Food and Agriculture Organization of the United Nations

Charles Sturt University
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Agriculture Water Environment

BRIEF 5

Modernizing irrigation for fisheries biodiversity and ecosystem services

Next Generation Water Management Policy Briefs

Cover photo:
October 2017, Panjarbhanga, Bangladesh - A fisherman fishes in the river Tista.
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Modernizing irrigation for fisheries biodiversity and ecosystem services

Next Generation Water Management Policy Briefs

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Next Generation Water Management
BRIEF 5

1. Introduction

The escalating trajectory of population growth in the Asia-Pacific region is exerting substantial pressure on the demand for food. The Asia-Pacific region is home to approximately 60 percent of the global population, with the figure projected to rise even further. This increase in population, coupled with improving living standards and a growing middle class, is resulting in a substantial increase in overall food demand. Moreover, there is a discernible shift towards diets that are higher in quality and diversity, characterized by a higher consumption of animal proteins, fruits and vegetables. Consequently, the region's agricultural and fisheries sectors face the challenging task of enhancing production in a sustainable manner, while ensuring the stability of ecosystems and biodiversity. Significantly, sustainable and productive fisheries are particularly important as fish serve as a vital dietary component in the Asia-Pacific region primarily owing to their abundant availability, nutritional value and cultural significance as a staple in traditional food practices.

The Mekong River is a vibrant ecosystem, hosting an estimated 600 to 850 freshwater fish species, making the Mekong River second only to the Amazon and potentially the Congo River basin in terms of the world's richest fish species diversity (Baird and Hogan, 2023; Valbo-Jørgensen *et al.*, 2009; Hortle, 2009). Approximately 8 percent of the global inland fisheries catch comes from the Lower Mekong Basin (Funge-Smith, 2018). Within the four countries constituting the Lower Mekong Basin – Cambodia, Lao People's Democratic Republic, Thailand and Viet Nam – freshwater fish and other aquatic organisms comprise a substantial 47 to 80 percent of animal protein intake (Hortle, 2007).

The Mekong River Basin is home to approximately 60 million people who rely on the river for agriculture and sustenance. The river serves not only as a crucial source of food security for local communities, but also plays a fundamental role in various non-agricultural activities, such as transportation, hydropower generation, and provision of essential ecosystem services, underscoring its multifaceted significance. As a result, the Mekong River Basin has seen substantial infrastructure development over the past 40 years. This includes the construction of dams for hydropower, the expansion of irrigation systems to enhance agricultural yield, and the building of roads and bridges to improve transport routes. While these developments are aimed at boosting economic growth and improving living standards, they simultaneously present challenges. For example, irrigation infrastructure, intended to bolster food security, paradoxically obstructs fish movements, creating fish barriers. This is particularly problematic for food security in the Mekong Basin as the majority of fish (e.g. 86 percent in the Lao People's Democratic Republic) are migratory, undertaking long upstream and downstream journeys as part of their reproductive life cycle. Such barriers adversely affect the quantity and size of fish available for capture, leading to subsequent impacts on the fisheries industry's productivity and, in turn, food security.

Box 1: Definition of Fish Barrier

A fish barrier is a physical obstruction in a watercourse that hinders the free movement of fish. Fish barriers are typically anthropogenic, meaning they are man-made, and often come in the form of dams, weirs, culverts, sluices, or other types of water control structures. These barriers can prevent fish from accessing habitats for spawning, feeding and refuge, which are crucial for different stages of their life cycles.

Fish barriers can lead to population declines by blocking migratory routes, fragmenting populations, and changing the physical characteristics of rivers, including flow rates and water quality. They can also isolate fish from their spawning grounds, leading to decreased reproduction rates.

However, it's important to note that not all barriers are complete obstructions to all species and sizes of fish. The degree of obstruction can vary depending on the design of the barrier, the species and size of fish, and the flow conditions.

