquatic ecology, though certain limitations were identified and discussed.

Räpple et al. (2017) investigated riparian vegetation encroachment along the Drôme River, France, to understand the relative importance of recruitment and lateral expansion and their controlling factors. A 3-km river reach was analysed using high-resolution aerial images from

2005 to 2011, complemented by airborne LiDAR (Light Detection and Ranging) data and field observations. Vegetation patches were digitized to assess recruitment timing and expansion patterns. It was found that the post-flood vegetated area doubled within six years, with recruitment peaking in 2006–2007. Expansion was observed to be positively correlated with growing season temperature, while recruitment was primarily influenced by hydrological connectivity. The process occurred first along low-flow channel margins and later extended to intermittent channels. The findings suggested that recruitment success depended on the time since the last channel-resetting flood and the geomorphic conditions established after such events. Furthermore, climate change was identified as a potential factor altering vegetation-geomorphic interactions by influencing expansion and survival during inter-flood periods.

Sustainable Management and Policies

Barreteau et al. (2003) explored innovative water management approaches in the Drôme River Valley by employing agent-based modelling (ABM) to facilitate stakeholder negotiations. This study assessed the effectiveness of ABM in comparison to traditional water resource management models, demonstrating that ABM significantly enhanced the decision-making process. Specifically, it improved spatial awareness among stakeholders and clarified the interconnectedness of water resource issues. The flexibility of ABM allowed it to adapt dynamically to evolving negotiation contexts, restructuring dialogues, and clarifying complex decisions regarding water allocations. Their findings emphasized that simulation tools like ABM are critical for fostering adaptive governance and promoting collaborative water management strategies.

Similarly, Pont et al. (2009) underscored the significance of interdisciplinary methodologies for managing gravel-bed rivers sustainably in their analysis of the Drôme River basin. By investigating historical geomorphic changes, they linked alterations in sediment transport dynamics directly to socio-economic and ecological impacts observed over the last two centuries. The researchers critically reviewed past water and sediment management approaches, pinpointing effective replenishment strategies for incised reaches. Their comprehensive evaluation integrated considerations of legal constraints, ecological impacts, and practical managerial feasibility. The study highlighted the necessity for an integrated framework combining geomorphological, ecological, and societal perspectives to ensure sustainable sediment management practices.

Comby et al. (2014) examined the implementation of decentralized water management in the Drôme River catchment from 1981 to 2008, focusing on stakeholder participation. They studied local newspaper coverage to assess public involvement and policy evolution. The study found that integrated water management was achieved through stakeholder engagement, compromise,

and local governance structures like the Commission Locale de l'Eau (CLE). However, implementation was not linear, with progress influenced by crises such as floods and droughts. The research highlighted the role of media in shaping public perception and emphasized the importance of participatory governance in sustainable water management.

George Clément (2024) critically analysed the applicability of Riverscapes Consortium models to the French context, using the Drôme watershed as a case study. The research assessed how geomatic tools developed in the U.S. could be adapted to European hydrosystems. The study identified challenges in data availability, model customization, and policy integration while highlighting the benefits of geospatial analysis for river management. By testing different models, Clément demonstrated their potential to enhance decision-making but also noted limitations in transferring methodologies across regions. The study emphasized the need for localized adaptations to improve model efficiency and guide sustainable water resource management in France.

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Siuslaw River Basin

I. SIUSLAW RIVER-OVERVIEW

a. BACKGROUND AND LOCATION

The Siuslaw River originates in the rain-drenched forests of the Oregon Coast Range and the fertile Lorane Valley, west of Eugene at North Latitude 44° 1' 1" and East longitude 124° 8' 14" and flows approximately 177 km long through the Central Oregon Coast Range to the Pacific Ocean near Florence, Oregon, in the United States of America. The Siuslaw River basin covers 504,000 acres and includes various creeks, wetlands, and lakes. One of its major tributaries is the North Fork Siuslaw River, which joins the main stem near Florence. The watershed borders are the Alsea River system to the north, the Willamette River system to the east, and the Smith River (a tributary of the Umpqua River) to the south.

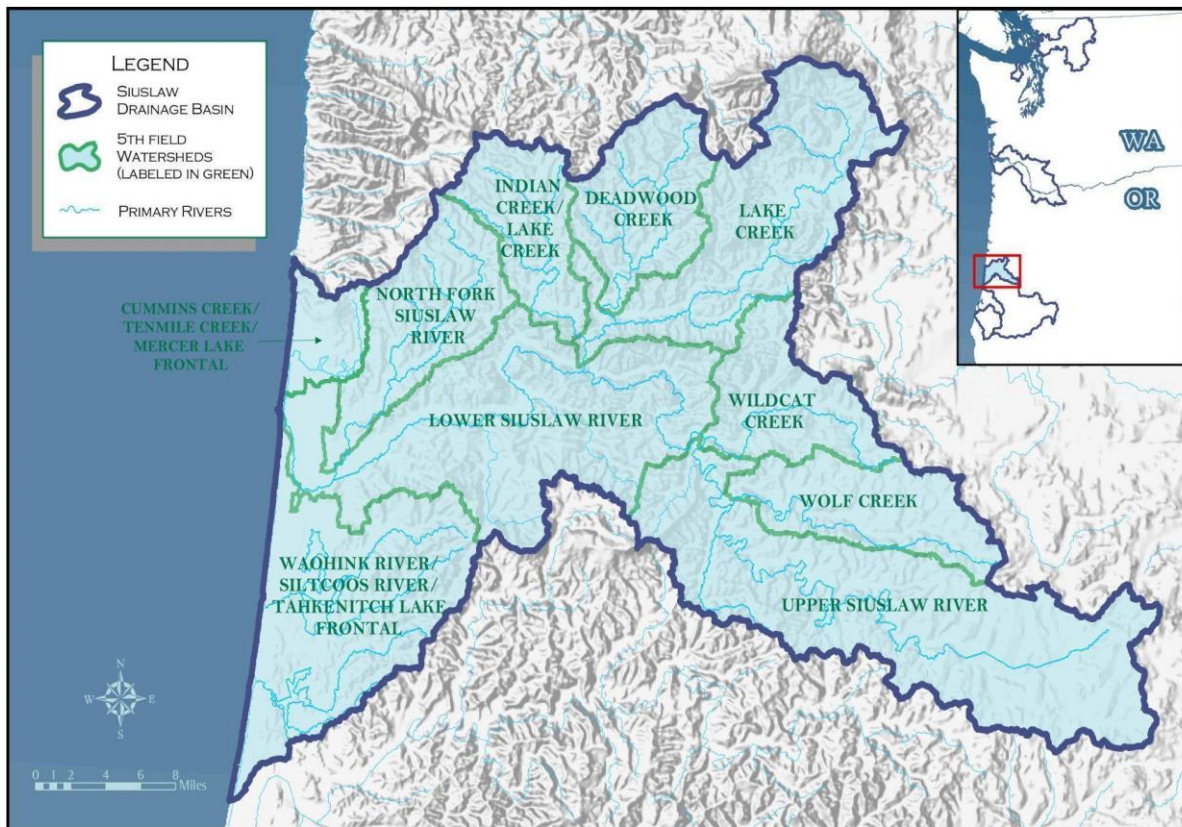


Figure 1: Siuslaw River Basin

(Source: Siuslaw Watershed Council)

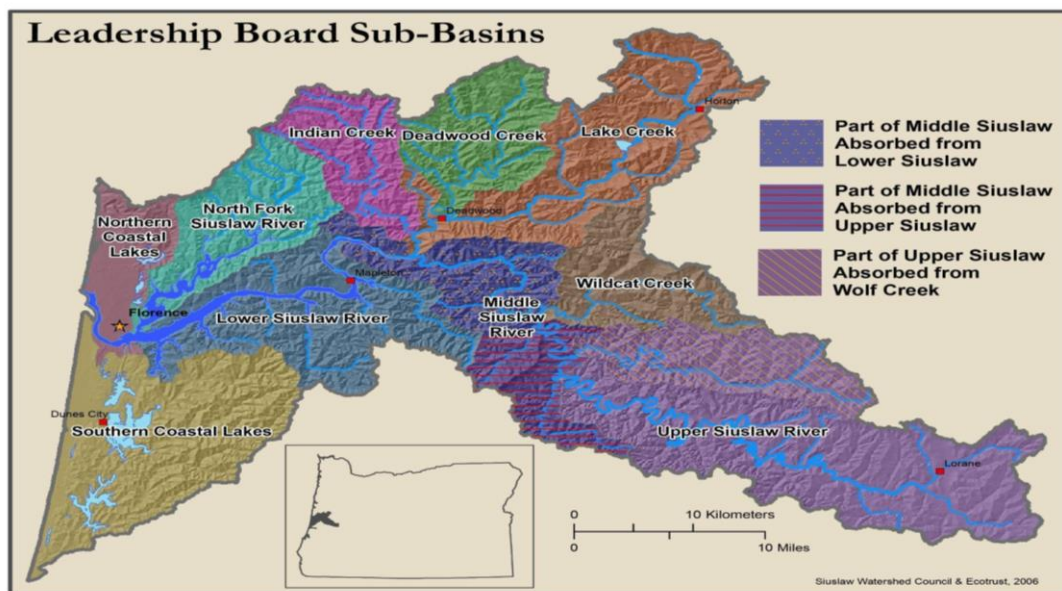


Figure 2: Siuslaw River Sub-Basins

(Source: Siuslaw Watershed Council)

b. MANAGEMENT AND ENVIRONMENTAL CHALLENGES

i. DECREASE IN COHO SALMON POPULATION

Coho Salmons are essential to the culture and society of the Pacific Northwest. The decline of salmon affects the tribal cultures, communities, economies, and health, impacting food security, cultural practices, and economic stability of Indigenous peoples. The Siuslaw River had an average return of 260,000 coho salmon annually throughout the years, but by 1997, this number had dropped to 500 (Beyond Toxics News).



Figure 3: Group of Wild Salmans

(Source: Beyond Toxics News)

ii. RUNOFF AND CHEMICAL CONTAMINATION

In Siuslaw River, a study found that pesticides like trifluralin and atrazine were present in the soil of forests through runoff. Atrazine was used by the timber industry, with aerial herbicide sprays occurring over salmon stream headwaters. This practice increases the vulnerability of salmons to chemical runoff (Beyond Toxics News).

iii. LOW WATER QUALITY

Aquatic ecosystems and water quality in the Siuslaw River are significantly affected by the presence of chemicals in the water, elevated water temperatures exceeding 18°C, and low dissolved oxygen levels that are less than 8 mg/L.

II. PROJECT DESCRIPTION

a. GOALS AND OBJECTIVES

Based on the Ecosystem and Environmental challenges, the following goals and objectives can be outlined:

1. To increase the amount of salmon population.
2. To ensure high-quality habitat for salmon at all life stages
3. To enhance water quality, reduce temperature extremes, increase dissolved oxygen, and limit pollutant runoff.
4. To have great connectivity between the primary stream channels and their floodplains and wetlands.
5. To ensure abundant and diverse riparian plant communities.

b. STRATEGIES AND INTERVENTIONS

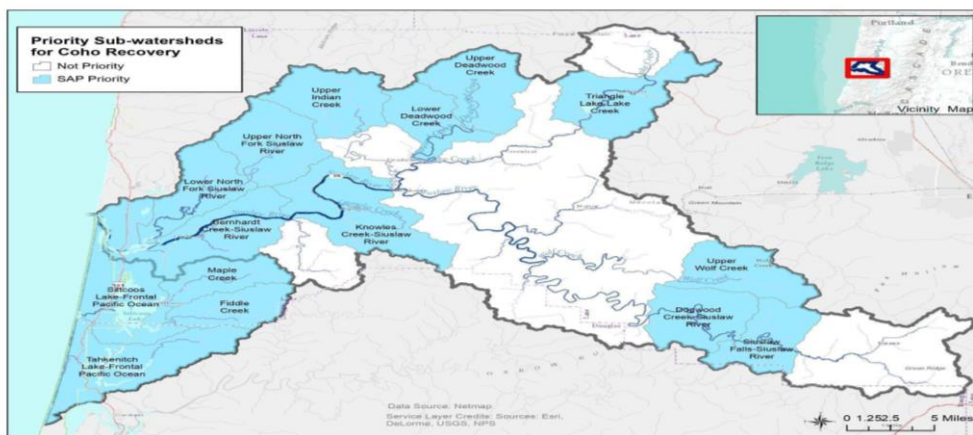


Figure 4: SAP Priority Sub-Watersheds

(Source: Siuslaw Watershed Council)

The Siuslaw Coho Partnership (SCP) has developed a Strategic Action Plan for the recovery of the Siuslaw's wild coho population. It has prioritized 11 sub-watersheds within the Siuslaw River Basin. These sub-watersheds show a high level of ecosystem functioning compared to other sub-watersheds (Siuslaw Watershed Council).

i. IMPROVING INSTREAM COMPLEXITY

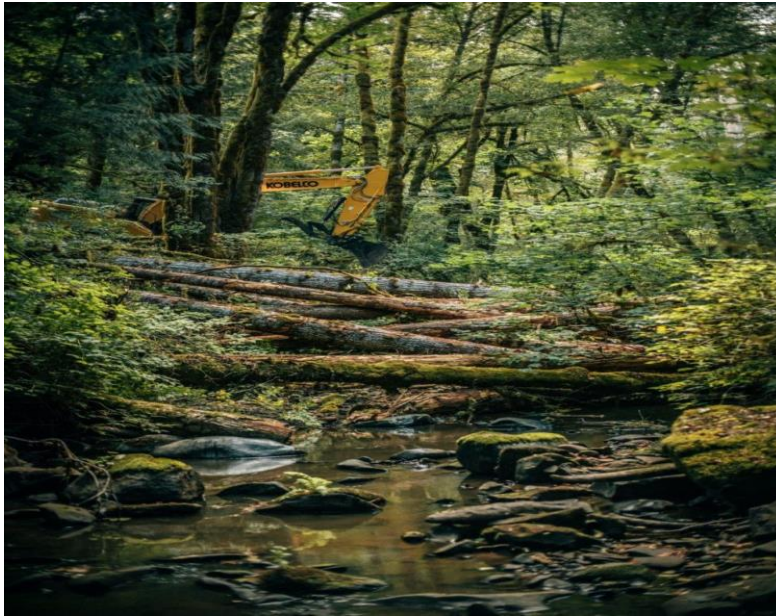


Figure 5: Woody Debris in the river

(Source: Siuslaw Watershed Council)

The Loss of features such as large wood, pools, connected off-channels, alcoves, and beaver ponds, limits the survival of juvenile coho in both summer and winter. In response, the Siuslaw Coho project (SCP) has proposed adding a large number of woody debris to 75 miles of identified habitats and other tributary reaches to restore stream interaction with off-channel habitats (Siuslaw Watershed Council- Restoring the Siuslaw River).

ii. FLOODPLAIN CONNECTIVITY

The periodic flooding of the floodplain results in an exchange of water, sediment, organic matter, nutrients, and organisms, which maintains essential off-channel habitats, which provide refuge for juveniles from high flows in winter and increased water temperatures in summer. For generating high-quality coho habitat and lateral connectivity between the channel and its floodplain, the SCP proposed to reconnect and protect disconnected floodplains of nearly 506 acres to increase the availability of off-channel habitats (Siuslaw Watershed Council-Restoring the Siuslaw River).

iii. TIDAL WETLAND CONNECTIVITY

Functioning tidal wetlands are very important for coho to rear, find refuge, and go through physiological changes before migrating to the ocean. For the diversity of coho, estuarine habitats are very important. So, the SCP proposed reconnecting 30 miles of slough and tributary

channels to increase the availability of estuarine-rearing habitats (Siuslaw Watershed Council-Restoring the Siuslaw River).

iv. RESTORATION ACTIVITIES

CULVERT REPLACEMENT

Poorly designed crossing structures cause the fish to lose its habitat. Improving culvert infrastructure to the perfect size and placement increases the connectivity of instream habitat, also improving water quality through erosion reduction. The SCP has proposed to upgrade working land infrastructure to improve water quality and increase habitat availability (Restoration activities-Siuslaw Watershed Council).



Figure 6: Completed culvert Project

(Source: Siuslaw Watershed Council)

RIPARIAN PLANTING

Riparian plantings are very important for both stream flow and water temperature. Vegetated stream banks keep streams shaded and cool. The SCP proposed to enhance 47 miles of Riparian vegetation to increase shade, improve water quality, and promote long-term large wood recruitment (Restoration activities-Siuslaw Watershed Council).



Figure 7: Completed Riparian Planting

(Source: Siuslaw Watershed Council)

RIPARIAN RESTORATION BY FENCING

The SWC (Siuslaw Watershed Council) worked with the landowners for responsible land management. To limit access of livestock to entering nearby streams or grazing important native vegetation along streambanks, they added or replaced fencing along the riparian area. Unrestricted Grazing can damage native plants, compact the soil, and lead to bank erosion over time. Maintaining native plant ground cover is crucial for the river bank stabilization (Restoration activities-Siuslaw Watershed Council).



Figure 8: Riparian Fencing along the river

(Source: Siuslaw Watershed Council)

C. KEY STAKEHOLDERS AND PARTNERSHIP

1. Siuslaw Watershed Council
2. US Fish and Wildlife Service
3. NFWF-National Fish and Wildlife Foundation

4. OWEB- Oregon Watershed Enhancement Board
5. Forest Service, Department of Agriculture
6. US Department of the Interior Bureau of Land Management
7. NOAA- National Oceanic and Atmospheric Administration

III. OUTCOMES AND IMPACT

1. JOB OPPORTUNITIES AND RECREATIONAL IMPROVEMENTS

Restoration projects have generated employment opportunities in lots of sectors like conservation, monitoring, and eco-tourism. In addition, the recovery of fish populations has supported local fishing industries.

2. INCREASE IN COHO SALMAN POPULATION

Populations of Coho returning to spawn in the Siuslaw Basin have seen an overall increase since a low in 1997. The following diagram shows the increase in salmon population over the past years. (Siuslaw Watershed Council-Restoring the Siuslaw River)

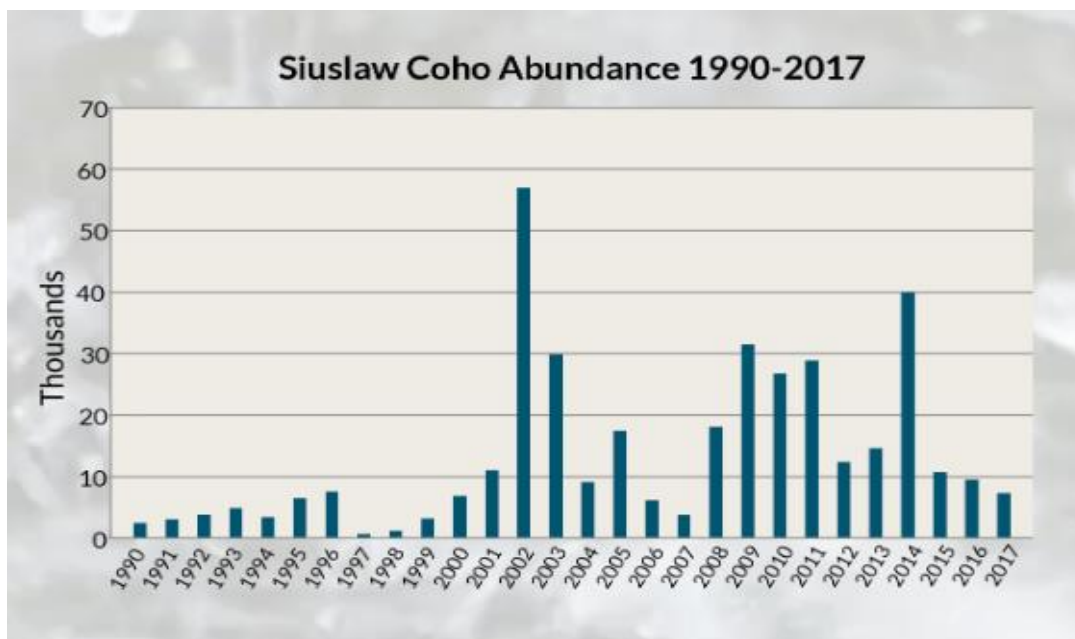


Figure 9: Coho Salmon Population

(Source: Siuslaw Watershed Council)

3. ENHANCED WATER QUALITY

There is a significant amount of reduction in temperature and increased dissolved oxygen content. Making it great for the coho salmon population and good water quality.

