



Food and Agriculture
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United Nations



International Water
Management Institute



WorldFish

**Increasing the benefits and
sustainability of irrigation through
the integration of fisheries**

**A GUIDE FOR WATER
PLANNERS, MANAGERS
AND ENGINEERS**



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A fisherwoman in an irrigation channel in the Ayeyarwady Delta, Myanmar.

Contents

Acknowledgments	vi
Abbreviations and acronyms	vii
Introduction: why should this guide be useful to you?	1

Part I

Understanding the impacts of irrigation systems on fisheries and some potential opportunities



1. Key characteristics of fisheries and irrigation systems	8
1.1 Fisheries	8
1.2 Irrigation systems	9
2. Mechanisms of impacts of irrigation on fisheries	11
2.1 Irrigation infrastructure and management	11
2.2 Role of fisheries in rural livelihoods	16
2.3 Governance of water and fisheries	16
3. Trends and opportunities in fisheries and irrigation	20
3.1 Fisheries: Trends and opportunities	20
3.2 Irrigation: Trends and opportunities	20
3.3 Opportunities for fisheries in irrigation	21

Part II

Integrating fisheries into irrigation systems



Step 1 – Understanding the context and engaging with stakeholders	26
1. Understanding the context	26
1.1 The irrigation system	26
1.2 Biophysical context	27
1.3 Socioeconomic and livelihoods context	28
1.4 Governance context	30
1.4.1 Local institutional arrangements	30

1.4.2	National legislation for fisheries, water resources, irrigation and the environment (constitutional rules)	31
1.4.3	Coordination between institutions, local partnerships and co-management	31
2.	Engaging with stakeholders.	32
2.1	Stakeholder identification, mapping and analysis.	32
2.2	Mechanisms for stakeholder engagement	33
2.3	Potential conflicts raised by irrigation systems.	34
2.3.1	Typology of conflicts.	34
2.3.2	Conflict resolution: from conflict to consensus?	35
	Step 2 – Assessing the key impacts and opportunities.	38
1.	Objectives and benefits of irrigation and fisheries	38
2.	Prioritizing impacts and opportunities through risk assessment	38
3.	Assessing the priority consequences	39
3.1	Biophysical impacts	40
3.2	Impacts on fisheries production and livelihoods	40
	Step 3 - Screening and scoping preliminary measures.	41
1.	Screening the potential options	41
1.1.	Mitigation	41
1.2.	Enhancement or improvements	41
2.	Scoping and selecting preliminary measures	44
	Step 4 – Evaluating the trade-offs and selecting the best measures	46
1.	Identifying the trade-offs	46
2.	Evaluating the trade-offs.	47
	Step 5 – Committing to implementation.	49
1.	Formalizing the agreement	49
2.	Committing to the implementation of measures.	49
	Step 6 – Monitoring and adapting.	50
1.	Monitoring and evaluation.	50
2.	Managing adaptively	50
	Concluding remarks	52
	References	53
	Glossary	57
Annexes		
Annex 1	Physical components of irrigation, flood control and drainage schemes	59
Annex 2	Governance of natural resource use and possible impacts of irrigation development	60
Annex 3	Prioritizing issues associated with risks	62
Annex 4	Typology of issues: Risks and opportunities-consequences-WCI options-operational and management options	63
Annex 5	Practical scenarios	72

Figures, tables, boxes and toolboxes

Figures

Figure 1.	Inland fisheries production in three regions: comparative percentages of global production . . .	3
Figure 2.	Irrigated area in three regions: comparative percentages of the global irrigated area	4
Figure 3.	Continuum from natural capture fisheries to aquaculture.	8
Figure 4.	Layout of a typical irrigation and drainage system	12
Figure 5.	Seasonal movements of fish in irrigation systems	13
Figure 6.	Integrated and participatory process for integrating fisheries into irrigation systems.	25
Figure 7.	A range of measures to enhance fisheries in irrigation systems	42

Tables

Table 1.	Livelihood functions of fishing.	10
Table 2.	Potential negative (-) and positive (+) impacts of irrigation on capture fisheries	14
Table 3.	Key local institutional arrangements for irrigation and fisheries	18
Table 4.	Typical trade-offs between water requirements for irrigation and fisheries	46