2. The impacts of river basin infrastructure development

Recent studies have shown an alarming decline in fish populations in the Mekong Basin, with one study finding an alarming 87.7 percent drop within the Mekong's Tonle Sap Basin over the last 17 years (Chevalier *et al.*, 2023). Overexploitation, habitat fragmentation, and alterations in water flow induced by large infrastructures are commonly ascribed as the catalysts for such declines. However, the cumulative risks created by smaller structures – diversion weirs, sluices, locks, flood control structures and bridges, which cumulatively obstruct migratory routes and access to wetlands and tributaries – often escape scrutiny. It is important to understand that much like large- scale infrastructure, small-scale infrastructure also modifies the natural water flow and depth of the river.

Fishermen ply their trade at sunset in southern Lao People's Democratic Republic on one of the many tributaries of the mighty Mekong River.

Box 2: Types of river basin infrastructure/fish barriers

Large-scale infrastructure

Dams: Dams are large structures designed to impound rivers, creating a reservoir behind them. They are often constructed for multiple purposes, including water supply, irrigation, flood control, and the generation of hydroelectric power. Dams significantly alter the natural flow and sediment transport of rivers.

Hydroelectric plants: These facilities harness the potential energy of flowing or falling water to generate electricity. While many are associated with large dams, there are also run-of-the-river hydroelectric facilities that divert a portion of a river's flow.

Levees: Levees are large embankments constructed along rivers to prevent inundation during high-flow events. While protective, they alter the river's natural flood dynamics and disconnect the river from its floodplain.

Canal systems: Canal systems are man-made channels designed to convey water for various purposes, including irrigation, navigation, water supply, or drainage. These systems can divert significant volumes of water from rivers, altering the natural flow.

Tidal barrages: Tidal barrages are dams constructed across the mouth of a tidal estuary, designed to generate electricity from the kinetic energy of tides. They alter the estuary's natural tidal flow patterns.

Small-scale infrastructure

Diversion weirs: Diversion weirs are low-head dams constructed across a river to elevate the water level upstream, enabling the diversion of flow for various purposes. They can alter river hydrodynamics and sediment transport, and potentially impede the movement of aquatic organisms.

Sluices: Sluices are adjustable gates or valves designed to control the flow of water in canals, rivers, reservoirs or other water bodies. Their operation can alter natural flow regimes and impact aquatic habitats.

Locks: Locks are devices incorporated into navigable waterways that function to raise and lower boats between stretches of water at different levels. Their operation can impact river hydrodynamics and aquatic ecosystems.

Flood control structures: These include a variety of smaller infrastructure designed to control or prevent flooding, such as storm surge barriers and floodgates. These structures alter natural flow and flood regimes.

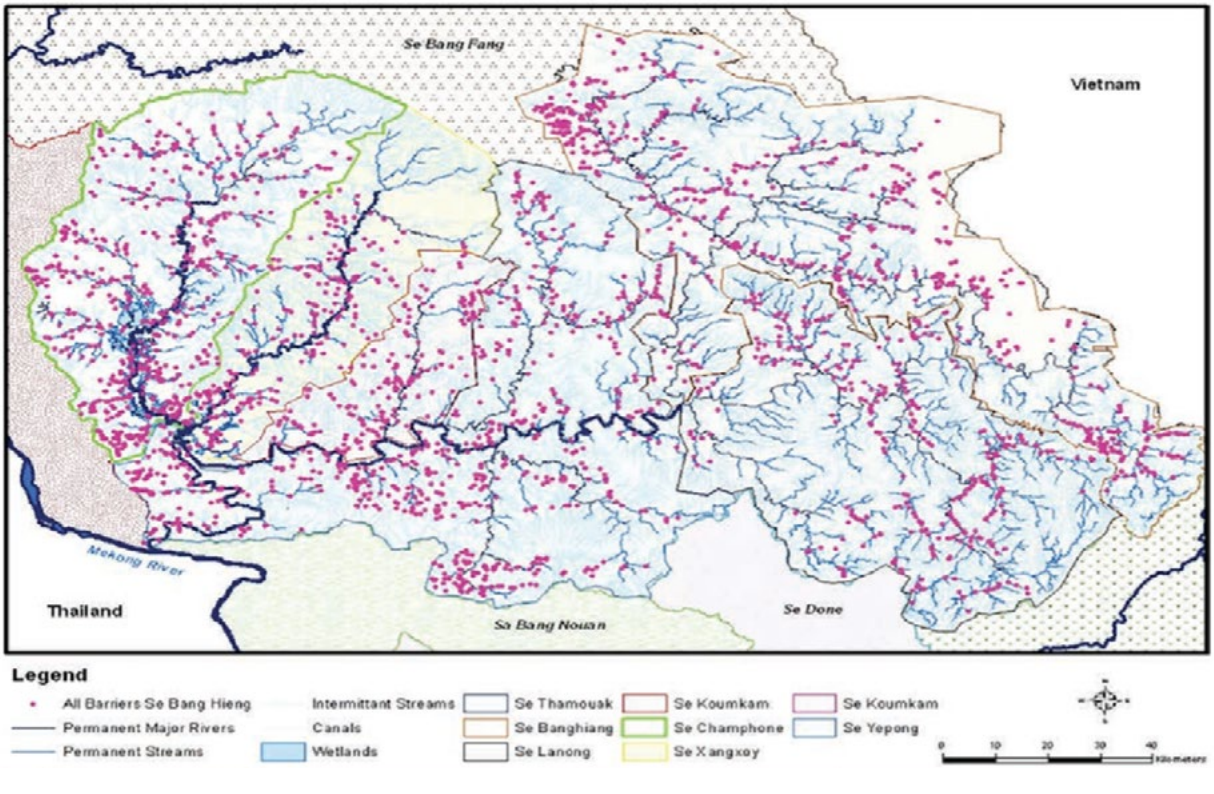
Bridges: Bridges are structures built to span physical obstacles, such as rivers or valleys. While their primary purpose is to facilitate transportation, the construction, operation, and even the shadow the river may cast, can impact ecosystems and biodiversity and disrupt fish behaviour.