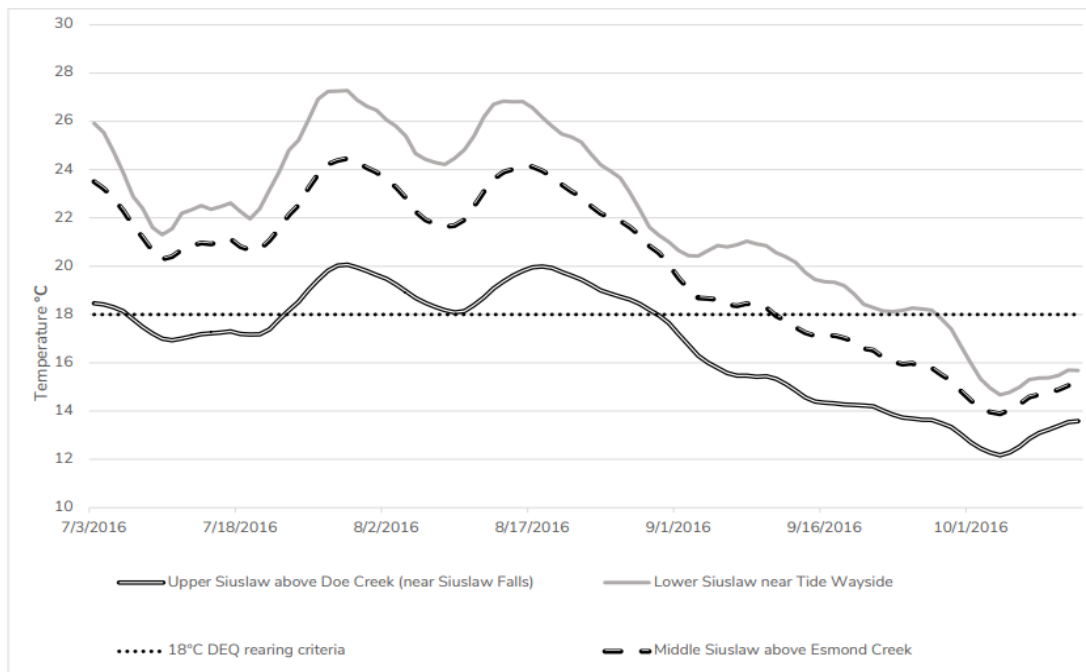


Figure 10: Decrease in water temperature

(Source: Final report 2016- Siuslaw Watershed Council)

4. INCREASED FOREST AREA

Land use and land cover changed over the last 20 years, with a marked shrubland transition to forest. This indicates the current industrial forest management practice of clear-cutting.

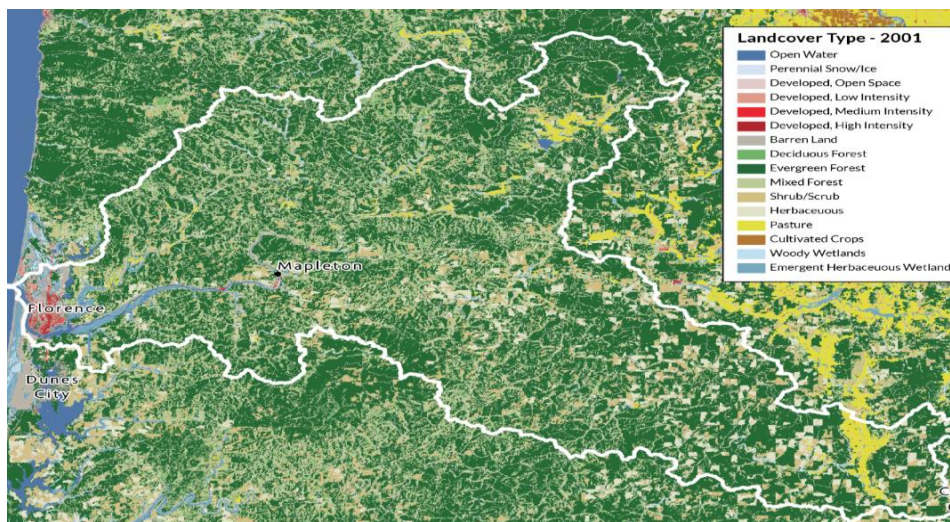


Figure 11: Land Cover 2001

(Source: Siuslaw Watershed Council)

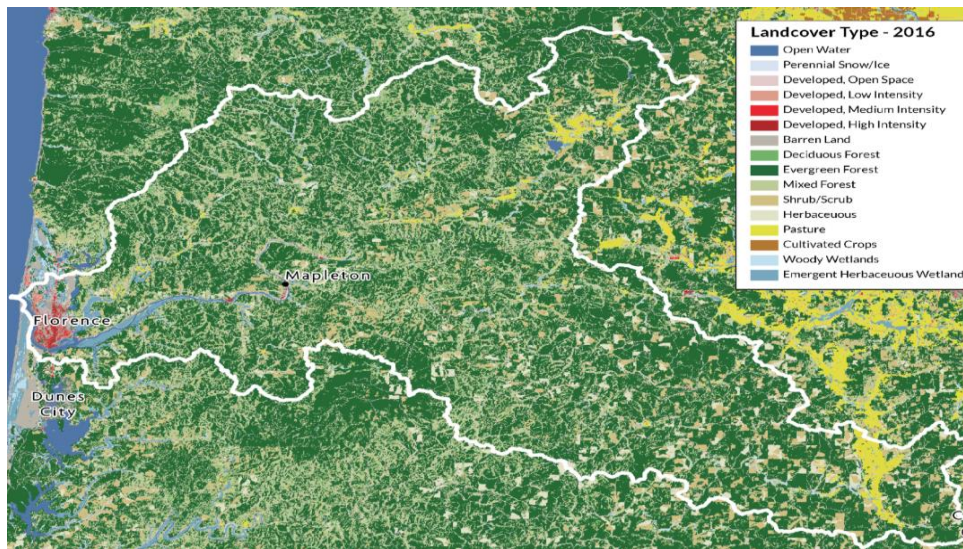


Figure 12: Land Cover 2016

(Source: Siuslaw Watershed Council)

5. EDUCATIONAL OUTREACH AND COMMUNITY ENGAGEMENT

Programs such as Watershed Camp and Native Plant Distribution have effectively educated residents on sustainable practices. As a result of the workshops and volunteer programs, there has been a significant increase in local participation.

IV. LESSONS LEARNED AND RECOMMENDATIONS

a. KEY TAKEAWAYS FROM THE PROJECT

- Increase in Forest land plays a huge role in the river ecosystem.
- Watershed management is important for long-term ecological balance.
- Community involvement plays an important role in successful restoration.
- Use adaptive management approaches to respond to environmental changes.

b. BEST PRACTICES AND STRATEGIES FOR REPLICATION

- Educational Programs- Through this, future generations will know the importance of the river and make the environment safe for all. Also educating the people on waste management.
- Native plant distribution enhances the ecological value of the environment.
- Water Quality Monitoring- Regular monitoring is necessary to assess progress and adapt strategies.

- Watershed Camps equip the next generation with the knowledge and skills for a lifetime of scientific learning and working for the health of their watershed.

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Alexander River

I. Case Study Overview

a. Project background and location

The Alexander River (Figure 1), known as Nahal Alexander in Hebrew and Wadi Zeimar in Arabic, is a 32 km river flowing from the western slopes of the Samaria Mountain range in the West Bank through Israel's Hefer Valley to the Mediterranean Sea, north of Netanya. The river's basin covers approximately 14,000 acres and serves as a critical ecological corridor in a densely populated region.



Figure 1. Alexander River

(Source: <https://old.ser-rrc.org/project/israel-alexander-river-restoration-project/>)

In 1995, a comprehensive master plan for the restoration of the whole Alexander River Basin (Table 1) was prepared by an interdisciplinary planning team headed by Architect Amos Brandeis. This master plan, having been approved by all 20 partners, provides a foundation for the restoration project and includes goals, strategies and an action plan. The implementation phase began in 1998 with several projects aimed at restoring the river. These projects address a wide variety of restoration issues, including removal of pollutants, management of the water supply, restoration of targeted sections of the river, overall ecological rehabilitation, drainage and flood defence, development of river parks (i.e. including a "demonstration project"), construction of a pedestrian and bicycle path along the river, education and public involvement, etc. Pollution Mitigation -- To stop the discharge of pollution/sewage from the Palestinian Authority (via the Nablus River) and from the Israeli towns of Netanya and Kfar Yona, an "emergency solution" was implemented in 2002 until such time that a joint treatment plant-- which will treat wastewater from both the Palestinian side and the Israeli side--can be established. In the first stage, the polluted water is pumped from the riverbed adjacent to the "green line" (i.e. the dividing line between the Palestinian Authority and Israel) and undergoes extensive treatment at the purification plant. It is then returned to the same place in the river, but in much better quality.

The sewage reaching beyond the "green line" is diverted by a small dam that was built. This "emergency solution" will be integrated with the permanent solution in the future. Riverbanks -- Approximately 18,000 cubic meters of earth were removed from the banks to reduce the slope from a steep incline at a ratio of approximately 1:2 to one of 1:5. The resulting moderate incline

has enabled the growth of a lush bank vegetation, pedestrian paths and human access to the waterline at several points. At the point of the river's winding, a stone "toe", largely hidden beneath the water, was fashioned to protect the bank from flood damage and erosion. Maximum attention was paid to drainage considerations when the channel was widened, and measures were taken to preserve the soil. Dams and Fish Ladders -- The concrete dam on the project's eastern extremity has been divided into four smaller dams, three of which are built out of natural stones. These dams were also built as "fish ladders" to ensure the passage of fish along the river. The dams are essential to maintaining the river's ecological continuity, creating unique ecosystems, ensuring water mixing and quality enhancement, and providing maximal water flow for visitor enjoyment.

Demonstration Project -- The Demonstration Project, launched in 1999, involved the restoration of a 750 m section of the river and the creation of an extensive river park to accommodate leisure and recreation activities. The park is very accessible from the national road system and features pedestrian walking paths, lush vegetation, and a hanging steel bridge that spans the river. In order to begin work on the park, the incline of the banks along this stretch first had to be moderated. Once a gentler slope had been created, approximately 35,000 seedlings and 350 trees were planted. All the plants and trees were chosen according to their ecological and historic suitability to the region, as well as their preference for specific locations (i.e. adjacent to the water line, on the banks, or beyond them). The selection process favoured vegetation with minimal water requirements in an attempt to reduce park maintenance and avoid the need for regular irrigation in a country that suffers from a severe scarcity of water. Preference was also given to plants that would help preserve the soil and stabilize the slopes. The hanging bridge, unique in its kind in Israel, will, on the one hand, offer a sculptural element in the heart of the project and, on the other hand, a means to cross to the southern bank. It also provides the public with a unique setting from which to view the river. As part of this project, three riffles were constructed along this section of the river in order to facilitate the passage of fish, oxygenate the water, and create a more aesthetic, riverine experience for visitors to the park. River Parks -- Six other river parks have been constructed along sections of the river, in addition to the Demonstration Project.

Riverbanks have been equipped with wheelchair-accessible pedestrian paths for hiking, jogging, and bike riding; and these paths trace a variety of circular and longitudinal routes along the most attractive sections of the river. In many places, terraced stones have been designed to allow for sitting and viewing the river. Parks are also equipped with high quality wooden garden furniture consisting of pergolas designed to provide shade, benches, picnic tables, garbage bins, etc. Signposts have been installed in many locations to provide directions, explain the objectives

and components of the restoration project, and offer diagrams and photographs of the river prior to restoration.

Table 1. Quick facts on Alexander River Restoration Project

(Source: <https://old.ser-rrc.org/project/israel-alexander-river-restoration-project/>)

Quick Facts	
Project Location	Alexander River, Isreal 32.384767, 34.891382
Geographic Region	Middle East
Country or Territory	Israel
Biome	Freshwater
Ecosystem	Freshwater Rivers & Streams
Area being restored	14,000 acres
Organization Type	Governmental Body
Time Frame	Project Stage: Implementation Start Date: 1995-08-21 End Date: 1995-08-21

b. Problem statement: management or environmental challenge

The primary causes of degradation are urbanization, transportation & industry. Two central problems have plagued the river for years: pollution from a variety of domestic, agricultural and industrial sources and development pressures in the open space surrounding the river that threaten its potential for leisure and recreation uses. The Palestinian City of Nablus is located at the source of the Alexander River, and the city has no sewage solution. Thus, the city's raw sewage flows into the river and causes severe pollution. In all, some 70 sources of pollution are discharged into the Nablus Stream, which flows through the Palestinian Authority, and then into the Alexander River. Another 25 different pollution sources plague the river from the Israeli side.

II. Project Description

a. Goals and objectives

To address the sources of pollutants causing the degradation of the Alexander River.

-

To facilitate the ecological rehabilitation of the river's flora and fauna, with special attention given to the rare and protected Nile soft-shell turtle (*Trionyx triunguis*) and to the preservation of its breeding sites along the river.

To protect the open spaces along the river and enable leisure and recreational activities in combination with agriculture

b. Strategies and interventions

Comprehensive Planning: Development of a master plan in 1995 led by Architect Amos Brandeis.

Infrastructure Development: Construction of wastewater treatment facilities such as the Yad Hanna reservoir.

Habitat Restoration: Rehabilitation of riverbanks and reintroduction of native species.

Community Engagement: Initiatives like 'Alexander River Trustees' involved local residents.

International Collaboration: Partnerships with Palestinian authorities and support from international entities like Germany.

c. Key stakeholders and partnerships

Alexander River Restoration Administration (ARRA), comprising 20 public and state entities.

Local communities and volunteers from both Israeli and Palestinian areas.

International partners, including Germany.

Project activities are conducted via a transparent process of intense public participation guided by the slogan "Returning the River to the People," and both children and adults are deeply involved at all levels.

III. Outcomes and Impact

a. Environmental benefits

Reduction of pollution in the Alexander River through water treatment facilities.

Significant improvement in water quality, leading to the river's revitalization.

Implementation of ecosystem restoration measures with successful outcomes.

Creation of river parks that enhance and beautify sections of the river.

Increased public interest and enthusiasm for environmental conservation.

Installation of fish ladders and riffles to further improve water quality.

Attraction of water birds due to improved ecosystem conditions.

b. Social benefits

Improved water quality, leading to better health.

Fostering a greater sense of community.

The new park attracting thousands of visitors every weekend.

Hosting community events such as the "River Festival," musical parades, tree planting events,

and educational visits.

Strengthening diplomatic ties through agreements between Israeli and Palestinian officials.

Promoting long-term cooperation between local councils and regional authorities.

Serving as a bridge between Israelis and Palestinians, fostering peace and collaboration.

c. Economic benefits

Treated sewage used for irrigation, reducing water waste and improving agricultural productivity.

Connection of industries and villages to the plant, improving regional water infrastructure.

Increased tourism in the area due to the park, boosting local businesses.

Potential long-term economic gains from improved environmental conditions and sustainable water management.

IV. Lessons Learned and Recommendations

Key takeaways from the project

The Alexander River Restoration Project is the leading river restoration in Israel and continues to attract international attention. The project has garnered four national awards, among them the Henry Ford Conservation Award in Israel (1997) and the award for “Beautiful Israel”, which was received from the President of Israel in 2001. In Brisbane, Australia in 2003, the project was awarded one of the world’s most prestigious international prizes for excellence in river management, the Thiess International River prize.

The Alexander River Restoration Project is a source of real hope that in spite of the complicated situation in the Middle East, Israelis and Palestinians will succeed one day in tearing down the security walls that divide them, and have peace and normal cooperation on the real important issues of life - health, environment, water, leisure, education etc. They will heal the abused river together, as neighbours, and continue to cooperate for a better future in this part of the world. The key takeaways from the project are given below.

Comprehensive planning is essential for successful ecological restoration.

Active involvement of local communities ensures project sustainability.

Cross-border cooperation is vital for managing transboundary water bodies.

Best practices and strategies for replication

The ultimate success of the rehabilitation scheme will be dependent upon the success of sewage treatment measures. Netanya’s sewage treatment plant (inaugurated in 1996), along with plans for effluent treatment and disposal facilities in industrial plants in the Emek Hefer Region, should bring about the expected improvements. Gardening, watering and cleaning of the parks and paths that have already been developed along the river must be done on a regular basis. The Administration hires a gardening contractor to coordinate and supervise these routine

–

maintenance activities; and in 2003, a group of volunteers started a course during which they will be trained as “River Devotees” to provide assistance with some of these duties. Almost every year, a major flood occurs, covering a large area of the floodplain. All the parks developed along the river are flooded, and all the sediments and waste must be removed and cleaned shortly after the flood. Preparedness for these floods has been incorporated into the management plan. Some of the best practices and strategies for replication are given below.

Engage the public through environmental education and stewardship programs.

Use adaptive management to regularly update strategies based on new data.

Leverage international cooperation for technical and financial support.

c. Areas for further improvement or research

Develop long-term monitoring programs to ensure ecological health.

Create climate adaptation strategies for the river basin.

Strengthen legal frameworks to prevent future pollution.

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Mekong River

I. Case Study Overview

a. Project background and location:

The Mekong River is the longest river in Southeast Asia and the 12th longest river in the world. It originates from the Tibetan Plateau in China and flows through Myanmar, Laos, Thailand, Cambodia, and Vietnam before merging into the South China Sea. The river stretches approximately 4,900 km, with an average annual discharge of 475 km³. The total catchment area of the Mekong River Basin is around 795,000 square kilometres. The Mekong River Basin is broadly divided into two sections. The Upper Mekong Basin, known as the Lancang River in China, accounts for 24% of the total basin area, covering about 190,800 km². The Lower Mekong Basin extends downstream from the China-Laos border, supporting diverse ecosystems and human settlements. The Mekong River is a lifeline for more than 70 million people belonging to over 90 ethnic groups, providing essential resources such as food, water, and transportation. The river basin also sustains one of the most diverse inland fisheries in the

world, with more than 1,300 fish species (Campbell, 2009; Osborne, 2009). The region's rich biodiversity includes around 20,000 plant species and 2,500 animal species, making it comparable to the Amazon and Congo river basins. Over the years, both cooperation and conflict have emerged in managing the river's water resources due to increasing population, economic development, and climate change. Various efforts have been undertaken to balance the needs of human communities and the preservation of the river's unique ecosystems.

b. Problem statement: management or environmental challenge

Managing the Mekong River Basin is highly challenging as the river flows across six different countries. The lack of cooperation among the countries and ongoing political unrest in certain regions further complicate the situation.