Boxes

Box 1.	Common components of irrigation systems	11
Box 2.	Reduced connectivity in Bangladesh floodplains	13
Box 3.	An example of an irrigation scheme and water resources mapping: Kirindi Oya, Sri Lanka	28
Box 4.	Outline of a socioeconomic profile	29
Box 5.	Examples of policy and legislative reforms, and harmonization of integrated water resources management for fisheries and irrigated agriculture	31
Box 6.	Successful examples of fisheries co-management	32
Box 7.	Typical scenarios of conflict	36
Box 8.	An example of conflict resolution	36
Box 9.	Cost of measures and technical requirements	44
Box 10.	Multi-criteria optimization in the Tana River	48

Toolboxes

Toolbox 1.	Characterizing the key features of irrigation systems	26
Toolbox 2.	Identifying, characterizing and mapping aquatic habitats.	27
Toolbox 3.	A framework for analysis of rural livelihoods	29
Toolbox 4.	Matrix showing the interest and influence of each stakeholder category	33
Toolbox 5.	Simplified conflict resolution process	37
Toolbox 6.	Semi-quantitative risk assessment	39
Toolbox 7.	Simple trade-off analysis.	48
Toolbox 8.	Operational steps for adaptive management	51

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Abbreviations and acronyms

CBF	culture-based fisheries
CBO	community-based organization
CSO	Civil Society Organization
EAFM	ecosystem approach to fisheries management
ECA	extended command area
EIA	environmental impact assessment
FAO	Food and Agriculture Organization of the United Nations
GDP	gross domestic product
IWRM	integrated water resources management
M&E	monitoring and evaluation
MCA	multi-criteria analysis
MOA	Memorandum of Agreement
MOU	Memorandum of Understanding
NGO	non-governmental organization
NT2	Nam Theun 2
SMART	specific, measurable, attainable, relevant and time-bound
SRI	system of rice intensification
TOA	trade-off analysis
USD	United States Dollar
WCI	water control infrastructure



Photo: Michael Akester,
WorldFish, Yangon, Myanmar.

INTRODUCTION

**Why should this guide be
useful to you?**

Purpose and scope

Irrigation – a major contributor to the Green Revolution – has significantly improved agricultural production worldwide, with consequent benefits for food security, livelihoods and poverty alleviation. Today, irrigated agriculture represents about 21 percent of cultivated land, but contributes approximately 40 percent of the total global crop production. Many governments continue to invest in irrigation as a cornerstone of food security and rural development. Investments in irrigation often represent a pragmatic form of adaptation to changing climatic conditions.

There is increasing recognition of the need to bring about changes across the full spectrum of agricultural practices to ensure that, in future, food production systems are more diverse, sustainable and resilient. In this context, the objectives of irrigation need to be much more ambitious, shifting away from simply maximizing crop yields to maximizing net benefits across a range of uses of irrigation water, including ecosystems and nature-based solutions. One important way to achieve this is by better integrating fisheries into the planning, design, construction, operation and management of irrigation systems.

‘Water control infrastructure’ (WCI) forms the backbone of most irrigation systems. In this guide, WCI is perceived as infrastructure specifically designed and operated for the purpose of irrigation, and includes reservoirs, embankments, weirs, gates (including tidal barrages), canals and pipes. **‘Fisheries’** is defined as the exploitation of fish and other aquatic organisms. This term encompasses natural capture fisheries, enhanced capture fisheries and culture-based capture fisheries in a continuum¹. While irrigation provides opportunities for aquaculture, this guide does not explicitly cover this activity, because it is less dependent on the **aquatic ecosystems modified by irrigation**.