Over the past 40 years, the magnitude of river infrastructure development in the Lower Mekong Basin countries has already impeded fish movements, posing a significant threat to the future of the fisheries industry. If the issue remains unaddressed, the projected risks entail:

- formation of an accumulation zone heightening fish vulnerability to overfishing, disease and injury during the early to middle wet season;
- delays in fish locating their spawning habitat, potentially undermining annual reproduction;
- delays in juvenile fish locating feeding habitats, which could curtail fisheries production; and
- escalated fish mortality due to capture in operating valves, exposure to harmful chemicals, and other detrimental agricultural practices.

The extent of the problem can be further illustrated by the volume of river basin infrastructure (fish barriers) in the Xe Bang Fai Catchment in the Lao People's Democratic Republic (Figure 1).

Figure 1: Mapping of fish barriers in the Xe Bang Catchment in the Lao People's Democratic Republic



Source: Baumgartner, L. *et al.* 2016. *Development of Fish Passage Technology to Increase Fisheries Production on Floodplains in the Lower Mekong Basin.* Australian Centre for International Agricultural Research. Canberra, Australia.

3. Prioritizing fish migration and fish passage in irrigation infrastructure

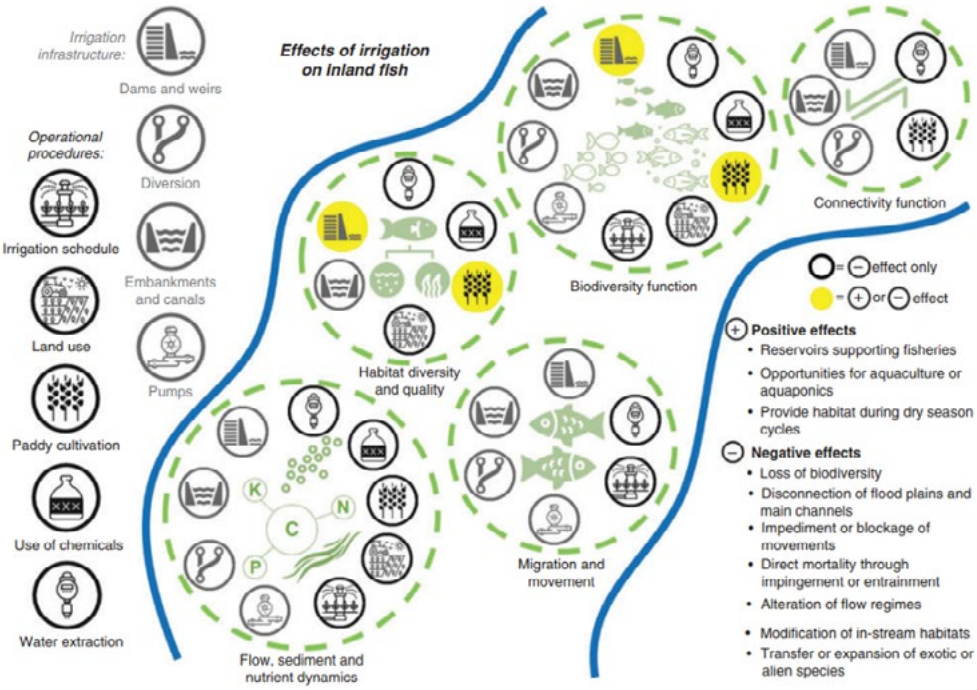
In the Lower Mekong Basin, irrigation systems often encompass a vast network of canals, ditches, pipes, pumps and gates, which disrupt the connectivity of aquatic habitats. These systems have significantly modified the natural waterways, creating physical barriers that impede fish migration and access to essential habitats.