The Mekong River Commission (MRC) was established to promote joint management of the river's resources, but it only includes four lower basin countries, Laos, Thailand, Cambodia, and Vietnam. The two upper basin countries, China and Myanmar, are not full members of the Commission. While Myanmar's share of the basin is relatively small, a major portion of the upper Mekong Basin lies within China's territory. Both China and Myanmar participate as "dialogue partners," but their cooperation remains quite limited. The absence of China, which plays a key role in upstream water management, significantly restricts the Commission's ability to implement integrated, basin-wide water resource management. Moreover, the MRC operates within the framework set by its member governments, limiting its authority to influence broader transboundary water governance.

Environmental Flows: Alterations to the mainstream flow due to dams that are under construction, planned, or proposed in China, Cambodia, and Thailand, along with changes in tributary flows caused by ongoing and planned dam projects in Laos and Vietnam, are expected to have widespread ecological and social impacts across the Mekong River Basin.

Water Resource Allocation: Water resource allocation remains one of the most critical challenges in the Mekong River Basin. The basin countries have diverse demands and varying degrees of dependency on the river for agricultural, industrial, and domestic purposes. The unequal distribution of water during the dry season often triggers conflicts, especially between upstream and downstream countries. Upstream nations like China and Laos prioritize hydropower development to meet their energy needs, whereas downstream countries such as Cambodia and Vietnam depend heavily on the river for agriculture, fisheries, and livelihoods. The pronounced seasonal variations in water availability, with abundant flows during the wet season and scarcity in the dry season, further intensify competition for water resources. Moreover, the absence of a comprehensive water-sharing agreement involving all riparian countries creates tension and poses significant obstacles to effective cooperative water

management.

Hydropower Development: Hydropower development is a key economic driver in the Mekong region, particularly in Laos and China. Currently, more than 150 dams are either operational, under construction, or planned along the Mekong River and its tributaries. While hydropower plays a crucial role in enhancing energy security and promoting economic growth, it poses significant environmental and social risks. Dams alter the river's natural flow, disrupt fish migration routes, and reduce sediment transport, which is vital for maintaining the fertility of agricultural lands in downstream regions.

Additionally, the risk of water-related emergencies, such as dam failures and sudden changes in water levels, is increasing. Climate change is likely to worsen the situation, making floods and droughts more frequent and severe in the future, further threatening the livelihoods of millions of people dependent on the river's resources.

Environmental Degradation: The Mekong River Basin is experiencing significant environmental degradation due to deforestation, mining, and agricultural expansion. The conversion of wetlands and floodplains into agricultural land reduces the river's natural capacity to absorb floodwaters and maintain water quality. Additionally, mining activities along the river, particularly sand mining, lead to riverbed erosion and increased sedimentation, which can affect aquatic habitats.

Water Quality: There are several obvious potential sources of water pollution. One is growth and industrialization of cities and towns within the basin, the second is spillages from navigation, the third is broad-scale land use change.

Fisheries: The Mekong River Basin is among the most biodiverse regions in the world, supporting more than 1,100 fish species, including the critically endangered Mekong giant catfish. However, biodiversity in the region is rapidly declining due to dam construction, habitat destruction, and pollution. Hydropower dams pose a significant threat to fish migration, as they act as physical barriers, preventing fish from reaching their spawning grounds (Mattson et al. 2002, Allan et al. 2005).

The loss of biodiversity not only disrupts the ecological balance but also threatens the livelihoods of millions of people who rely on fish as a primary source of protein and income. The ongoing degradation of aquatic ecosystems highlights the urgent need for sustainable water management practices to protect both the environment and local communities.

Transboundary Cooperation: Managing a transboundary river basin like the Mekong requires cooperation among all riparian countries. However, political tensions, differing national interests, and the absence of a binding legal framework present significant obstacles to effective collaboration. The lack of transparent data sharing and communication further complicates joint

decision-making.

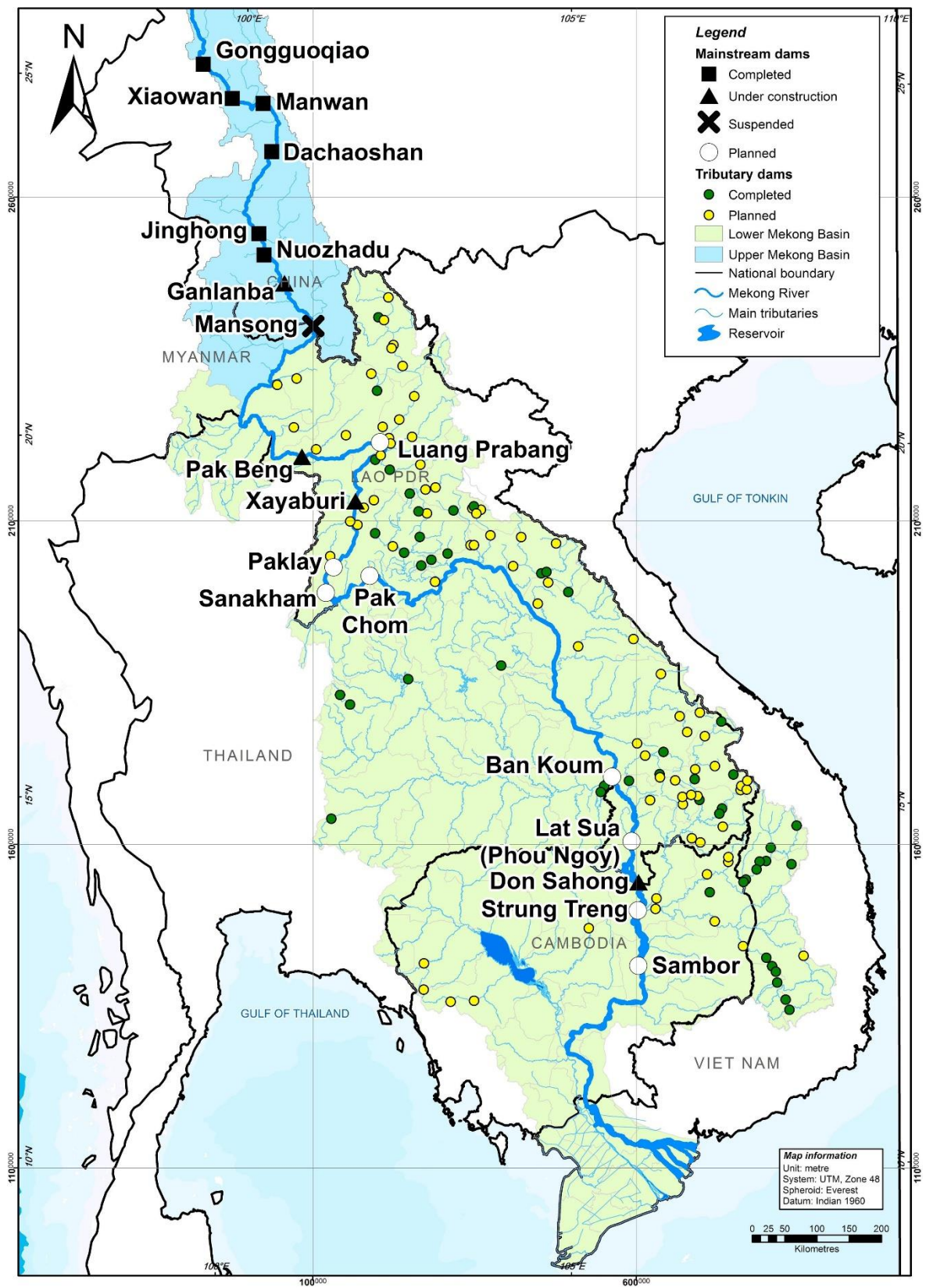


Figure 1 The Mekong River basin and the details of dams

II. Project Description

a. Goals and objectives

According to MRC, the objectives are as follows (Mekong River Commission, 2021):

Food and livelihood security: Agriculture and fisheries will continue to contribute to local food and income security. Sustainable hydropower development will contribute to employment and national poverty reduction.

Resilience against flood and drought: Infrastructural developments will reduce natural flood plain storage. Together with the impact of climate change, this will increase the severity of both mainstream floods and tributary flash floods. As cities and populations grow, more protection is needed to secure infrastructure, assets and lives. Greater drought resilience is also needed, especially in light of climate change impacts.

Energy security: Regional energy demands will continue to grow and the need for national energy security will remain important for the Member Countries. Demand for hydropower is expected to remain high as a cost-effective source of renewable energy.

Improved navigation: It is important to maintain freedom of navigation and enhance river-borne transport networks to support remote communities, facilitate shipment of bulk goods and strengthen regional interconnectivity.

b. Strategies and interventions

Mekong River Commission (MRC): The 1995 Mekong Agreement, which led to the establishment of the Mekong River Commission (MRC), provides a framework for cooperation among the Lower Mekong Basin countries like, Cambodia, Laos, Thailand, and Vietnam. However, the absence of China and Myanmar as full members, despite being key upstream countries, significantly limits the agreement's effectiveness in promoting comprehensive basin-wide water management.

Integrated Water Resources Management (IWRM): Integrated Water Resources Management (IWRM) is a key strategy adopted in the Mekong River Basin to promote sustainable water use. The MRC has developed IWRM-based basin development strategies to balance competing water demands for agriculture, energy production, and ecosystem conservation. This approach emphasizes stakeholder participation, data sharing, and coordinated planning among different sectors and countries. By considering social, economic, and environmental aspects, IWRM provides a holistic framework for sustainable water resource management across the basin.

Environmental Flow Assessments: Environmental flow assessments play a crucial role in determining the minimum water flows needed to sustain healthy ecosystems. The MRC has carried out several environmental flow studies to evaluate the potential impacts of hydropower projects on aquatic habitats and biodiversity. These assessments provide scientific data to support decision-making and help balance development priorities with environmental sustainability. The findings are used to promote more sustainable dam designs and operational practices, ensuring that ecological health is considered alongside economic development.

Community-Based Management: Community-based management approaches empower local communities to actively participate in water resource management. Several programs have been introduced to engage communities in monitoring water quality, restoring wetlands, and adopting sustainable fishing practices. This participation not only strengthens environmental stewardship but also enhances local capacity and resilience to climate change impacts. The MRC has supported numerous pilot projects across the basin, promoting community-based management as a vital component of sustainable water governance.

c. Key stakeholders and partnerships

Mekong River Commission (MRC): The MRC facilitates cooperation and joint decision-making among member countries.

National Governments: Governments of China, Myanmar, Laos, Thailand, Cambodia, and Vietnam play key roles in policy formulation and implementation.

International Organizations: Organizations such as the World Bank and Asian Development Bank provide funding and technical support.

Local Communities: Local communities contribute to watershed management, biodiversity conservation, and sustainable livelihoods.

Non-Governmental Organizations (NGOs): NGOs such as WWF and IUCN play a vital role in advocating for environmental conservation and community participation.

III. Outcomes and Impact

a. Environmental benefits

Pollution control measures have contributed to improved water quality by reducing agricultural runoff and industrial pollutants. Wetland restoration efforts have enhanced biodiversity and provided natural flood control. The installation of fish passages or fishways has supported the migration of fish species, helping to sustain aquatic biodiversity. Additionally, community-based watershed management initiatives have played a key role in reducing soil erosion and deforestation, further promoting ecosystem health and sustainability.

b. Social benefits

The major social benefit is the dialogue facilitated by the MRC, which has helped resolve conflicts over water allocation among riparian countries. Local communities have been actively involved in decision-making and watershed management. Alternative income-generating activities such as eco-tourism and sustainable agriculture have been promoted, which has improved the livelihood of the community.

IV. Lessons Learned and Recommendations

a. Key takeaways from the project

The Mekong River project highlights the vital role of transboundary cooperation in managing shared water resources. The MRC's efforts in facilitating dialogue and joint decision-making have shown that collaborative governance can lead to positive outcomes. The active participation of local communities has been a key factor in the project's success. When communities are empowered and involved in decision-making processes, the sustainability and acceptance of interventions are greatly enhanced.

b. Best practices and strategies for replication

Involving local populations in decision-making processes enhances the effectiveness and sustainability of projects. Establishing river basin organizations with representatives from government, NGOs, and local communities fosters inclusive governance and promotes better coordination in water resource management.

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Blackwood River

I. BLACKWOOD RIVER - OVERVIEW

a. BACKGROUND AND LOCATION

The Blackwood River basin is located in the South-West of Western Australia and it is one of the large river systems originating from the wheat belt town of Wagin and flowing through towns like Boyup Brook, Bridgetown and Nannup before reaching the coastal waters at Augusta. The Latitude of the Blackwood River is $34^{\circ} 18' 60.00''$ S and Longitude is $115^{\circ} 10' 60.00''$ E. The Blackwood river catchment area is 22,594 square kilometers. The catchment is divided into three sub-catchments, the upper, middle and lower/coastal Blackwood River and it extends 300 km inland from the river mouth of the Blackwood River at the Hardy inlet near the town of Augusta (Healthy Rivers). The Blackwood River is the union of two major tributaries - the Beaufort rivers and Arthur rivers. The river has 41 tributaries, which include Balingup Brook, Dinninup Brook, Tanjannerup Creek, Christmas Creek, Ti Tree Gully, Tweed River, Boyup Brook and St John Brook.

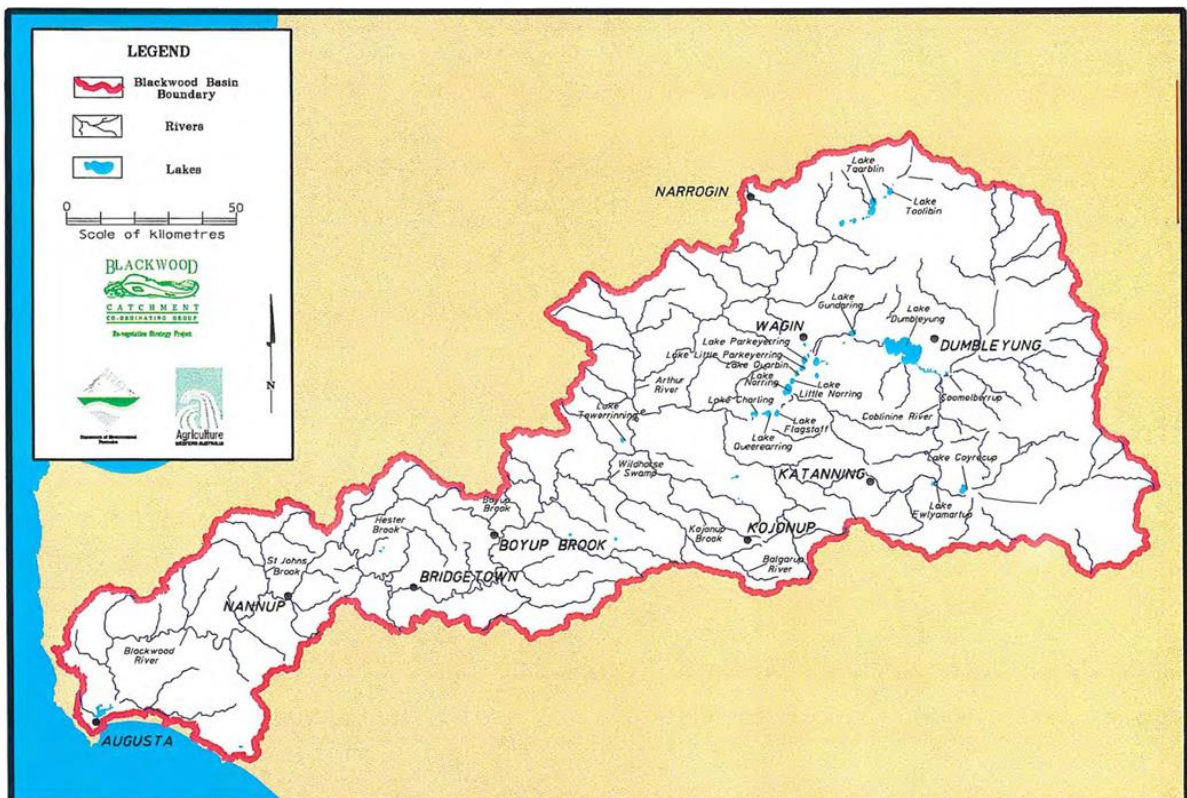


Figure 1 Blackwood river basin

(Source : Department of Biodiversity, Conservation and Attractions)

b. MANAGEMENT AND ENVIRONMENT CHALLENGES

The Blackwood River Basin has several Environment Challenges which include, Salinity, Land Clearing, reduction in fish catchment, ground water and ecology issues and these challenges are managed by a detailed study conducted by certain organisations like Blackwood Basin Group (1992), Healthy Rivers.

1. SALINATION - Salinization of South-West Western Australian rivers and the implications for the inland fish fauna - the Blackwood River, a case study

Due to extensive land clearing, for agriculture use and for industries, the Blackwood River Basin of Western Australia (Healthy Rivers), has been facing challenges with salinity issues which has caused several damage to the region's endemic freshwater fishes. Due to low annual average rainfall, there are naturally occurring salt lakes and wetlands in the upper catchment. In the upper catchment, which is being dominated by estuarine and halotolerant teleosts, has caused salinization in the main channel of the Blackwood River which also shows significant differences in teleost communities among the naturally vegetated area. 85% of the original vegetation has been removed in the Blackwood catchment and salinity in the streams has increased from 500 mg/L in the 1950s to 2000 mg/L in the late 1990s (Revisiting the Blackwood River and Hardy Inlet). The Department of Water Quality has taken steps for reducing salinity by maintaining healthy wetlands through government policies and schemes.



Figure 2 Lake Dumbleyung

(Source : Stream salinity status and trends in south-west Western Australia)

2. GROUND WATER - The importance of groundwater to the Blackwood and other iconic rivers of the South-West of Western Australia

The Blackwood has the region's longest section of natural permanent groundwater-fed flow (Department of Water, Government of Western Australia). It shows the reverse of river behaviour by being more saline in winter than in summer. This is due to the result of salt in the catchment and the fresh groundwater feeding into the river. Throughout the year, the freshwater from the Yarragadee and Leederville aquifers discharges into the Blackwood which is just downstream of the Nannup. During winter, rainfall affects the salt in headwaters of the Blackwood which washes downstream and increases the salinity of the flow. In summer, since the rainfall is low, fresh groundwater influences more on the quality of the river water.

A study (September 2016 Securing Western Australia's water future) shows how the ecology of the Blackwood River has changed during different levels of salinity and it also shows that during winter, the freshwater fish species such as Balston's Pygmy Perch which is listed as a 'Vulnerable' species under the Federal Environmental Protection and Biodiversity Conservation Act 1999 seek refuge in the freshwater tributaries like Milleannup Brook or Poison Gully and during summer, as the river freshens, these marine fishes move back into the main channel. This indicates how the groundwater discharge in summer is important for the migration of freshwater Cobbler, which is the largest freshwater fish species in the Southwest

part of Western Australia. This shows that decrease in the water quality and groundwater volume has caused harm to the rivers and the aquatic species they support. So, continuous monitoring and sustainable management of groundwater around the rivers is important for looking after these systems.

3. FISH MANAGEMENT - The Hardy Inlet Estuarine Fishery management issues

Due to high exploitation of fisheries in Blackwood Catchment of Hardy Inlet, the Department of Primary Industries and Regional Development has released the fisheries management papers, in which an Integrated Fisheries Management Review Committee has been established, where a report has been released (Fisheries Management Paper No. 169). This Report shows different frameworks for Commercial Fishing and Recreational Fishings, which mentions a strategy to integrate the management and sustainable use of fish resources - (Fisheries Management Paper No. 165).

The Western Australian Government has also actively worked to incorporate the concept of sustainable government policies, activities and decision-making. This report also explains the key issues surrounding fishery and provides a range of recommendations for future management of the fishery. This report has certain objectives to conserve fish and to protect their environment. To achieve the optimum economic, social and other benefits from the use of fish resources, the Department of Fisheries follows the guidelines of Fish Resources Management Act 1994, which aims to ensure that the exploitation of fish resources is carried out in a sustainable manner through Ecologically Sustainable Development (ESD) policy.



Figure 3: Hardy Inlet commercial fishing area

(Source : Department of Primary Industries and Regional Development)

II. PROJECT DESCRIPTION

a. GOALS AND OBJECTIVES

The Government of Western Australia has its own goal and objectives to overcome its challenges and adapting to environmental issues

- Adapting to Changing Climate - Develop infrastructure to withstand extreme weather events.
- Improving River Health - Develop water management plans
- Land use management - Promote sustainable agriculture, forestry, and mining practices
- Eco-tourism Development - Encourage tourism that support local communities
- Conservation of Ecology - Protecting native species and restoring habitats

b. STRATEGIES AND INTERVENTIONS

1. Climate change

In Blackwood River catchment, the average annual rainfall varies from 1100 mm in the west to 400 mm in the east. The upper catchment has naturally occurring salt lakes and wetland. The middle catchment is covered with native vegetation and the lower river is influenced by tidal events, receiving estuarine water. Due to extensive land clearing, much of the upper and middle catchment has issues with dryland salinity (Healthy Rivers). In addition, the changes in climate, rainfall, temperature, evaporation and extreme weather events have influenced the water cycle - which is the primary indicator of hydrology. This has also been observed to have a direct effect on water quality and vegetation. Therefore, proper river assessments plans and strategies can help to understand how rivers respond to these changes, and proper interventions to support the development of these changes on the river basin and surrounding environment should be considered.

2. Water for rivers and strong communities

River health data is used in helping to determine ecological water requirements. In evaluating the effectiveness of river flow and to support water-dependent ecosystems, River Health Assessment is needed. This involves things like: building an understanding of the flow patterns. To ensure aquatic animals are able to move within a river - to reach important habitats at key times, understanding habitat needs of the water-dependent species is needed. And to determine the flows in the dry season water planning is needed. Water allocation plans show how much water can be taken from groundwater and from surface water resources. This plan includes protecting the water-dependent environment and safeguarding the sustainability of the resource.

3. Development of Infrastructure

Land use and development activities are carefully designed near rivers to avoid flooding risks to the properties and infrastructure near the flow. This includes avoiding altered hydrological systems, erosion, degradation of water quality and ecosystems and harm to social values, such as visual amenities, recreation, heritage and sense of place. Vegetation within the foreshore area is critical to rivers through its role in providing shade, aquatic habitat (logs, detritus), food sources, bank stability, and in buffering impacts from land use (such as trapping contaminants and sediment in water run-off from the catchment). Land use planning considers this information when advising on new developments, such as in determining how far from the river line that a new housing development has to be in order to preserve a reasonable vegetation buffer.

4. Monitoring the River

In some instances, it can be difficult to accurately predict the complete response of river ecosystems to changes, particularly when multiple changes occur simultaneously, such as increased water use combined with drying climate. For this reason, monitoring and evaluation programs (such as many of the assessments of Healthy Rivers) to assess changes and identify ways to adapt the way to manage the flow of the river is required. This can involve responding to the impacts - to understand how to avoid or reduce similar situations in the future (for example, fish kills and pollution events). The data collected through river health assessments can also be compared across rivers and regions to assess and improve practices from historic land uses. For example, determining farm management practices that minimize ecosystem stress through fertilizer management strategies, optimal foreshore buffers and appropriate weir design to allow fish passage.

c. KEY STAKEHOLDERS AND PARTNERSHIPS

1. Department of water and Environmental Regulations, Government of Western Australia
2. Blackwood Ecological Services PTY LTD
3. Blackwood Catchment Co-ordinating Group
4. Agriculture Western Australia
5. Conservation and Land Management
6. Water and River Commissions
7. Department of Environmental Protection
8. Water Corporation
9. Harvey Water
10. Peel Harvey Catchment Council
11. Harvey River Restoration Task Force
12. Department of Environment and Science, Government of Queensland

III. OUTCOMES AND IMPACT

a. ENVIRONMENTAL BENEFITS:

The Hardy Estuary, which is situated next to Augusta in the South-West of Western Australia, drains nearly 23,000 square kilometers of land and has the highest volume of discharge in the ocean of all South-West estuaries. The Hardy Estuary is an iconic system, which is valued for its beauty, recreational opportunities and ecological values (Blackwood Ecological Services PTY LTD). It is one of the only large estuaries on the south coast of Western Australia that is

permanently open to the marine environment, supporting a unique diversity of water-dependent biota. It serves as a critical nursery for fish and an important habitat for migratory waterbirds, as well as other endemic flora and fauna. The Blackwood River system contains all eight freshwater fishes which are endemic to the region (Healthy Rivers) and these catchments also help in supporting productive agricultural industries including beef, dairy and blue gum plantations. Unfortunately, these land uses have led to nutrient enrichment, dryland salinity, and acid sulphate soils with several associated impacts to the health of the riverine ecosystems and Hardy Estuary. The Hardy Inlet has experienced regular potentially toxic cyanobacterial blooms since year 2005 and the decomposition of excess algae leads to low oxygen concentrations which result in fish kills and odours (Healthy Estuaries WA). Healthy riverine ecosystems protect the estuaries by processing nutrients and trapping the other contaminants. Thus, for managing the health of the Hardy Estuary and for protecting the intrinsic ecological values of the rivers, the river health assessment is needed.

b. SOCIAL BENEFITS:

The Blackwood River in Western Australia provides several social benefits to the local community which includes:

- Recreational opportunities - fishing and boating,
- Tourism development - a sense of place and community identity,
- Cultural connection to the land
- Environmental education
- Potential for social interaction through shared activities along the riverbank.



Figure 4 Boating in Augusta River

(Source : Augusta River Tour)

c. ECONOMIC BENEFITS:

The Blackwood River and other rivers in the South-West of Western Australia play a major role in supporting the local industries, agriculture, tourism and the environment. The Southwest region of Western Australia, of the Blackwood river valley has a very long tradition for its agriculture, cattle, and fishing industries. According to the Australian Bureau of Statistics, livestock for meat (cattle, sheep) are raised and grain growing is a major industry in that region. In addition to this, major orchard crops in this region include apples, plums, prunes, pears, potatoes, carrots, broccoli, and onions are exported. In 2006, almost three-fourths of all apples produced in Western Australia and two-thirds of grape production were from the Southwest region (Australian Bureau of Statistics). The fishing industry, although smaller than other food-related sectors in the region, is also important, particularly in commercial fishing and in aquaculture, with Marron, Silver Perch, Yabbies, and trout being among the dominant sub sectors. The Southwest of Western Australia, specifically within the BRV (Blackwood River valley) region, has experienced remarkable growth in the development of the wine grape growing sector in recent years. Additionally, the government aims to achieve the optimum economic, social and other benefits from the use of fish resources and recreational activities.

IV. LESSONS LEARNED AND RECOMMENDATIONS

a. KEY TAKEAWAYS FROM THE PROJECT:

- River Health Assessment
- Tourism Development
- Local Community involvement
- Conservation and restoration of natural vegetation and groundwater
- Environment and Ecology Assessment

b. BEST PRACTICES AND STRATEGIES FOR REPLICATION:

The SWIRC (South-West index of river condition) is a toolkit developed by the Department of Water and Environmental Regulation to provide an integrated assessment of river health for South-West of Western Australia. It helps in establishing baseline conditions, evaluating the effectiveness of management actions, assessing the impacts from various land uses or stream alterations, understanding ecological requirements and prioritizing investment in protection or

restoration. The indicators used in the SWIRC (South-West index of river condition) toolkit are:

- Aquatic Biota - Fish and Crayfish / Macro-Invertebrates
- Water Quality - Salinity / Dissolved Oxygen / Temperature / Turbidity / Phosphorus / Nitrogen
- Fringing Zone - Nativeness / Vegetation Extent
- Hydrology - Flow Stress Ranking
- Land use - Land Cover Change / Land Use / Infrastructure
- Physical form - Erosion / Connectivity / Artificial Channel

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Grand River

I. Case Study Overview

a. Project background and location

The Grand River is located in the heart of Southern Ontario (Figure 1). It provides the common thread that links natural and human heritage features and landscapes throughout the basin. Its rich diversity of heritage resources illustrates key elements in the history and the development of Canada, many of which remain intact today. The river and its tributaries provide a broad range of excellent recreational opportunities.

The designation of the Grand River as a Canadian Heritage River marked the beginning of a second generation of Canadian Heritage Rivers. Prior to 1990, almost all nominated rivers were either within protected areas or were short sections of larger rivers. In contrast, the Grand River

is located in one of the most densely populated parts of Canada where almost all lands are privately owned and managed within a complex multi-agency, multi-jurisdictional setting. The designation included the entire Grand River (290 km) and its four major tributaries, the Nith, Conestogo, Speed and Eramosa Rivers - a total of 627 km.

In 1987, the Grand River Conservation Authority (GRCA) spearheaded a participatory process to have the Grand River, and its major tributaries declared a Canadian Heritage River. This coveted status was achieved for the Grand River and its major tributaries the Nith, Conestogo, Speed and Eramosa Rivers in 1994, based on a wide array of outstanding human heritage and recreation values.

The management plan that was tabled with the Canadian Heritage Rivers Board as part of the requirement for the designation was called The Grand Strategy. This document provided a collaborative framework for managing important values and for actions that strengthen the knowledge, stewardship and enjoyment of the heritage and recreational resources of the Grand River basin. It was based on a common vision, beliefs, values and principles, and goals.



Figure 1. The Grand River Basin

(Source: <https://www.grandriver.ca/our-watershed/maps-and-data/>)

b. Problem statement: management or environmental challenge

The primary challenges included:

Loss of native aquatic habitats due to river modifications.

Decline in fish populations and biodiversity.
Limited public access and recreational use of the river.
Economic underutilization of the riverfront areas.

II. Project Description

a. Goals and objectives

Ecological Restoration: Restore the river's natural flow and habitats to support native species.
Recreational Enhancement: Improve public access and create opportunities for water-based activities.
Economic Revitalization: Stimulate local economy through tourism and riverfront development.
Community Engagement: Involve residents in the restoration process to foster stewardship.

b. Strategies and interventions

Dam Removal: Eliminate obsolete dams to restore natural rapids and fish migration paths.
Habitat Restoration: Reintroduce native vegetation and create habitats for aquatic species.
Infrastructure Development: Construct trails, parks, and access points to encourage public interaction with the river.
Educational Programs: Implement initiatives to educate the community about the river's ecological importance.

c. Key stakeholders and partnerships

The GRCA is a partnership representing basin municipalities. The basin includes 32 local municipalities (cities and townships) and seven regions and counties. In some cases, only a portion of the municipality is within the Grand River basin. The key stakeholders of GRCA are:

Dufferin County

Grey County

Wellington County

City of Guelph

Halton Region

Perth County

Region of Waterloo

Oxford County

City of Hamilton

County of Brant

City of Brantford

Norfolk County

Haldimand County

III. Outcomes and Impact

a. Environmental benefits

Biodiversity Increase: Return of native fish species and improved aquatic habitats.

Water Quality Improvement: Enhanced filtration and reduced pollutants due to restored ecosystems.

Ecosystem Resilience: Strengthened natural processes supporting long-term ecological health.

b. Social benefits

Recreational Opportunities: Expanded activities such as kayaking, fishing, and riverside trails.

Community Engagement: Increased public involvement in environmental stewardship.

Educational Resources: Enhanced learning opportunities about local ecology and conservation.

c. Economic benefits

Tourism Growth: Attraction of visitors leading to increased revenue for local businesses.

Job Creation: Employment opportunities in construction, hospitality, and recreational services.

Property Value Increase: Enhanced riverfront aesthetics boosting real estate values.

IV. Lessons Learned and Recommendations

a. Key takeaways from the project

Collaborative Approach: Partnerships among nonprofits, government, and communities are crucial.

Adaptive Management: Flexibility in strategies ensures responsiveness to emerging challenges.

Community Involvement: Engaging locals fosters ownership and long-term project success.

b. Best practices and strategies for replication

Comprehensive Planning: Develop detailed plans integrating ecological, social, and economic goals.

Stakeholder Engagement: Involve diverse groups from project inception to implementation.

Sustainable Design: Incorporate environmentally friendly practices in restoration efforts.

c. Areas for further improvement or research

Long-Term Monitoring: Establish programs to assess ecological and social impacts over time.

Climate Adaptation: Research methods to enhance resilience against climate change effects.

Policy Development: Advocate for supportive policies to maintain and protect restored areas.

A detailed analysis of hydrogeology and groundwater studies should be conducted

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Mersey Basin

[Not Received]

Pasig River

Case Study Overview

River Overview

The Pasig River is a 27-kilometer-long tidal estuary that serves as a vital waterway cutting through Metro Manila. It links Laguna de Bay, the largest lake in the Philippines, to Manila Bay, passing through the heart of the capital. Historically, the river was the lifeblood of Manila, serving as a primary transport route and supporting commerce, trade, and daily life. The river flows through several key cities and districts, including Taguig, Pasig, Makati, Mandaluyong, Manila, and San Juan, before emptying into Manila Bay. Due to its location, it has played an essential role in shaping the development of Metro Manila.

The flow of the Pasig River is unique because it is influenced by tides. During the dry season, when water levels in Laguna de Bay are low, tides from Manila Bay push water inland, reversing the river's flow. In the wet season, particularly during heavy monsoon rains, water from Laguna de Bay overflows, forcing the river to carry excess water towards Manila Bay. This reversal in flow contributes to flooding issues in Metro Manila, especially in areas near the riverbanks. The discharge rate of the river ranges from 12 to 275 cubic meters per second, peaking between October and November when rainfall is at its highest. The river has several major tributaries, including the Marikina River, which brings water from the eastern highlands of Rizal province; the San Juan River, which drains parts of Quezon City and San Juan; the Napindan River in Taguig; the Pateros River, and numerous esteros (canals) crisscrossing the city. These tributaries once played a crucial role in the city's drainage system, but many have been heavily polluted or encroached upon due to urbanization. The Pasig River has been a crucial part of Manila's history. During the Spanish colonial period, it served as a major trade route, connecting Manila to Laguna de Bay and nearby provinces. The riverbanks became home to bustling communities that relied on water-based transport and commerce. Boats carried goods such as rice, textiles, and spices, making the river a key economic hub.

The river was also a center of daily life, used for passenger boats, cargo transport, and essential activities such as fishing, bathing, and washing clothes. In the past, many families, including barge and raft dwellers, lived along the river and depended on it for their livelihood. Additionally, the Pasig River was once a rich natural habitat, supporting 25 fish species and 13 other aquatic organisms, which sustained local fisheries. Beyond trade and transportation, the river has cultural and historical importance, being home to landmarks such as Malacañang

Palace, the official residence of the Philippine president, and several centuries-old bridges like the Jones Bridge and MacArthur Bridge, which connect key districts of Manila.

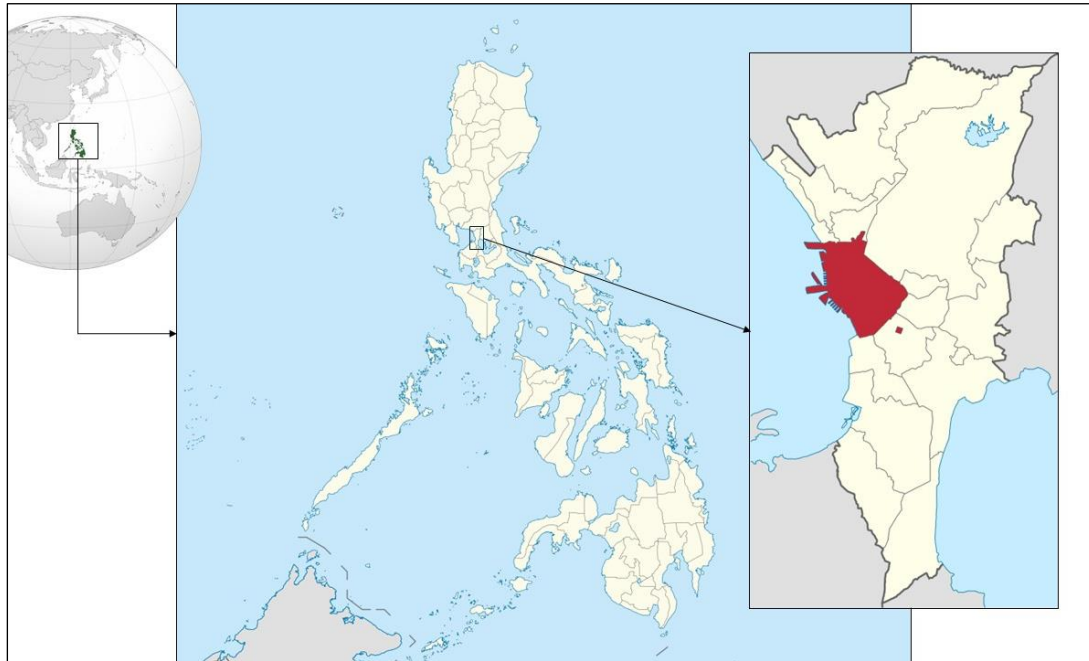


Figure 1. Map of Metro Manila, Philippines



Figure 2. Pasig river

Problem Statement

The environmental and management challenges of the Pasig River, as identified by the DENR in 1991 with funding from DANIDA and technical support from Carl Bro International, highlight the key issues that formed the basis for rehabilitation efforts.

Industrial Pollution: 45% of total pollution. 315 out of 2,000+ factories identified as major polluters, releasing 145 t/day of BOD. Key contributors: textile and food industries. Pollution rate expected to decrease by 2% per year due to urbanization and transport development. [1]

Domestic Liquid: Also 45% of total pollution. 4.4 million residents in the catchment area, but only 12% connected to a sewer system. The remaining 88% discharged untreated sewage into the river. 148 t/day of BOD comes from sewage outlets. MWSS prioritized water supply over sewage management due to funding issues. [1]

Solid Waste Pollution: 10% of total pollution. 30 t/day of BOD from solid waste. Floating waste blocks sunlight, harming plants, while sunken waste suffocates aquatic life. MMA collected 70–100% of barangay waste, but riverside settlements dumped directly into the river. 34 t of rubbish in 1990, projected to rise to 55 t by 2005. [1]

Lack of Strategic Rehabilitation: Pollution has worsened since the 1970s. Previous programs failed due to legal complexities, bureaucratic delays, and lack of coordination among agencies. LGUs failed to enforce zoning laws, leading to uncontrolled development. A comprehensive plan is needed. [1], [2]

Flooding Issues: Poor drainage and solid waste blockages caused severe flooding. In 1986, parts of Metro Manila were submerged in 2.1 meters of water. DPWH initiated de-clogging programs, drainage construction, and river wall renovations. ₱100 million spent annually on flood control over the past five years. [1], [2]

Diminished Use of the River: Once used for transportation and recreation, but pollution led to reduced activities. Now classified as Class D, discouraging water sports. Upgrading to Class C could allow rowing and sculling. Ferry services (1990s) discontinued due to financial losses, foul odors, and floating debris. BOD levels must be reduced from 327 t/day to 200 t/day to restore aquatic life. [1]

Previous Rehabilitation Programs: Several programs failed due to lack of community and private sector involvement. Imelda Marcos envisioned a tourist hub with floating casinos and restaurants, but it failed due to lack of sustainability. [2]

Project Description

Goals and Objectives

1. Restoring Water Quality and Eliminating Odour

Reduce offensive odours caused by untreated wastewater from households, industries, and informal settlements.