However, over the past 20 years, irrigation intensification in the Lower Mekong Region has slowly reached a plateau, with no significant expansion in surface-water irrigated areas since the early 2000s (FAO, 2020). This is due to the shifted focus in irrigation investment from expansion to the modernization of aging infrastructure. While irrigation modernization presents an opportunity to consider solutions to increase river connectivity to support biodiversity, ecosystem services and productive fisheries, current efforts seldom take into account the positive externalities that the refurbishment and modernization of irrigation infrastructure could deliver. This is vastly due to the siloed nature of irrigation modernization.

Typically, irrigation modernization efforts lack coordination or consultation among the stakeholders that have mandates regarding water resources (Baumgartner *et al.*, 2023). Without coordination, irrigation modernization lacks understanding of the unique biodiversity and ecosystem needs of the environment in which the infrastructure is installed. For fisheries this is particularly harmful, since without the full understanding of the complex nature of fish behaviour and the impacts of infrastructure on fish behaviour, unintended negative consequences to ecosystems, biodiversity and food security are guaranteed (See Figure 2). The knowledge required to adequately address the negative consequences of infrastructure on fish habitats includes a broad spectrum of variables, including: flow, sediment, and nutrient dynamics; spatial and temporal aspects of migration and movement; habitat diversity and quality; biodiversity; and connectivity functions - encompassing not only channel but also lateral flow to floodplain wetlands (Lynch *et al.*, 2019). However, expertise in these areas is often disseminated across various disciplines and sectors.

Without intersectoral coordination, plans to modernize irrigation infrastructure overlook the importance of nurturing productive fisheries as a key pillar of food security and nutrition for dependent communities. In the absence of intersectoral coordination and cross-disciplinary knowledge, irrigation modernization falls short of adequately addressing unintended outcomes. In the case of the resulting poor environmental planning, policymakers are often limited to devising reactive ad hoc policies to address environmental sustainability and food security well after the damage has been done.

Figure 2: Impact of river infrastructure on inland fisheries



Source: Lynch, A. *et al.* 2019. *Speaking the Same Language: Can the Sustainable Development Goals Translate the Needs of Inland Fisheries into Irrigation Decisions?* Marine and Freshwater Research, 70 (9), 1211–1228. https://www.publish.csiro.au/mf/pdf/MF19176.

4. Engineering solutions for river connectivity

Engineering solutions, such as fish ladders or fishways, are gaining recognition as effective tools for restoring river connectivity, facilitating fish migration and, consequently, enhancing the health and productivity of fisheries. These structures serve as a lifeline for fish populations, providing them with an avenue to traverse barriers and reach critical habitats for spawning, maturing and feeding, thereby ensuring the restoration of the river's natural ecosystem dynamics.

Box 3: Definition of fish ladders/fishways

Fish ladders or fishways are man-made structures added to dams and other water control structures to help fish bypass these barriers and continue their natural migration patterns. The ladders offer a stepped waterway that allows fish to swim and leap through a series of relatively low steps in the path of the river flow. The design of these structures takes into consideration the swimming capabilities of the species intended to use them, creating a gradient that is passable for the fish.