Implement stricter wastewater treatment regulations and expand sewerage infrastructure.

2. Reducing Biochemical Oxygen Demand (BOD) and Improving Water Flow

Decrease BOD load from 330 t/day to 200 t/day to restore aquatic life.

Require industries to pre-treat wastewater before discharge.

Use aeration techniques to improve oxygen levels.

Regulate river flow through controlled water releases from Laguna de Bay and dredging operations.

3. Waste Management and Prevention of Solid Waste Dumping

Strengthen regular waste collection services.

Install floating trash traps at key locations to intercept garbage.

Promote recycling programs and public awareness campaigns to encourage proper waste disposal.

4. Flood Control and Drainage System Improvement

Implement drainage system upgrades and de-clogging programs to mitigate flooding.

Allocate ₱100 million annually for flood control infrastructure, including levees, spillways, and pumping stations.

Reinforce river walls to prevent overflow.

5. Enforcing Zoning Regulations and Land Use Policies

Strengthen enforcement of the 1981 Zoning Ordinance to prevent uncontrolled riverbank development.

Designate protected zones and impose strict penalties for violations.

Ensure coordinated efforts among government agencies for effective policy implementation.

Strategies and Interventions

1. Establishment of the River Rehabilitation Secretariat (RRS): The RRS, under DENR, was created to coordinate rehabilitation efforts. It is responsible for planning, monitoring, and

evaluating projects, endorsing viable programs, addressing resource deficiencies, and improving policies. The RRS also builds partnerships and provides training for stakeholders.

2. Industrial Pollution Abatement: Two key projects, "Waste to Energy" and "Secondary Industry from Waste Recovery," engage major industrial polluters in the Clean River Pact, ensuring compliance with DENR effluent standards. The RRS, DENR, and Laguna Lake Development Authority monitor industries along the river to reduce pollution.

3. Liquid Waste Management: The MWSS has a long-term sewerage improvement program to expand treatment facilities. The Septic Tank Management Program (STAMP) was launched to de-sludge domestic and commercial septic tanks. However, financial constraints have delayed full implementation.

4. Solid Waste Management: The Waterways Sanitation Service of the MMA, with local governments and the Philippine Coast Guard, is leading clean-up efforts. Boom traps are installed at strategic locations to collect floating debris. Awareness campaigns and community involvement programs encourage waste segregation and recycling.

5. Infrastructure Development: Dredging operations are improving water flow, with 22 sunken vessels resurfaced. River walls are being renovated, and riverside parks are being developed to prevent further squatter settlements. Squatter relocation programs are also underway. The Environmental Management Bureau's water quality lab is being upgraded to serve as a National Reference Laboratory.

7. Personnel Development: The Manpower Development Unit focuses on training personnel in coordination, project management, environmental education, communication, and technical skills to enhance program effectiveness.

8. Water Quality Monitoring: The Pasig River's water quality is tested twice a month using 10 sampling stations at key locations, including San Juan River, Marikina River, Manila Bay, and Laguna de Bay. Parameters such as BOD, dissolved oxygen, coliform levels, salinity, phosphates, and nitrates are analyzed using the Mike 11 System to model pollution and water flow.

Key stakeholders and Partnerships

1. Government Stakeholders

President of the Philippines – Provides national leadership, declares the project a priority, issues executive orders, and mobilizes funding.

Congress of the Philippines – Enacts environmental laws, allocates budgets, and strengthens pollution control measures.

Presidential Task Force for Pasig River Rehabilitation – Ensures multi-agency coordination, monitors implementation, and reports to the President.

–

River Rehabilitation Secretariat (RRS) – Facilitates inter-agency coordination, oversees implementation, but faces bureaucratic delays and funding issues.

Department of Environment and Natural Resources (DENR) – Enforces pollution control laws, manages clean-up efforts, and penalizes violators.

2. Local Government Units & Community Leaders (3)

Local Government Units (LGUs) – Implement waste management programs, support relocation efforts, and monitor riverbank settlements.

Barangay Officials – Enforce local waste disposal policies, mediate disputes, and conduct clean-up campaigns.

Informal Settlers – Work with NGOs and government agencies on relocation and housing solutions.

3. Private Sector Partners

San Miguel Corporation (SMC) – Leads dredging projects, funds Pasig River Expressway (PAREX), and supports flood control.

Metro Clark Waste Management Corporation – Manages solid waste processing and prevents illegal dumping.

4. Non-Governmental Organizations (NGOs) & Advocacy Groups

Greenpeace – Advocates for stricter environmental regulations and corporate responsibility.

Save the Pasig Movement – Organizes awareness campaigns and community training in waste management.

5. Academic & Research Institutions

University of the Philippines (UP) – Conducts research on water quality and environmental impact.

Polytechnic University of the Philippines (PUP) – Engages students in sustainability and clean-up projects.

Department of Education (DepEd) – Integrates environmental education into school curricula.

Outcomes and Impact

a. Environmental Benefits

Revival of Aquatic Life: Once declared biologically dead in the 1990s, the Pasig River has seen

the return of various species, including kanduli (sea catfish) and tilapia, indicating improved water quality.

Establishment of Environmental Preservation Areas (EPAs): Development of 41,151.93 linear meters of EPAs, including linear parks, walkways, greenbelts, and revetment/parapet walls. These serve as buffer zones for public safety, reduce direct waste discharge, provide river access, and promote recreation and tourism.

b. Social Benefits

Relocation and Housing: Approximately 19,000 families living along the riverbanks have been relocated to safer areas, reducing health risks associated with pollution and improving living conditions.

Development of Public Spaces: Safe and accessible walkways, bikeways, green corridors, and parks have been created along the riverbanks, encouraging healthy lifestyles and community engagement.

c. Economic Benefits

Revitalized River Transportation: Enhancement of the Pasig River Ferry Service has provided a faster, safer, and more convenient public transport option, potentially boosting local economies along its route.

Economic Hubs and Commercial Spaces: Development of economic hubs and commercial spaces along the riverbanks has spurred job creation and entrepreneurial opportunities, inspired by successful riverside developments in cities like London, Bangkok, and Paris

.

Lessons Learned and Recommendations

a. Key Takeaways from the Project

Challenges in Coordination: The program's initial phase revealed difficulties in managing numerous government agencies. The newly established Pasig River Rehabilitation Commission (PRRC) lacked a well-defined mandate and sufficient political influence, hindering effective collaboration.

Overambitious Scope: The program's extensive scope and complex implementation structure were overly ambitious. Modifications in scope and implementation arrangements were necessary to achieve progress.

Enforcement of Environmental Laws: Existing laws against littering and dumping supported waste reduction efforts. However, enforcement was inconsistent, and logistical challenges, such as the expiration of waste collection boat contracts, impeded progress.

Community Engagement: Educating riverside communities on waste management proved essential for successful waste collection. Limited personnel for training underscored the need

for greater community involvement.

b. Best Practices and Strategies for Replication

Delegated Implementation: Assigning specific responsibilities to sector agencies with established mandates improved program effectiveness. This approach facilitated better coordination and execution of projects.

Comprehensive Planning: Developing a detailed plan of operation that is flexible to adapt to changing economic and political environments is vital. Regular reviews and updates ensure responsiveness to new challenges and opportunities.

Resource Mobilization: An aggressive campaign to raise resources is essential to implement key projects. Prioritizing resource generation and creatively revising plans can prevent delays due to funding shortages.

Public Participation: Engaging private organizations and the public in rehabilitation efforts ensures continuity and leverages additional expertise. Active participation fosters a sense of ownership and sustained support for the program.

c. Areas for Further Improvement or Research

Institutional Strengthening: Enhancing the mandate and political influence of coordinating bodies like the PRRC is necessary for effective program implementation. Institutionalizing coordination systems through legislation can provide the required authority and continuity.

Risk Assessment and Mitigation: Conducting thorough risk assessments and developing mitigation plans based on previous experiences can prevent overly ambitious scopes and ensure more realistic and achievable objectives.

Logistical Support: Addressing logistical challenges, such as securing adequate waste collection resources and ensuring the availability of sludge disposal sites, is crucial for maintaining river cleanliness and preventing pollution.

Policy Enforcement: Strengthening the enforcement of environmental laws and zoning ordinances is essential. This includes ensuring that policies like the 10-meter clearance on waterways are effectively implemented to prevent illegal encroachments and protect riverbanks.

Community Education: Expanding educational programs on waste management for riverside communities can enhance participation and compliance, leading to more sustainable waste reduction practices.

Conclusion

One of the most important rivers in Metro Manila is being revitalized with the Pasig River

Rehabilitation Project. The initiative showed significant gains in community involvement, aquatic biodiversity, and water quality. Despite the difficulties in managing scarce resources, enforcing environmental regulations, and coordinating multiple stakeholders, the initiative accomplished significant milestones like the re-establishment of the Pasig River Ferry Service, the development of public green spaces, and the relocation of informal settlers.

The project's key lessons highlight the significance of active community involvement, persistent policy enforcement, and realistic planning. Future developments should concentrate on bolstering community education initiatives, improving logistical assistance, and fortifying institutional frameworks.

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Nile

I. Case Study Overview

a. Project Background and Location

The Nile River Basin (Fig. 1) is one of the longest transboundary river systems in the world, covering approximately 3.1 million km². The basin extends across 11 countries: Burundi, Democratic Republic of Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, South Sudan, Sudan, Tanzania, and Uganda (Negm, A. M., 2017). The river stretches over 6,700 km from its headwaters in the Kagera Basin to the Mediterranean Sea (Deribe et al., 2024) and serves as the primary water source for millions of people. The river basin provides crucial resources for agriculture, hydropower generation, biodiversity conservation and domestic use, and supports the livelihoods of over 300 million people (Wolf, A. T., & Newton, J. T., 2007). However, the transboundary nature of the river has made its management a challenge due to conflicting national interests, rapid population growth, increased water demands and climate change impacts (Oestigaard, T., 2012; Martens, 2011; Fielding et al., 2018). The two main tributaries of the Nile River are The White Nile, originating from Lake Victoria and the Blue Nile which originates from Lake Tana in Ethiopia (Bekele et al., 2012). The major tributaries and dams in the Nile River Basin are presented in Fig. 2.

b. Problem Statement: Management and Environmental Challenges

The Nile River Basin is facing multiple environmental and management challenges. The major ones are water scarcity, poor water quality, climate change, and political and environmental issues.

- **Water scarcity:** Increasing demand for water due to population growth and economic development has adversely affected the freshwater resources in the basin (Radwan, T. M., et al., 2019). Egypt relies on the Nile for 96% of its freshwater needs, while upstream countries, particularly Ethiopia, seek greater access for agricultural and industrial use (Martens, 2011; El-Fadel et al., 2003).
- **Population growth and urban expansion:** As cities and agricultural lands expand, the conversion of fertile land into urban areas reduces food production capacity further, making water management an urgent priority (Radwan et al., 2019).

- **Water pollution:** Industrial and agricultural pollution have led to deteriorating water quality, affecting both human populations and aquatic ecosystems (Bekele et al., 2012; El-Khayat et al., 2021).
- **Geopolitical tensions:** Disputes over water allocation and dam construction projects, such as the Grand Ethiopian Renaissance Dam (GERD), have made cooperative management of the river difficult (Basheer, M., et al., 2023; El-Fadel et al., 2003).

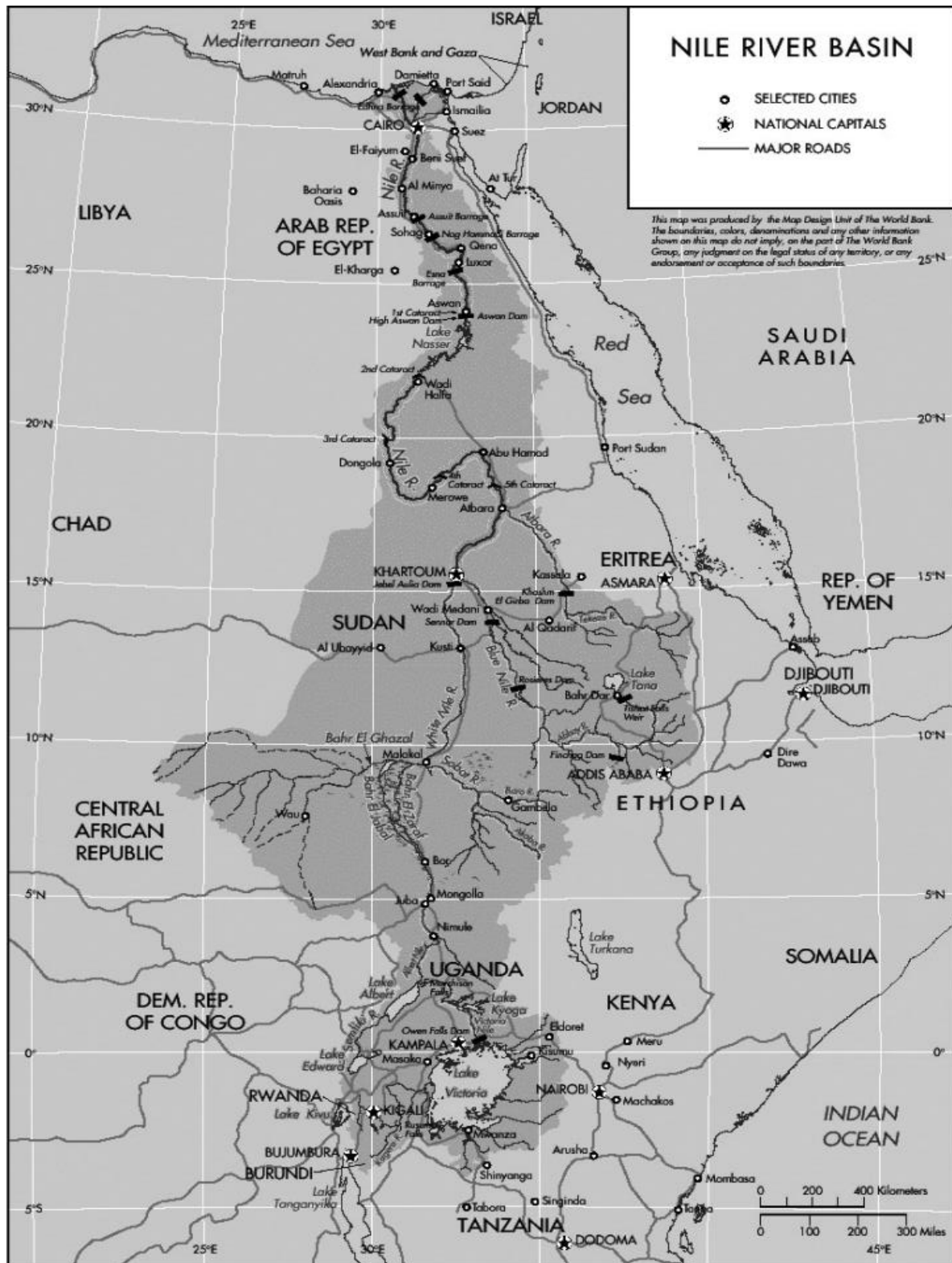


Fig.1 Map of the Nile River Basin (Source: Oestigaard, T. (2012).

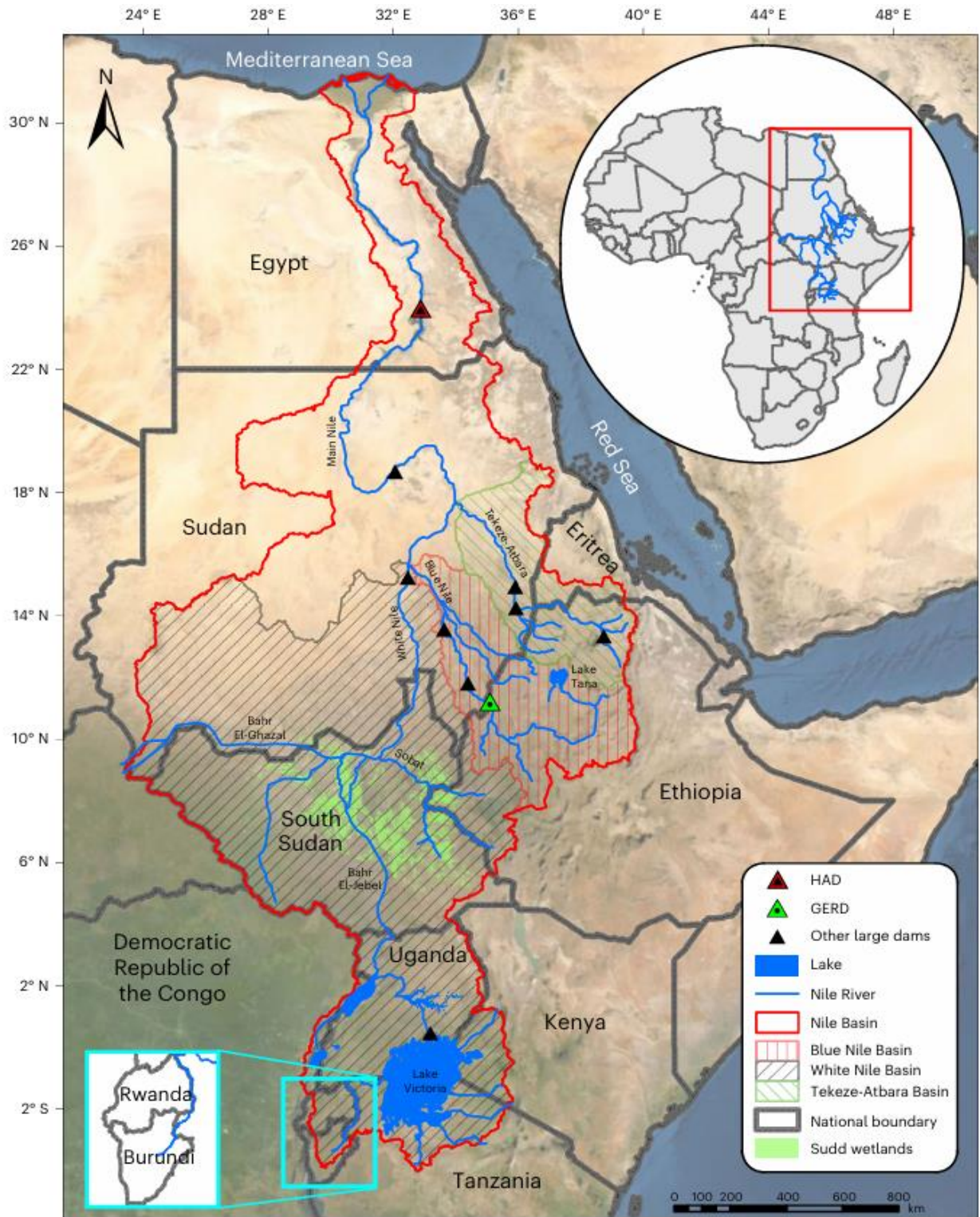


Fig. 2 The Nile River Basin and its Major Tributaries and Dams (Source: Nechifor, V., et al. (2023))

- **Climate change:** Fluctuations in water availability, extreme weather conditions affecting agricultural productivity, hydropower generation and altering precipitation patterns (Nkwasa et al., 2022; Basheer et al., 2023) are major challenges. The Ethiopian

Highlands, which is the major part of the river basin, experiences droughts due to less precipitation and lower inflows into the river system (Khir-Eldien & Zahran, 2017).

- **Environmental Degradation:** Deforestation, soil erosion, and wetland loss threaten the ecological balance of the basin and pollution further degrades the quality and sustainability of water resources in the river basin (Elshehawi, S., et al., 2021; Ali et al., 2011).
- **Lack of Regional Cooperation:** While the Nile Basin Initiative (NBI) aims to improve collaboration, challenges remain in achieving equitable water distribution and integrated management (Wheeler et al., 2018; El-Fadel et al., 2003).

II. Project Description

a. Goals and Objectives

The primary goal of the Nile Basin Initiative (NBI) is to promote equitable and sustainable use of the water resources of the river among all riparian countries while balancing economic development and environmental protection. One of its key objectives is to enhance cooperation in water management by developing policies that address water scarcity and mitigate climate change impacts (World Bank, 2008). Strengthening transboundary cooperation among riparian states to address water scarcity and geopolitical tensions (Deribe et al., 2024; El-Fadel et al., 2003) is also a major consideration. The initiative also aims to support the economic and social development of Nile River Basin countries through improved water governance, infrastructure development, and capacity-building programs (Negm, A. M., 2017). Enhancing water quality management through pollution control measures and sustainable industrial and agricultural practices is crucial for maintaining the health of the Nile River (Bekele et al., 2012; El-Khayat et al., 2021). The NBI aims to improve dialogue among the stakeholders in order to prevent conflicts and ensure efficient water resource management for future generations (Guvele, C. A., 2003). Mitigating climate change impacts involves improving irrigation efficiency, promoting climate-resilient agriculture and developing adaptive hydropower strategies to enhance sustainability (Basheer et al., 2023). Furthermore, restoring degraded ecosystems through wetland conservation, reducing deforestation, and implementing soil erosion control measures are essential for developing long-term environmental resilience (Bekele et al., 2012; Elshehawi et al., 2021).

b. Strategies and Interventions

To achieve the above mentioned objectives, several strategies have been implemented in the Nile River Basin. These include:

- **Integrated Water Resource Management (IWRM):** Development of Integrated Water Resource Management (IWRM) policies to ensure sustainable water use (Oestigaard, T., 2012). Establishing collaborative frameworks for equitable water allocation among the Nile River Basin countries (Bekele et al., 2012; Deribe et al., 2024; El-Fadel et al., 2003).
- **Infrastructure Development:** Investment in infrastructure projects, such as irrigation systems and hydropower dams and wastewater treatment facilities to improve water efficiency and reduce pollution (Martens, 2011; Radwan, T. M., et al., 2019). The climate-resilient dams including the Grand Ethiopian Renaissance Dam (GERD) and the High Aswan Dam (HAD) is vital for addressing climate variability through coordinated reservoir operations transboundary cooperation and hydropower resilience to ensure long term water and energy security (Wheeler et al., 2018).
- **Climate adaptation measures:** Implementing afforestation programs, adoption of improved agricultural practices, drought-resistant crops and flood control mechanisms to mitigate the impact of climate change on food security (Nkwasa, A., et al., 2022; Basheer et al., 2023; Elshehawi et al., 2021).
- **Economic and Hydrological Balance:** A study on the **Grand Ethiopian Renaissance Dam (GERD)** suggests that cooperative water-sharing and real-time hydrological data exchange can maximize economic and resilience benefits across Ethiopia, Sudan, and Egypt (Nechifor et al., 2023).
- **Conflict resolution mechanisms:** Strengthening diplomatic negotiations, multilateral agreements, and transboundary cooperation mechanisms like the Nile Basin Initiative (NBI) to facilitate negotiations, policy formulation, and address water disputes, particularly those surrounding GERD (Basheer et al., 2023; Wheeler et al., 2018; El-Fadel et al., 2003).
- **Climate Change Projections:** According to projections, climate change is expected to significantly alter precipitation and streamflow patterns in the Nile River Basin, requiring dynamic adaptation policies (Nechifor et al., 2023).

c. Key Stakeholders and Partnerships

The management of the Nile River Basin involves multiple stakeholders:

- **National Governments:** Formulate and implement water policies (Guvele, C. A., 2003).
- **International Organizations:** Entities such as the World Bank, African Union, and United Nations Development Programme (UNDP) provide financial and technical support (World Bank, 2008; Bekele et al., 2012).
- **Research Institutions and NGOs:** Contribute to knowledge generation and advocacy efforts to promote sustainable water use (Ahmed, W., et al., 2021).
- **The Nile Basin Initiative (NBI):** A coalition of riparian states working to foster cooperation and sustainable water management (World Bank, 2008; El-Fadel et al., 2003).
- **Local Governments and Communities:** Stakeholders engaged in implementing conservation programs and sustainable agricultural practices (Awulachew et al., 2012).

III. Outcomes and Impact

a. Environmental Benefits

Efforts to manage the Nile River Basin sustainably have yielded several environmental benefits:

- Soil conservation practices and watershed management programs have minimised soil erosion and sedimentation (Negm, A. M., 2017).
- Protection of wetlands and biodiversity hotspots has contributed to ecosystem preservation (Elshehawi, S., et al., 2021).
- Wetland conservation programs have helped to protect biodiversity and improve water retention capacity (Awulachew et al., 2012).
- Adaptive strategies such as afforestation and improved water management have mitigated the impacts of droughts and floods (Basheer et al., 2023).
- Reduction of carbon emissions through renewable energy projects, such as hydropower, has supported climate change mitigation efforts (Basheer, M., et al., 2023).
- Pollution control initiatives, coupled with improved irrigation techniques, have resulted in conservation of water resources, and reduced wastage. It has also minimized industrial and agricultural contaminants in the Nile River (Ali et al., 2011; El-Khayat et al., 2021; Multsch et al., 2017).

b. Social Benefits

The management interventions in the Nile River Basin have had positive social impacts:

- Improved access to clean water and sanitation has enhanced public health and reduced waterborne diseases (World Bank, 2008).
- Strengthened regional cooperation has contributed to conflict resolution and diplomatic relations (Wolf, A. T., & Newton, J. T., 2007).
- Capacity-building programs and knowledge-sharing initiatives have empowered communities to participate in water resource management (Guvele, C. A., 2003).
- Investments in infrastructure have improved access to electricity and essential services, enhancing quality of life (Radwan, T. M., et al., 2019).
- Sustainable agriculture and water management practices have enhanced food security and income generation for local communities (Bekele et al., 2012).
- Participation in water governance and decision-making processes has empowered the local population (Awulachew et al., 2012).

c. Economic Benefits

Economic development in the Nile River Basin has been supported by improved water management strategies:

- Investments in hydropower projects have created job opportunities and expanded energy access (Radwan, T. M., et al., 2019).
- Investments in hydropower, irrigation, and conservation projects have generated employment opportunities (Martens, 2011).
- Trade opportunities between Nile River Basin countries have been strengthened through collaborative projects (Ahmed, W., et al., 2021).
- Modern irrigation and water conservation techniques have increased crop yields, improved food security, and boosted local economies (Nkwasa et al., 2022).

IV. Lessons Learned and Recommendations

a. Key Takeaways from the Project

- Transboundary cooperation is essential for equitable water distribution and conflict resolution (Basheer et al., 2023; El-Fadel et al., 2003).
- Investment in renewable energy and sustainable agriculture provides long-term environmental and economic benefits (Khir-Eldien & Zahran, 2017).

- Integrated approaches that combine water conservation, pollution control, and climate adaptation yield better long-term outcomes (Bekele et al., 2012).

b. Best Practices and Strategies for Replication

- Promoting drought-resistant agriculture can help to mitigate the adverse impacts of climate variability (Basheer et al., 2023).
- Adoption of early warning systems to mitigate flood and drought risks (Nicholson, 2000).
- Remote sensing and GIS-based monitoring of water resources can facilitate efficient water management (Deribe et al., 2024).
- Expanding water conservation initiatives across African river basins facing similar challenges (Strzepek & McCluskey, 2007)
- Strengthening legal frameworks and negotiation platforms can reduce geopolitical tensions (Basheer et al., 2023; El-Fadel et al., 2003).
- Implementing coastal protection measures to mitigate the impacts of sea-level rise on the Nile Delta community (Khir-Eldien & Zahran, 2017)

c. Areas for Further Improvement or Research

- **Long-Term Climate Resilience Strategies:** More research is required on predicting climate-induced variations in water availability and the development of adaptive water management frameworks (Nkwasa et al., 2022).
- **Sustainable Agricultural Practices:** Investigation into alternative irrigation methods and the integration of water-efficient crops to maximize food production while minimizing water use (El-Khayat et al., 2021).
- **Enhanced Water Governance:** Strengthening institutional frameworks and exploring new governance models to improve transboundary water-sharing agreements and mitigate conflicts (Basheer et al., 2023).
- **Technology Integration:** Adoption of advanced remote sensing, AI-driven water monitoring systems, and data-driven decision-making tools to optimize water resource management (Deribe et al., 2024).

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Amazon

About the Basin

The Amazon River Basin is the largest river basin in the world, covering an area of approximately 7 million square kilometres across nine South American countries: Brazil, Peru, Bolivia, Colombia, Ecuador, Venezuela, Guyana, Suriname, and French Guiana. It lies between 5°N to 20°S latitude and 50°W to 80°W longitude. The Amazon River, originating from the Andes Mountains in Peru, flows for about 6,992 kilometres (4,345 miles) before emptying into the Atlantic Ocean in Brazil. The basin contains the world's largest tropical rainforest, playing a crucial role in global climate regulation and biodiversity conservation. Its major tributaries include the Madeira, Negro, Japurá, Putumayo, and Purus Rivers.



Figure 4. Index Map of Amazon River (Image Source: https://en.wikipedia.org/wiki/File:Amazonriverbasin_basemap.png)

Climate Change

The Amazon's hydrological cycle is vital for ecosystems and energy production, but climate change threatens river flow and flood patterns. Sorribas et al. (2016) used the MGB-IPH model with 1D river hydraulics and five Coupled Model Intercomparison Project Phase 5 (CMIP5) General Circulation Models (GCMs) to assess climate-induced hydrological changes. Findings showed reduced discharge in eastern basins and less flooding in central and lower Amazon regions during low-water periods. Although there have been notable advancements, uncertainties in the models persist, highlighting the need for more robust regional climate models, expanded observation systems, and cross-border partnerships. Future investigations should also integrate land-use changes with climate-induced hydrological variations to enhance

water management and adaptation approaches.

Moreover, Guimberteau et al. (2017) investigated how deforestation and climate change would influence 21st-century hydrology by applying three land surface models (LSMs) in conjunction with three general circulation models (GCMs). By integrating new land-cover change scenarios from AMAZALERT, the study achieved greater regional accuracy. The study showed that under extreme deforestation, evapotranspiration (ET) declined by up to 7%, while runoff increased, especially during the dry season in southeastern Amazonia. Large uncertainties in hydrological projections stemmed from variations in climate models, land surface models, and deforestation scenarios, thus highlighting the need for more refined forecasting approaches.

Diodato et al. (2020) conducted a comprehensive analysis of sediment discharge in the Amazon Basin and found that extreme weather events, especially storms and droughts, play a pivotal role in shaping erosion patterns. Using a hydro-climatological model, researchers reconstructed sediment trends from 1859 to 2014), demonstrating how climate-driven hydrological shifts and alterations in land-use practices amplify sediment transport. In addition, anthropogenic activities such as Hydropower development, agriculture, and mining further intensify the sediment dynamics, underscoring the urgent need for enhanced, proactive monitoring and effective management strategies globally. The study highlighted the rising frequency of the extreme hydrological events and underscored the need to incorporate sediment models with climate data analyses. Enhanced hydrologic models are crucial to effectively address climate-driven and anthropogenic-induced sediment disruptions through improved forecasting and planning.

Ravena et al. (2024) focused their research on the Purus River Basin, a critical region in the Amazon, to evaluate climate change threats and develop a governance framework. By employing advanced climate modelling, land-use analysis, and risk governance principles, they introduced the Risk Governance Model for the Amazon (R-GOMAM). This approach integrates fuzzy logic with a fuzzy inference system (FIS) to interpret climate, hydrological, and socio-economic data. Using the Regional climate model (RegCM4), the researchers effectively simulated precipitation trends, enabling scenario-based risk assessments for Santa Rosa do Purus, Pauini, and Beruri from 2015 to 2025). Their findings revealed that the existing institutional frameworks in Amazonas and Acre are inadequate for tackling climate risks, leading to the development of the R-GOMAM model to enhance stakeholder participation and improve risk governance, which aligns closely with Brazil's National Policy of Protection and Civil Defence (PNDEC), thus promoting resilience.

Drought

In their study, Paredes-Trejo et al. (2021) employed the Standardized Precipitation-Evapotranspiration Index (SPEI) to examine long-term drought trends in the Amazon River Basin (ARB) from 1901 to 2018. They observed a drying trend across the basin, accompanied by an upsurge in the short-term droughts occurrences since the 1970s. The study identified high-risk sub-basins, such as Ucayali, Japurá-Caquetá, and Xingu, witnessing persistent drought conditions. It was noted that the critical climate oscillations such as El Niño-Southern Oscillation (ENSO) and Atlantic Multidecadal Oscillation (AMO) do influence these drought patterns. Findings suggest that rising temperatures due to climate change may intensify drought severity, posing challenges for vegetation, water resources, and local communities.

Ribeiro et al. (2022) used the Hadley Centre Global Environmental Model version 3 (HadGEM3-GA6) model to investigate the 2015/2016 Amazon drought, examining the anthropogenic contributions to its severity. The findings revealed that anthropogenic-induced climate change heightened the likelihood of such droughts by nearly fourfold, indicating that El Niño alone could not account for the extreme dry conditions. The drought also reduced photosynthetic capacity across 400,000 km², threatening the Amazon's carbon sink role. These findings highlight serious long-term concerns, as extreme droughts could accelerate the Amazon's transition from a carbon sink to a carbon source, further intensifying climate change, thus urging reduction in emissions and climate resilience strategies to mitigate future drought impacts.

Drought monitoring in the Amazon Basin often overlooks short-term hydrological shifts, limiting effective resource management. The study conducted by Lenczuk et al. (2024) introduced the Multivariate Drought Severity Index (MDSI), a novel tool that integrates ground based GPS displacement data and satellite-derived Gravity Recovery and Climate Experiment (GRACE) measurements to enhance drought detection. By applying wavelet decomposition and statistical modelling, MDSI captured short-term drought signals better than conventional methods, aligning closely with the Standardized Streamflow Index (SSI) and Enhanced Vegetation Index (EVI). This improved hydroclimatic sensitivity underscores the importance for better forecasting, expanded GPS networks, and machine learning approaches to strengthen drought management strategies across the basin.

Clarke et al. (2024) examined the severe 2023 Amazon drought, concluding that climate change overshadowed El Niño as the main driver of extreme conditions. Using climate models and observational data, researchers found that anthropogenic warming significantly increased the

likelihood of extreme drought conditions, exacerbating water shortages, ecosystem stress, and socioeconomic impacts. The study highlighted that human-induced global temperature rise had intensified precipitation deficits and evapotranspiration rates, making agricultural and ecological droughts 30 times more likely. The findings underscore the urgent need for robust sustainable water management, improved early warning systems, and coordinated global efforts to curb fossil fuel emissions and deforestation to mitigate future drought risks, limiting the region's vulnerability to drought.

Hydrological Studies

Correa et al. (2017) employed a Hydrological Retrospective (HR) methodology combining precipitation datasets with the MGB-IPH model, to reconstruct over three decades of major floods and droughts in the Amazon Basin. The analysis revealed intensifying flood events in the basin's northwestern section and increasingly severe droughts in its south-central region. The MGB-IPH model demonstrated robust performance, accurately representing historical extremes and validating its reliability. The study underscores the significance of the climate reanalysis and hydrological modelling in identifying evolving climate patterns by assessing past trends and future risks, therefore highlighting their global applicability for future water resource management worldwide.

Groundwater plays a crucial role in the Amazon River Basin, influencing water cycles, ecosystems, and climate variability, yet remains underexplored due to limited monitoring. Frappart et al. (2019) analysed groundwater storage changes from 2003 to 2010 using GRACE satellite data, integrating multi-satellite observations with the hydrological models. Results showed that seasonal groundwater variations accounted for 20–35% of total water storage, exceeding 450 mm amplitudes in Alter do Chão and Iça aquifers. The study also identified significant interannual variability, up to 120 mm, linked to hydrological shifts and extreme events, such as the 2005 drought, underscoring groundwater's critical influence on the Amazonian water balance.

With an emphasis on streamflow, evapotranspiration (ET), and groundwater storage, Heerspink et al. (2020) investigated how the hydrology of the Amazon Basin had changed in response to variations in the climate and land cover. Using 35 years of data from 126 gauging stations, the study integrated Climate Hazards Group Infrared Precipitation with Stations data (CHIRPS), MODIS ET, and GRACE groundwater observations, applying nonparametric Mann-Kendall and Theil-Sen analysis. The study emphasized the need to consider full water budget dynamics, especially groundwater storage, for sustainable water, food, and energy management amid

ongoing climate and land-use changes. In order to improve predictions of streamflow, evapotranspiration, and water availability, future research should specifically describe the dynamics of groundwater storage.

The Amazon Basin accounts for approximately 20% of global river discharge, emphasizing the importance of accurately understanding runoff variability for effective climate and water resource management. Chen et al. (2020) analysed monthly runoffs patterns from 2003 to 2015 by applying the $dS/dt = P - ET - R$ (SPER) method, utilising data from GRACE satellites, European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5 reanalysis, and Global Precipitation Climatology Project (GPCP) precipitation data. Results revealed that GRACE-based runoff estimates closely matched with in situ observations but exhibited larger seasonal fluctuations. Observed discrepancies were attributed primarily to the underestimation of submarine runoff and floodplain overflow during wet seasons, while ERA5 overestimated evapotranspiration by ~ 2 cm/month. The study underscores the necessity of integrating satellite observations, climate models, and in situ data for better runoff estimation.

Fassoni-Andrade et al. (2021) provided a comprehensive review of recent advancements in satellite-based remote sensing (RS) for Amazon hydrology. The study emphasised improved monitoring capabilities for precipitation, evapotranspiration, surface water, and groundwater monitoring, highlighting RS's critical role in detecting climate change impacts and anthropogenic activities such as deforestation and dams. Despite significant progress, the study identified existing limitations of RS technologies, advocating for the integration of higher-resolution data satellite data and interdisciplinary collaboration to effectively support sustainable water management, strengthen environmental governance, and improve policy responses to Amazonian hydrological challenges.

Reservoir and Hydropower Management

Stickler et al. (2013) investigated the effects of deforestation on Amazonian hydropower using climate and hydrological models. Initially, local deforestation increased water discharge; however, extensive regional deforestation reduced rainfall and river flow by as much as 36%, thus significantly jeopardizing hydropower generation. Projections indicate that with 40% deforestation by 2050, Belo Monte Dam's power output could decline to merely 25% of its full capacity. The study emphasised the necessity of integrating forest conservation into energy development plans to secure sustainable hydropower production.