The growing recognition of fish ladders as a restorative solution has gained traction in Southeast Asia, particularly in the Lower Mekong Basin. Concrete case studies have shown the positive outcomes of integrating fish life cycle considerations into irrigation infrastructure to restore fish passage and promote productive fisheries. For example, in the Lao People's Democratic Republic, a programme funded by the Australian Centre for International Agricultural Research (ACIAR), implemented by Charles Sturt University has proven the effectiveness of fish ladders. The programme "Quantifying biophysical and community impacts of improved fish passage in the Lao People's Democratic Republic PDR and Myanmar" showcased that fish ladders allow fish to traverse both upstream and downstream of water control structures that are less than 6 metres in height, leading to an increase in fisheries production (Barlow, 2017). Following this example, Charles Sturt University (CSU) has been working with Fisheries Administration (FA) of the Ministry of Agriculture, Forestry and Fisheries of Cambodia to retrofit a fishway for the Stung Pursat Barrage in Cambodia to promote fish passage.

Box 4: Fishway design for the Stung Pursat Barrage Fishway

The Stung Pursat Barrage, an infrastructure development near Cambodia's Tonle Sap, was originally constructed as part of an extensive water management project for irrigation purposes and flood control, and to provide a consistent water supply for agricultural, industrial and residential uses. The structure, however, has posed a significant obstacle to the local fish species' migratory patterns, thus affecting local fisheries and biodiversity in the Tonle Sap, the largest freshwater lake in Southeast Asia.

Local fish species, including the critically important mud carp (Henicorhynchus lobatus and H. siamensis), largely depend on seasonal migrations between the Tonle Sap and the Mekong River. The barrier created by the Stung Pursat Barrage hindered these migrations, leading to significant declines in fish populations. The barrage also altered the local aquatic ecosystem, threatening biodiversity. Recognizing these issues, local authorities, together with Charles Sturt University, have pursued the design of a fishway to facilitate fish migration.

Considering the range of species and sizes of fish present in the region, the chosen design was a vertical slot fishway. This fishway type accommodates a wide variety of fish sizes and swimming abilities and consists of a series of pools, separated by vertical slots that allow fish to ascend the barrier, providing resting spots and variable flow conditions. The design and construction were tailored to mimic the water velocity, depth and turbulence conditions necessary for different fish species to navigate the passage successfully.

Fish Pass at Damnak Chheukron irrigation system on the Pursat River in Cambodia. The site was completed as part of an Asia Development Bank irrigation infrastructure project.

Once completed, the implementation of the vertical slot fishway at the Stung Pursat Barrage is expected to enable the populations of various species to stabilize. The fishway will play a crucial role in maintaining biodiversity in the Tonle Sap region and positively impact local fisheries.

Increasingly, legal frameworks and development plans in many countries within the Mekong Region and beyond express support for incorporating considerations for fish migration and passage into irrigation infrastructure planning. For example, Indonesia recently introduced fisheries considerations in its National Irrigation Guidelines, making way for a new era of incorporating biodiversity considerations in irrigation investment and design. However, a formidable challenge remains in actualizing these policies. To transition from policy to practice, there is a pressing need for increasing capacity building, coordinated efforts and active engagement from both irrigation and water resources management sectors in championing fish passage solutions.