Hydropower development in the Amazon Basin has intensified conflicts among developers, governments, indigenous communities, and environmentalists. Latrubesse et al. (2017)

introduced the Dam Environmental Vulnerability Index (DEVI) to evaluate potential environmental risks associated with 140 existing and 428 proposed dams. Results revealed that even partial implementation of these projects would lead to irreversible ecological disruptions affecting the floodplains dynamics, estuaries, sediment transport processes, and regional climate patterns, with the Madeira River sub-basin emerged as the region facing the greatest threats. The study underscores the urgent need for a comprehensive basin-wide assessments, innovative policy solutions, and enhanced transnational collaboration to reconcile hydropower development with environment conservation.

Athayde et al. (2019) conducted a comprehensive review of twenty years of research on hydropower development in the Brazilian Amazon, identifying critical environmental, socio-economic, and governance impacts such as river disruption and biodiversity loss, alongside socio-economic challenges including displacement of local communities. The study emphasized the urgent need for integrated planning and stakeholder engagement. Future research should focus on cumulative impacts, alternative energy, and inclusive governance for sustainability.

Mayer et al. (2021) conducted an in-depth evaluation of the social, economic, and environmental impacts resulting from the Belo Monte hydropower project in Brazil. The research revealed a noticeable decline in public support, largely due to adverse consequences from forced resettlement and socio-economic displacement. Using the Dam Environmental Vulnerability Index (DEVI), the authors highlighted significant ecological disruptions, including extensive alterations to floodplains ecosystems, sediment transport, and biodiversity. Additionally, the study underscored inequitable cost distribution and lack of procedural justice in dam planning. Consequently, the study advocated for integrated planning, stakeholder participation, and alternative energy strategies to mitigate long-term socioenvironmental impacts.

Castro et al. (2021) explored the geopolitical significance of Amazonian hydropower within Brazil's broader energy system, emphasizing its role in economic specialization and highlighting the accompanying socio-environmental impacts. Their analysis included renewable expansion, smart grid technologies, and energy security. Despite a growing shift toward renewable sources, hydropower continues to dominate Brazil's energy framework. The study emphasized the need for integrated, coherent policies that effectively balance energy security with environmental sustainability and social equity, suggesting pathways toward a more diversified and resilient energy system.

Hydropower expansion in the Amazon Basin has significantly altered natural river flow patterns and flood regimes, leading to ecological disruptions. Chaudhari et al. (2022) utilized the Catchment-based Macro-scale Flood-Dam (CaMa-Flood-Dam) model to analyze the impacts of existing large dams across the Xingu, Madeira, and Tocantins rivers. Their findings revealed dramatic alterations in downstream flows, by up to three orders of magnitude. Moreover, planned dams could further reduce flood durations by approximately 10%, adversely affecting floodplains, sediment transport, and ecosystems. The study emphasizes the urgent necessity for sustainable hydropower management, integration of satellite data, and optimize dam operations to minimize the environmental impacts

Sediment transport and river morphology changes

Constantine et al. (2014) explored how sediment transport shapes river morphology and floodplain evolution in the Amazon Basin. The authors demonstrated that sediment supply significantly influences the way meandering rivers reshape their floodplain environments. The research concluded that changes in sediment loads, whether resulting from natural phenomena or human-induced activities such as deforestation and mining, directly affect the river planform, causing shifts in river courses and landscape transformations. These findings emphasize the crucial role of sediment dynamics in controlling river behaviour and underscore the necessity of managing sediment fluxes to maintain the ecological health and stability of Amazonian rivers.

Expanding on sediment dynamics, Li et al. (2022), in their study titled “Reversal of the Sediment Load Increase in the Amazon Basin Influenced by Divergent Trends of Sediment Transport from Solimões and Madeira Rivers,” investigated historical trends in sediment transport within two major Amazon tributaries. The study revealed that sediment loads have fluctuated primarily due to factors such as deforestation, dam construction, and climate variability. Initially, these rivers experienced significant increase in sedimentation, however recent trends indicate a notable reversal in sediment transport trends. This shift likely reflects the cumulative impacts of upstream conservation initiatives, modified land-use practices, or shifts in hydrodynamic conditions. The study highlights the necessity of sustained sediment monitoring to better predict river dynamics, inform river basin management strategies, and proactively address environmental risks related to sedimentation.

Naffaa et al. (2024) utilised the River Discharge and Sediment Model (RDSM) to simulate discharge and sediment transport patterns across the Amazon Basin from 1980 to 2009, incorporating the effects of land-use changes and dams. The model effectively captured

monthly and annual discharge dynamics, achieving a Kling-Gupta Efficiency (KGE) score ranging from 0.57 to 0.92. Additionally, the model estimated the annual sediment transport at Óbidos Porto to be approximately 6.46×10^8 tonnes/year. The findings aligned with field measurements, validating the model's accuracy. These results validated RDSM's effectiveness, highlighting its utility for assessing future reservoir sedimentation, aiding in water resource management and enhancing comprehension of sediment dynamics within the Amazon Basin. Naffaa et al. (2024) applied the River Discharge and Sediment Model (RDSM) to simulate river discharge and sediment transport patterns within the Amazon Basin from 1980 to 2009. This comprehensive model integrated detailed runoff generation processes, sediment yield calculations, and riverine sediment transport at a high spatial resolution. Model validation using data from Hybam project data revealed good agreement in discharge estimates achieving Kling-Gupta Efficiency (KGE) scores between 0.57 and 0.92, although sediment transport predictions displayed greater variability. The study estimated an annual sediment flux of 5.96×10^8 tonnes transported to the ocean, consistent with the previous field measurements. Findings underlined the impacts of land use changes, reservoirs, and climate variability on sediment dynamics, emphasizing the need for improved monitoring and modeling to support sustainable basin management.

Moving beyond physical sedimentation processes, Zumak et al. (2025) explored the socio-environmental risks associated with sediment dynamics in "Riverine Communities in the Central Amazon: Erosion and Sedimentation Risks." By combining remote sensing data with socioeconomic indicators, the researchers analyzed how sedimentation and erosion affect local communities within the Mamirauá Sustainable Development Reserve. The study revealed that sedimentation impacts approximately 18.5% of communities, while erosion poses threats to about 26%, leading to displacement, infrastructure damage, and social isolation. Highlighting these critical socio-environmental consequences, the authors emphasize the urgent need to incorporate sediment-related risks into broader disaster management and mitigation frameworks, particularly in the context of climate change and extreme hydrological events in vulnerable Amazonian regions.

Water Quality and Pollution Studies

In the study titled "Biological Monitoring Using Macroinvertebrates as Bioindicators of Water Quality of Maroaga Stream in the Maroaga Cave System, Presidente Figueiredo, Amazon, Brazil," Uherek and Gouveia (2014) evaluated water quality using macroinvertebrates as bioindicators. Applying the Biological Monitoring Working Party (BMWP) Score System, the

researchers effectively assessed the ecological integrity of the stream. The results classified the Maroaga stream as ‘clean or not significantly altered,’ highlighting the accuracy and reliability of macroinvertebrates for biological monitoring. This approach effectively captures long-term ecological dynamics that chemical analyses may miss. The study highlights the need for integrating biological assessment methods, such as macroinvertebrate indicators, into comprehensive water management strategies in Brazil, supporting sustainable environmental policies and practices..

A study on “Construction of a novel water quality index and quality indicator for reservoir water quality evaluation: A case study in the Amazon region” carried out by Lobato et al. (2015) constructed a novel Water Quality Index (WQI) and Quality Indicator (QI) tailored specifically to analyse water quality dynamics influenced by hydrological cycles and anthropogenic activities. The findings revealed distinct patterns, with conservation areas consistently exhibiting better water quality compared to regions facing intensive human activities, where significant degradation was observed. The study emphasized the importance of incorporating hydrological data with advanced statistical analyses for better environmental monitoring and water management practices, promoting sustainable conservation and usage of water resources.

Monteiro et al. (2016) investigated the effects of natural and anthropogenic factors on water quality in the Caeté Estuary, Brazil. The study revealed significant eutrophication, intensified by poor sanitation, high population density, and increasing commercial activities, especially in the upper estuary sector. Utilizing water quality assessments coupled with the DPSIR analytical framework, the researchers identified elevated concentrations of nutrient and coliform levels, particularly pronounced during the dry season. Although mangrove ecosystems naturally contributed nutrients via outwelling processes, human activities markedly exacerbated pollution levels. The study recommended strategic urban planning, effective wastewater treatment systems, and water-use policies to safeguard the integrity of estuarine ecosystems.

Medeiros et al. (2017) conducted a detailed water quality assessment of Brazil's Murucupi and Arapiranga rivers using the Water Quality Index (WQI). Their findings indicated substantial anthropogenic impacts, especially in the Murucupi River, where industrial discharges and domestic effluents severely compromised water quality in numerous areas. Conversely, the Arapiranga River, located in a region with less industrial activity, exhibited comparatively better water conditions. The study highlights the urgent need to implement stricter pollution control measures and enhanced wastewater treatment infrastructures to effectively mitigate

industrial pollution and preserve aquatic ecosystems.

Rosell-Melé et al. (2018) conducted a detailed investigation into oil pollution affecting soils and sediments in the Northern Peruvian Amazon, focusing on contamination from local oil extraction activities. Through comprehensive chemical analyses, the study detected significant levels of petrogenic hydrocarbons notably steranes and hopanes, in regions traditionally utilized by the indigenous communities for hunting and fishing. These pollutants were traced directly to oil spills and the discharge of produced water. The results raised alarming concerns regarding wild life exposure and human health risks from soil ingestion, highlighting the urgent necessity for improved pollution management protocols. The study emphasized the importance of stringent pollution control measures and emphasized further research on the long-term impacts of oil activities in the Amazon.

Rico et al. (2021) examined the impact of pharmaceuticals and urban contaminants on freshwater ecosystems in the Amazon. Researchers conducted the largest chemical monitoring campaign in the region, analysing 43 contaminants at 40 different sampling sites across major Amazonian rivers and cities. Findings showed urban areas as significant contamination hotspots, with the detection of up to 40 different contaminants, some reaching unprecedented global concentration levels. Pharmaceuticals, psychostimulants, and hormones posed risks to 50–80% of aquatic species near cities. The study highlighted the immediate need for improved wastewater treatment infrastructure and continuous environmental monitoring to safeguard biodiversity within the Amazon Basin.

Ecological and environmental studies

Castello et al. (2013) provided a comprehensive review on the vulnerability of Amazon freshwater ecosystems to anthropogenic and climatic stressors, particularly focusing on the impacts from hydropower expansion, deforestation, and climate change. It highlighted how these combined pressures significantly threaten regional biodiversity, compromise water quality, and reduce ecosystem resilience. Additionally, hydrological alterations stemming from infrastructure development and climate variability intensified habitat fragmentation and disrupt crucial riverine processes. The authors strongly recommended adopting integrated conservation strategies, enhancing improved governance, and implementing sustainable water resource management approaches to effectively mitigate ecological risks and preserve Amazonian freshwater ecosystems.

Hydrological connectivity within Amazonian freshwater ecosystems faces growing disruptions due to dams, mining activities, extensive deforestation, and climate change. Castello et al.

(2016) reported that with 154 dams currently operational and an additional 277 planned, the basin may soon retain only three free-flowing tributaries. Furthermore, significant land-cover transformations have already impacted around 20% of the basin area, with riparian forests declining by nearly 50% in some areas. Climate change exacerbates these pressures by increasing the frequency of droughts, floods, and ecosystem degradation, negatively affecting water quality, fish yields, and freshwater availability. Existing management policies lack consistency and fail to address cumulative effects, necessitating a comprehensive basin-wide research and governance framework to protect hydrological connectivity.

The Upper Teles Pires Basin faces significant threats to water resources from intensive deforestation and agriculture. In their study, Lopes et al. (2020) employed Multi-Criteria Analysis (MCA) and spatial modeling techniques to effectively identify priority areas for forest restoration, improving water quality and ecosystem resilience. The results indicated that approximately 22.73% of the basin, especially areas along riverbanks and regions prone to erosion, demonstrated high suitability for restoration. Using Weighted Linear Combination (WLC) and Ordered Weighted Averaging (OWA) methods, the study provided predictive scenarios for informed decision-making, emphasizing the importance of robust hydrological monitoring, community participation, and improved spatial analysis for effective restoration planning.

Garrett et al. (2021) reviewed the persistent deforestation in the Brazilian Amazon, highlighting that federal policies prioritizing economic growth significantly contributed to environmental degradation, biodiversity loss, climate instability, and social conflicts. Despite past conservation efforts, deforestation persisted due to weak governance, inadequate land-use policies, and the expansion of agribusiness. The authors recommended the need for systemic changes, advocating agroforestry practices and improved forest governance, to achieve a sustainable balance between conservation and economic development. They cautioned that immediate action is essential to prevent further ecological damage and protect community livelihoods.

The Amazon Basin faces rising deforestation, altering river sediment dynamics. Using remote-sensing data from 2001 to 2020, Narayanan et al. (2024) identified rapid sediment load increases in heavily deforested eastern Amazon, whereas western regions experienced a delayed response of approximately 1–2 years. A critical threshold of just 5% deforestation triggered significant sediment changes posing severe threats to river ecosystems and hydropower infrastructure, calling for better sediment monitoring, robust conservation policies,

and advanced hydrological modelling are urgently recommended to mitigate long-term impacts.

Sustainable Management and Policies

Braga et al. (2013) analysed transboundary water governance challenges within the Amazon Basin, focusing on cooperation challenges among eight countries. They highlighted the Amazon Basin Cooperation Treaty as a key framework but incomplete governance structure, highlighting deficiencies in monitoring mechanisms, fragmented legal frameworks, and limited stakeholder participation. The study advocated for integrated, basin-wide policy strategies that address climate change, deforestation, and hydropower impacts to effectively balance regional conservation goals with economic development needs..

Maria Antonia Tigre (2019) assessed regional climate change adaptation strategies across Amazon countries, emphasizing the Amazon's significant vulnerability to extreme weather events and the lack of cohesive regional policies to address these risks. The study analysed national adaptation commitments within the Amazon Cooperation Treaty Organization and compared them with adaptation frameworks in Central America. Findings indicated that Amazon countries lack a unified regional strategy and emphasized the need for integrated governance and cooperation. The paper advocated for transboundary climate adaptation policies to enhance resilience, effectively manage water resources, and ensure long-term environmental sustainability within the Amazon Basin.

Athayde et al. (2019) examined the increasing proliferation of small hydropower plants (SHPs) throughout the Amazon, critically assessing their cumulative environmental impacts. The analysis emphasized that existing policies in Brazil inadequately address the long-term ecological and social effects of SHPs, particularly their role in disrupting river connectivity, degradation of biodiversity, and threats to indigenous livelihoods. Using the case of the Cupari River Basin, the study identified significant shortcomings in the environmental licensing process, which often fails to consider the collective impact of multiple small dams. Consequently, the authors advocated for robust strategic environmental assessments, integrated hydropower planning, and enhanced governance mechanisms to effectively mitigate environmental and social risks in the Amazon Basin.

Fisher et al. (2020) examined conflict management within Peru's Amarakaeri Reserve, focusing particularly on complex disputes arising from land tenure and competition over natural resources. A three-year intervention improved stakeholder engagement and governance through capacity-building and conflict resolution. Key findings emphasized the value of

adaptive management practices, and inclusive decision-making frameworks, and ongoing multi-stakeholder engagement, recommending sustained, long-term collaboration as essential for achieving durable conservation outcomes.

Complementing this, Lopes et al. (2021) explored participatory conservation and social justice in the Amazon Basin through the "Just Aquatic Governance" framework. It examined how governance regimes have evolved and proposed a model integrating recognitional, procedural, and distributional justice principles. The study emphasized the critical need to align conservation strategies with local rights, promote gender equality, and equitable resource distribution. The study stressed the importance of participatory governance in freshwater ecosystem conservation while addressing socio-economic inequalities. It called for policies that balance environmental protection with community empowerment to foster sustainable, just conservation efforts in the Amazon.

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Congo

[Not received]

Mississippi

I. Case Study Overview

a. Project Background and Location

The Mississippi River is one of the most important river systems in the World, spanning approximately 3.2 million km² across 31 states in the USA and two Canadian provinces, representing about 41% of the contiguous United States (Guo, 2023). This river basin is a lifeline for over 18 million people who live along its banks and millions more who depend on its resources for agriculture, industry, and recreation (America's Watershed Initiative, 2020). It is also a critical hub for biodiversity, supporting a rich mosaic of ecosystems, including wetlands, forests, and floodplains, which are home to countless species of flora and fauna (Turner & Rabalais, 2003).

The Mississippi River Basin serves as both a vital ecological and economic resource, as well as a significant cultural and historical symbol. It has shaped the development of North America,

serving as a trade conduit, a source of water and food, and a driver of economic and social growth (Anfinson, 2005). The agricultural productivity of the Mississippi River Basin is unparalleled; a significant portion of the world's corn, soybeans, and cotton are produced in this river basin.

As one of the most extensively studied river basins in the world, the Mississippi River Basin offers invaluable lessons for watershed management. Its long history of human intervention, combined with its ecological and economic significance, makes it a critical case study for understanding the complexities of managing large river systems (National Research Council, 2012). The challenges of the river basin, ranging from extreme weather events to pollution, are emblematic of the issues faced by river basins worldwide. By studying the Mississippi River Basin, policymakers, researchers, and practitioners can gain insights into effective strategies for ensuring resilience, sustainability, and equity, that can be applied to other river systems on the Earth.

b. Problem Statement

The Mississippi River faces numerous environmental and management challenges that threaten its health and sustainability. Climate change is projected to cause more extreme weather patterns, leading to increased flooding and droughts, while urbanization and agriculture degrade water quality, reduce habitats, and threaten biodiversity. Nutrient loading from agricultural runoff contributes to algal blooms and dead zones in the Gulf of Mexico, and sediment transport from farming leads to sedimentation, impacting water quality and habitats. Habitat loss due to urbanization, agriculture, and development fragments ecosystems, while invasive species like Asian carp disrupt native biodiversity. Water quality is further impaired by industrial waste, sewage, and agricultural runoff, making flood management a challenge in balancing protection with healthy floodplains. Over allocation of water resources results in difficulties in ensuring water availability to all users, while ageing infrastructure poses safety and health risks. Navigation and shipping impact water flow and habitats, necessitating resilience and adaptation measures for the future. Environmental justice concerns arise as low-income communities are disproportionately affected. Soil health is vital for reducing erosion and improving agricultural sustainability. Fisheries management is threatened by overfishing, habitat loss, and pollution. Historic preservation is often overlooked but essential. Indiscriminate waste disposal into waterbodies, (including plastic contamination), affects water

bodies. Industrial pollution degrades water quality and human health. Infrastructure development must be balanced with environmental impacts. Public engagement plays a crucial role in stewardship and policy support. Collaborative governance is necessary for managing the multistate watershed, as land use changes exacerbate runoff, erosion, and habitat loss. Maintaining aquatic ecosystem health is a grave challenge, with waterborne diseases posing risks to human populations and groundwater contamination threatening drinking water and habitats (Guo, 2023).

II. Project Description

a. Strategies and Interventions

The National Flood Insurance Program (NFIP), established in 1968, aims to reduce flood risk and provide affordable flood insurance to property owners in participating communities. Administered by the Federal Emergency Management Agency (FEMA), the NFIP encourages floodplain management by requiring communities to adopt and enforce regulations that minimize development in high-risk areas. In exchange, residents gain access to federally subsidized flood insurance, which helps cover flood-related damages. Despite its benefits, the NFIP faces challenges, including low participation rates, with only 20-30% of eligible residents enrolled, and financial sustainability issues due to frequent payouts for major flood events. The program also promotes non-structural measures, such as floodplain buyouts and elevation of structures, to reduce vulnerability. However, increasing flood risks from climate change and continued development in flood-prone areas highlight the need for reforms. Efforts to modernize the NFIP focus on improving risk assessment, incentivizing community resilience, and balancing affordability with fiscal responsibility, ensuring that it remains a key tool in mitigating flood impacts nationwide.