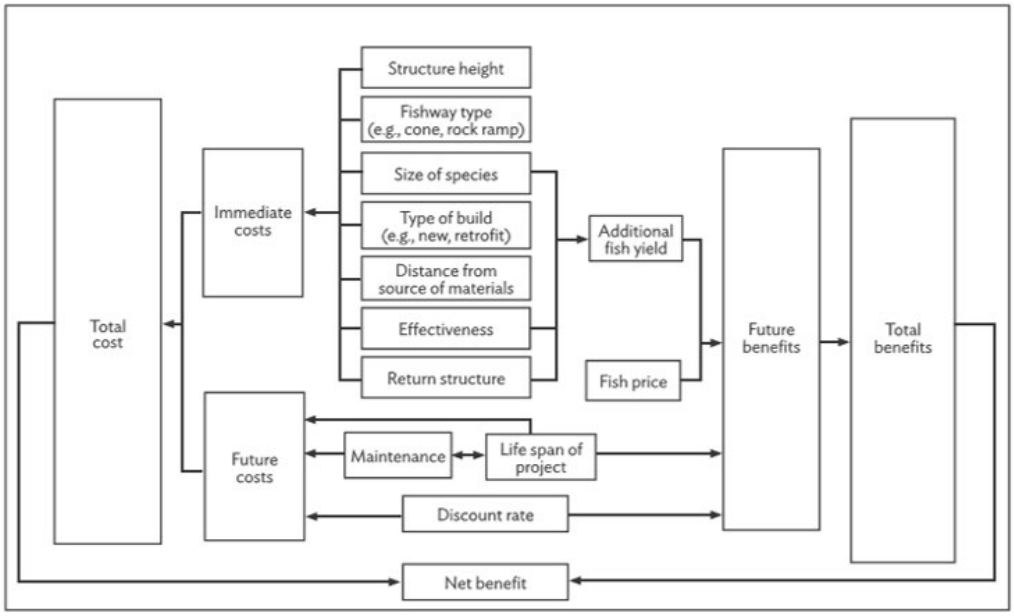
5. Recommendations and conclusions

The protection and restoration of fish passages offer numerous advantages, including the preservation of biodiversity, the fortification of climate resilience, and the enhancement of food security and household economies. While it is encouraging to see the governments of the Lower Mekong Basin, in collaboration with international donors, commencing explorations into research requirements and building capacity within the irrigation and fisheries sectors to evaluate and mitigate the potential impacts of existing fish barriers, present investments still fall short of the magnitude of the problem and its resolution.

The ongoing efforts towards achieving irrigation modernization that considers biodiversity and ecosystem services need to be reinforced by robust agendas and intersectoral collaboration that support policies that perceive irrigation infrastructure as an asset to bolster food security through both crop production and fisheries. On a broader level, this integration requires policies that emphasize the fundamental tenets of productive fisheries, the designing of suitable fish passages in infrastructure development, the identification of budgetary gaps, and an increase in context-specific applied policy research.

Additionally, policy formulation and execution will require capacity-building efforts backed by robust scientific data collection. A starting point for national governments is to map out existing barriers and gather evidence of fishery declines within a catchment area (including the affected locations and communities) in order to prioritize barriers where the creation or retrofitting of fishways would generate the most significant positive impact. In contexts where resources are limited, a cost–benefit analysis for each identified fishway would be critical, wherein different options can be weighed and evaluated for optimal benefit versus cost, as depicted in Figure 3.

Figure 3: Various parameters influencing the cost–benefit analysis of a fishway project



Source: Cooper, B., Crase, L. & Baumgartner, L. J. 2019. *Estimating Benefits and Costs: A Case of Fish Passages in the Lao People's Democratic Republic PDR and the Development of the Lower Mekong Fishway Support Tool*. Marine and Freshwater Research, 70 (9), 1284–1294. https://www.publish.csiro.au/mf/MF19156.

The overarching strategy for improved and more productive fisheries is adaptive management. This approach understands that generating knowledge is crucial to building institutional capacity, improving governance, and refining policy and practice. Such a strategy would enable research to guide the development agenda, hence leading to informed development decisions.

Awareness has already gained momentum in the Lower Mekong Basin but needs to extend to the other countries with extensive river systems and associated dependence on fisheries resources. It is critical for international donors to stipulate lending terms that make fishways a conditional requirement for investments in irrigation projects.

Box 5: Key considerations for project development

Country context and stakeholders. Every country and river catchment is unique, and the local context must be understood and key stakeholders identified, involved and empowered. A design in one region (e.g. United States of America) will not necessarily transfer to another (e.g. Southeast Asia) due to large differences in fish species, institutionalized capacity and available materials, among other factors.

Water sector partnerships. It is essential to collaborate with key water sector stakeholders. For example, if a dam or weir is owned by the irrigation department, then it should be a priority to understand and involve the department as a key partner in the development of a fishway.

Research and capacity development. For widescale implementation and institutionalization of fish passage, sound research is needed within the local context to design and build appropriate fishways. In addition, it is important to strengthen in-country capacity on technical aspects and increase investments in creating supporting policy, legislation, and governance structures for fish passage.

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The Next Generation Water Management Policy Brief Collection

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