Upper Mississippi River Restoration (UMRR) was implemented to monitor the environmental status of the river and restore degraded habitat: The ecosystem of the Upper Mississippi River has been degraded by human activities such as construction of dams and land-use changes, despite the importance of the river as an ecological and economic resource. The Upper Mississippi River Restoration Program, initiated in 1986, tackles issues such as diminishing wetlands, disturbed fish migration, habitat loss, and deteriorating water quality. Wetland management to support migratory birds, island construction to prevent erosion and promote aquatic vegetation, and backwater flow management to improve fish overwintering conditions are important restoration measures. With its integration to ecological and

hydrological modeling, long-term resource monitoring, and stakeholder participation, adaptive management is essential. The efficacy of these strategies is shown by successful initiatives like the Lake Chautauqua Habitat Rehabilitation and Enhancement Project (HREP), which restored wetland habitats by improving water level management, reducing sedimentation, and enhancing conditions for migratory birds and aquatic life, and the Pool 8 Islands Restoration (Theiling et al.)

The Hypoxia Task Force (HTF), led by the U.S. Environmental Protection Agency (EPA), is a collaborative initiative aimed at reducing nutrient pollution in the Mississippi/ Atchafalaya River Basin (MARB) and mitigating the hypoxic zone in the Gulf of Mexico. The HTF brings together Federal Agencies, 12 States, and the tribal representatives to implement comprehensive nutrient reduction strategies, focusing on both point sources (e.g., wastewater treatment plants) and non-point sources (e.g., agricultural runoff). The U.S. EPA plays a central role by providing funding, technical assistance, and scientific expertise through programs like the Clean Water Act Section 319- Non point Source Pollution Program and the Gulf Hypoxia Program (GHP), which supports state-level efforts to scale up conservation practices and improve water quality. Similar to the HTF, other programs like the National Water Quality Initiative (NWQI) and the Mississippi River Basin Healthy Watersheds Initiative (MRBI), led by the U.S. Department of Agriculture (USDA), target agricultural runoff by promoting best management practices (BMPs) such as cover cropping, nutrient management, and wetland restoration. These initiatives emphasize adaptive management, stakeholder engagement, and long-term monitoring to ensure the effectiveness of conservation efforts. Together, these programs demonstrate a coordinated approach to addressing nutrient pollution, leveraging Federal, State, and local partnerships to protect water quality and restore ecological balance in the MARB and the Gulf of Mexico. (HTF, 2023; USDA, 2023)

The Lowermost Mississippi River Management Program (LMRMP) is a strategic initiative designed to enhance the sustainability, navigation, flood protection, and ecological health of the Lowermost Mississippi River (LMR). Led by the Louisiana Coastal Protection and Restoration Authority (CPRA), Water Institute of the Gulf, and Royal Engineers & Consultants, the program develops long-term (25-50 years) management strategies to address sediment and water management while considering future environmental conditions such as sea level rise and projected climate change. The primary goal of the program is to implement a holistic approach to water and sediment management that ensures the long-term sustainability

of the LMR, with key objectives including reducing coastal land loss, protecting ecosystems, mitigating flood risks, maintaining navigation channels, and integrating multi-stakeholder benefits. To achieve these objectives, the LMRMP focuses on several management strategies, including maintaining current sediment and flow management practices under a Future Without Action (FWOA) scenario, optimizing diversion operations to balance flood control and ecosystem benefits, and using dredged sediment for coastal restoration and barrier island stabilization. The program also explores alternative navigation channel alignments to optimize sediment flow, as well as adjustments to the Old River Control Structure (ORCS), a critical system of gates and diversion channels that regulates water distribution between the Mississippi and Atchafalaya Rivers, to improve sediment transport and reduce flood risks. Environmental scenarios considered include sea level rise projections, storm surge impacts, and changes in river flow and sediment transport under different climate and land-use conditions. The LMRMP involves collaboration with Federal, State, and local agencies, including the U.S. Army Corps of Engineers (USACE), Louisiana Department of Wildlife and Fisheries (LDWF), and various NGOs, with public engagement playing a key role in decision-making. By integrating flood control, navigation needs, and environmental restoration, the program aims to ensure long-term sustainability and resilience in the face of projected climate change and human impacts (LMRMP, 2022).

b. Key Stakeholders and Partnerships

The Mississippi River Basin involves a diverse array of stakeholders, each with distinct priorities and roles in addressing flood management, nutrient reduction, and sustainable water resource management. These stakeholders include Federal and State agencies, tribal representatives, local and regional groups, research institutions, NGOs, and the private sector. Their collaborative efforts are essential for achieving the ecological, economic, and social goals of the river basin. An integrated overview of the key stakeholders, their roles, and the partnerships that drive progress in the basin are presented below.

Federal Agencies

- U.S. Environmental Protection Agency (EPA): Leads the HTF and provides funding, technical assistance, and scientific expertise for nutrient reduction initiatives. Programs like the Clean Water Act Section 319 Nonpoint Source Program and the GHP support state-level conservation efforts.

- U.S. Department of Agriculture (USDA): Implements programs such as the NWQI and the MRBI to reduce agricultural runoff through BMPs. Financial incentives through programs like the Environmental Quality Incentives Program (EQIP) and Conservation Reserve Program (CRP) encourage farmers to adopt sustainable practices.
- National Oceanic and Atmospheric Administration (NOAA): Monitors the hypoxic zone in the Gulf of Mexico and performs research on nutrient pollution impacts. The Runoff Risk Advisory Forecasts of NOAA help farmers time fertilizer applications to minimize nutrient losses.
- U.S. Geological Survey (USGS): Conducts long-term monitoring and modeling of nutrient loads in the river basin, providing critical data for decision-making.
- U.S. Army Corps of Engineers (USACE): Manages river systems and infrastructure projects, including the Upper Mississippi River Restoration (UMRR) program, that focuses on habitat restoration and water quality improvement.
- Federal Emergency Management Agency (FEMA): Oversees the National Flood Insurance Program (NFIP), which provides affordable flood insurance to property owners in the participating communities. FEMA also coordinates disaster response and recovery efforts, encouraging floodplain management through regulations and incentives.

State Agencies and Tribal Representatives

- The Departments of Agriculture and Environment from the 12 HTF Member States develop and implement state-specific nutrient reduction strategies. Programs like the Nutrient Reduction Exchange in Iowa foster partnerships between municipalities and farmers to reduce nutrient loads. State agencies also play a key role in floodplain management and enforcing NFIP regulations.
- Louisiana Department of Wildlife and Fisheries (LDWF): Collaborates on ecosystem restoration and wildlife conservation efforts within the LMRMP framework.
- The National Tribal Water Council ensures that tribal perspectives and priorities are integrated into nutrient reduction and flood management efforts, fostering collaboration with Federal Agencies such as the USEPA and FEMA.

Local and Regional Stakeholders

Farmers, agricultural associations, conservation organizations, Universities, and local watershed groups collaborate on research, outreach, and implementation of conservation practices. For example, the Iowa Nutrient Research Center at the Iowa State University works

with Federal Agencies to advance nutrient reduction science. Local governments and levee districts also play a critical role in implementing the NFIP regulations and maintaining flood resilience infrastructure.

Private Sector

Industries and agricultural businesses balance economic growth with sustainability, often partnering with NGOs and government agencies to adopt environmentally friendly practices. The private sector also engages in flood risk reduction through participation in the NFIP and support for sustainable land-use practices.

NGOs and Conservation Groups

NGOs advocate conservation and sustainable management of resources as well as community engagement in the Mississippi River Basin. They work with Federal and State agencies to promote policies that prioritize environmental protection and flood resilience. During floods, NGOs are often among the first responders, providing disaster relief and supporting recovery efforts.

Research Institutions

- Universities and research institutions partner with Federal and State Agencies to conduct studies, develop innovative conservation practices, and provide technical support for watershed planning. Their work informs policy decisions and helps advance integrated water resource management.
- The Water Institute of the Gulf: Plays a central role in the LMRMP, conducting research on sediment transport, coastal restoration, and climate change impacts.

Key Partnerships

- EPA and State Agencies: The EPA provides funding and technical support to the States for scaling up conservation practices. For instance, the Nutrient Reduction Exchange program in Iowa, supported by the USEPA, encourages partnerships between municipalities and farmers to reduce nutrient loads.
- NOAA and State Agencies: The Runoff Risk Advisory Forecasts of the NOAA help farmers in States like Ohio and Wisconsin time fertilizer applications to minimize nutrient losses, demonstrating the integration of federal science with local agricultural practices.

- **USACE and State/ Local Stakeholders:** The UMRR program involves collaboration with State agencies, local stakeholders, and conservation groups to restore habitats and improve water quality. Projects like the Lake Chautauqua HREP highlight the effectiveness of these partnerships.
- **FEMA and Local Communities:** Through the NFIP, FEMA works with local governments to enforce floodplain management regulations, providing flood insurance to residents while encouraging risk reduction measures like floodplain buyouts and building height.
- **Multi-State Collaborations:** Sub-basin committees like the Upper Mississippi River Basin Association (UMRBA) and the Ohio River Valley Water Sanitation Commission (ORSANCO) facilitate regional coordination among states, ensuring that nutrient reduction and flood management efforts are aligned across State lines.
- **LMRMP Collaborations:** The Lowermost Mississippi River Management Program involves partnerships between the CPRA, USACE, LDWF, the Water Institute of the Gulf, Royal Engineers & Consultants, and environmental NGOs. These collaborations focus on optimizing sediment and water management, coastal restoration, and flood protection in the face of projected climate change and sea level rise.
- **Universities and Research Institutions:** These institutions partner with Federal and State agencies to conduct studies, develop innovative conservation practices, and provide technical support for watershed planning.

III. Outcomes and Impact

a. Environmental Benefits

National Flood Insurance Program (NFIP): By enforcing floodplain management regulations, the NFIP has minimized development in high-risk areas, reducing the frequency and severity of flood damage (FEMA, 2023). Non-structural measures like floodplain buyouts and height of structures have helped restore natural floodplains, improving water retention and biodiversity (Brody et al., 2018).

Upper Mississippi River Restoration (UMRR): Restoration projects have significantly reduced sediment and nutrient loads, enhancing water quality and aquatic habitats (Theiling et al., 2020). Initiatives like the Lake Chautauqua Habitat Rehabilitation and Enhancement Project (HREP) have successfully restored wetlands and fish habitats, supporting migratory birds and aquatic species (UMRR, 2021).

Hypoxia Task Force (HTF): The efforts of the HTF have led to a measurable decrease in

nitrogen and phosphorus levels in the Mississippi River Basin, contributing to the reduction of the hypoxic zone (EPA, 2023) in the Gulf of Mexico. Improved water quality has supported the recovery of fish population and other aquatic life, enhancing overall ecosystem health (Rabotyagov et al., 2014).

Lowermost Mississippi River Management Program (LMRMP): The use of dredged sediment for coastal restoration has mitigated land loss and stabilized barrier islands, protecting inland areas from storm surges (LMRMP, 2022). Optimizing sediment flow has enhanced deltaic ecosystems, supporting plant and animal species dependent on these habitats (CPRA, 2023).

b. Social Benefits

National Flood Insurance Program (NFIP): Access to affordable flood insurance has empowered communities to recover more quickly from flood events, reducing long-term displacement and social disruption (Kousky, 2018). Educational initiatives have raised public awareness about flood risks and preparedness, fostering a culture of safety and resilience (FEMA, 2023).

Upper Mississippi River Restoration (UMRR): Restored habitats have boosted recreational activities like fishing and birdwatching, improving community well-being and engagement (Theiling et al., 2020). Active participation of local communities in restoration projects has strengthened social cohesion and environmental stewardship (UMRR, 2021).

Hypoxia Task Force (HTF): Reduced nutrient pollution has led to cleaner drinking water sources, benefiting public health and reducing healthcare costs (EPA, 2023). Collaborative efforts have fostered stronger relationships between Federal, State, and local stakeholders, enhancing collective action and trust (Rabotyagov et al., 2014).

Lowermost Mississippi River Management Program (LMRMP): Improved flood control measures have safeguarded communities, reducing the risk of property damage and loss of life (LMRMP, 2022). Restoration projects have protected culturally significant landscapes, preserving heritage and community identity (CPRA, 2023).

c. Economic Benefits

National Flood Insurance Program (NFIP): By reducing flood damage, the NFIP has saved billions of dollars in potential recovery costs, benefiting both individuals and the economy (Kousky, 2018). Insurance Premium Reductions: Communities that adopt stringent floodplain management practices often qualify for lower insurance premiums, providing financial relief

to residents (FEMA, 2023).

Upper Mississippi River Restoration (UMRR): Enhanced ecosystems have boosted tourism and recreational industries, generating revenue and creating jobs (Theiling et al., 2020). Restored fish habitats have supported commercial and recreational fishing, contributing to local economies (UMRR, 2021).

Hypoxia Task Force (HTF): BMPs have improved agricultural productivity and sustainability, benefiting farmers and the broader economy (EPA, 2023). Conservation projects have created employment opportunities in sectors like construction, environmental monitoring, and research (Rabotyagov et al., 2014).

Lowermost Mississippi River Management Program (LMRMP): Optimized navigation channels have reduced shipping costs and improved trade efficiency, boosting economic activity (LMRMP, 2022). Effective flood control measures have reduced the need for costly infrastructure repairs, saving public funds (CPRA, 2023).

IV. Lessons Learned and Recommendations

a. Key Takeaways from the Project

- **Integrated Approach:** Successful flood and ecosystem management require a holistic approach that balances environmental, social, and economic objectives (FEMA, 2023; UMRR, 2021).
- **Stakeholder Engagement:** Active involvement of local communities and stakeholders is crucial for the success and sustainability of restoration projects (EPA, 2023; LMRMP, 2022).
- **Adaptive Management:** Continuous monitoring and adaptive management strategies are essential to respond to changing environmental conditions and project outcomes (Theiling et al., 2020; CPRA, 2023).

b. Best Practices and Strategies for Replication

- **Community-Based Planning:** Engage local communities in the planning and implementation of flood and ecosystem management projects to ensure relevance and support (Kousky, 2018; UMRR, 2021).
- **Public-Private Partnerships:** Leverage partnerships between Government agencies, private sector, and NGOs to pool resources and expertise (EPA, 2023; LMRMP, 2022).
- **Data-Driven Decision Making:** Utilize scientific research and data analytics to inform decision-making and optimize project outcomes (Theiling et al., 2020; CPRA, 2023).

c. Areas for Further Improvement or Research

- Climate Change Adaptation: Develop strategies to enhance the resilience of flood and ecosystem management projects to climate change impacts (FEMA, 2023; LMRMP, 2022).
- Economic Valuation: Conduct comprehensive economic assessments to quantify the benefits of ecosystem services and inform policy decisions (Kousky, 2018; EPA, 2023).
- Technological Innovation: Invest in new technologies for monitoring, modeling, and managing flood risks and ecosystem health (Theiling et al., 2020; CPRA, 2023).

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Conclusions

The comprehensive review of international river basins—ranging from the Thames and Rhine in Europe to the Murray–Darling in Australia—reveals that achieving sustainable river management is a multifaceted challenge that demands long-term commitment, adaptive management, and robust stakeholder collaboration. Across these case studies, improved water quality, restored floodplain connectivity, and the reintroduction of migratory species demonstrate that integrated, basin-scale management can reverse decades of environmental degradation. However, the process is complex and context specific, requiring continuous monitoring, technological innovation, and policy adjustments to address emerging issues such as climate change and diffuse pollution.

Summary and Major Takeaways

- Integrated river basin management, based on a shared, science-driven framework, is key to restoring and preserving river ecosystems.
- Long-term, adaptive strategies that combine pollution control, habitat restoration, and flood risk management have yielded significant environmental, social, and economic benefits.
- Success hinges on robust intergovernmental and cross-border cooperation, as seen in the Rhine and Murray–Darling basins, where coordinated actions have led to improved water quality and ecological continuity.

Best Practices, across basins

- **Holistic Planning:** Establish basin-wide management plans (e.g., Thames Basin Management Plan, Rhine 2020) that integrate water quality, flood management, and ecological restoration.
- **Regular Monitoring:** Implement continuous water quality, biodiversity, and hydrological monitoring systems to guide adaptive management (e.g., ICPR’s

monitoring of the Rhine).

- **Stakeholder Engagement:** Involve local communities, Indigenous groups, industry, and governmental agencies in planning and decision-making processes.
- **Infrastructure Upgrades:** Invest in advanced wastewater treatment, sediment management, and fish passage systems to restore river health.
- **International and Cross-Sector Collaboration:** Foster cooperation between countries and across sectors to share data, best practices, and technological innovations.

Comparison of major issues across basins

- **Pollution:** European rivers such as the Rhine suffered from severe industrial and municipal discharges, whereas in Australia's Murray–Darling Basin, over-allocation and diffuse agricultural runoff are predominant concerns.
- **Flood Management:** All basins face flood risk; however, the Thames and Rhine needed to overcome historical fragmentation in governance, while the Murray–Darling Basin struggles with water scarcity exacerbated by extreme droughts.
- **Biodiversity Loss:** The Rhine experienced near-extinctions of migratory fish and other sensitive species due to pollution, while the Murray–Darling Basin has seen significant declines in native fish and wetland-dependent species as a result of over-extraction and climate impacts.
- **Climate Change:** Each basin is affected differently—European rivers are adapting to increased flood risks and altered seasonal flows, while the Murray–Darling is increasingly threatened by prolonged drought and rising salinity.

Adopted approaches to overcome the major issues across basins

- **Integrated Policy Frameworks:** Enact comprehensive legislation (e.g., the Dam Safety Act in India; the Water Act 2007 in Australia) to consolidate responsibilities and improve regulation.
- **Restoration Programs:** Implement large-scale restoration initiatives (e.g., Rhine Action Program, Thames restoration) that focus on reactivating floodplains, reconnecting oxbow lakes, and upgrading riverbank structures.

- **Water Reallocation and Trading:** Introduce water trading and buyback schemes to redistribute water more equitably and sustainably (as seen in the Murray–Darling Basin’s water recovery programmes).
- **Technological Innovations:** Use advanced hydrological modeling and real-time monitoring systems to forecast extreme events and guide adaptive management.
- **Community-Centric Interventions:** Empower local and Indigenous communities through participatory governance and culturally sensitive management practices.

Policy learnings

- **Emphasize Adaptive Governance:** Policies must remain flexible to accommodate climate variability, technological advances, and evolving socio-economic conditions.
- **Foster Cross-Border and Inter-State Cooperation:** Successful river management requires collaboration across political boundaries, ensuring that shared water resources are managed in the collective interest.
- **Integrate Ecological and Social Objectives:** Effective policies should balance environmental restoration with social and economic development, recognizing the cultural and livelihood importance of rivers.
- **Prioritize Sustainable Investment:** Long-term financial commitments and investments in water infrastructure are essential for maintaining and improving river health.
- **Institutional Accountability and Transparency:** Clear mandates, robust monitoring, and regular reporting are vital to build trust among stakeholders and ensure the successful implementation of river basin management initiatives.