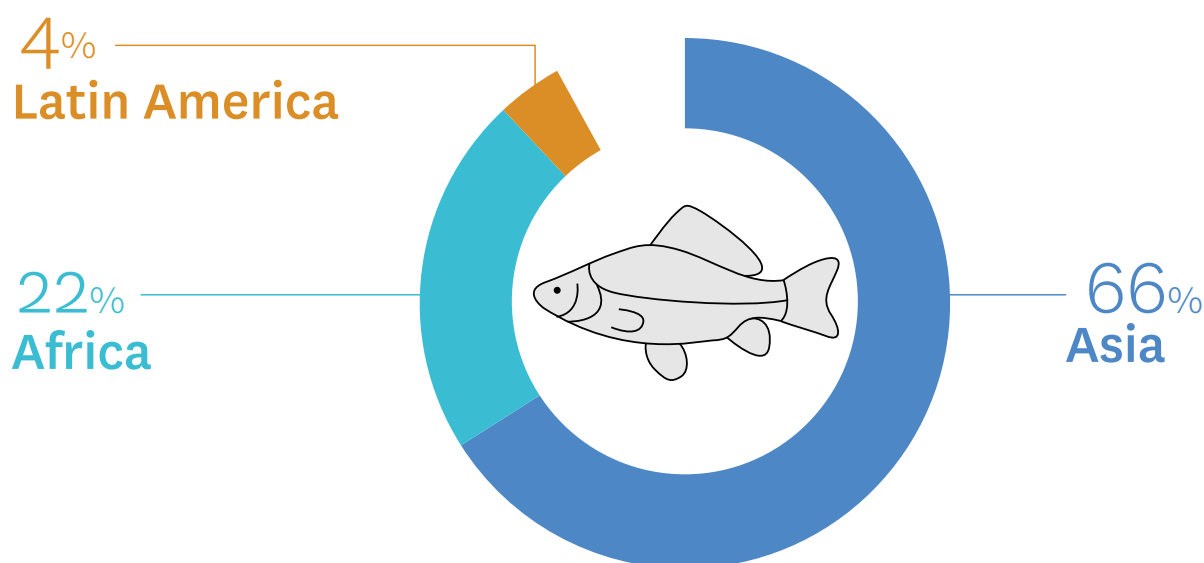
This guide focuses on how to **sustainably optimize and broaden the range of benefits from irrigation development - not only economic but also social and environmental benefits**. It emphasizes the opportunities that fisheries could provide to increase food production and economic returns, enhance livelihoods and public health outcomes, and maintain key ecosystem services. The guide considers possible **trade-offs** between irrigation and fisheries, and provides recommendations on how these can be minimized.

Importance of fisheries

Inland fisheries contribute to a range of benefits, including food production, household income, livelihoods, health, and the growth of regional and national economies. The Food and Agriculture Organization of the United Nations (FAO) reported an inland fisheries catch of 11.9 million tonnes in 2019, representing 13 percent of total global capture fisheries production (FAO, 2018a). Inland fisheries occur in almost every country in the world, although just 17 countries produce 80 percent of the total global fish catch. The Asian region has the highest inland fish catch, representing 66 percent of the total global fish catch (Figure 1). This high contribution is a function of the major inland fishery ecosystems and wetlands (including vast areas of managed rice field ecosystems) that present extensive and productive habitats.

¹ This continuum is described in Part I, Section 1.1.

Figure 1. Inland fisheries production in three regions: comparative percentages of global production



Source: Funge-Smith, 2018.

At least 43 percent of the world's inland fish catch comes from 50 low-income, food-deficit countries. In many countries with a low gross domestic product (GDP), the per capita supply of fish food produced from inland waters is greater than that of marine capture fisheries or aquaculture (Funge-Smith, 2018). Inland fisheries represent an efficient producer of food, with a far lower resource use footprint than livestock or other protein-rich foods. Fish constitute much more than simply a source of dietary energy (calories) or even just protein (see also Section 1.1, Table 1). High in essential vitamins and minerals, fish are important for alleviating micronutrient deficiencies, childhood stunting and health conditions, including rickets, cardiovascular diseases, high blood pressure, gestational diabetes and preeclampsia, childhood blindness and anemia. Given that fish consumption can prevent childhood stunting, it is important to ensure that inland fish are accessible and affordable in comparison to other animal source foods. This is particularly important for fighting hunger and malnutrition among poor populations that are currently dependent on inland fisheries (Funge-Smith and Bennett, 2019).

Throughout much of the developing world, inland fisheries play a crucial role in food and nutrition security and in building the resilience of rural livelihoods, while also being socially and culturally important. Yet, fisheries are often overlooked in the planning, design, construction, operation and management of irrigation systems. Irrigation systems designed, built and operated solely for land-based crop production can have negative impacts on fisheries, ranging from a loss of productivity and biodiversity to a loss of livelihoods. Such impacts can become, in some situations, a source of conflict between fishers, farmers and irrigation managers.

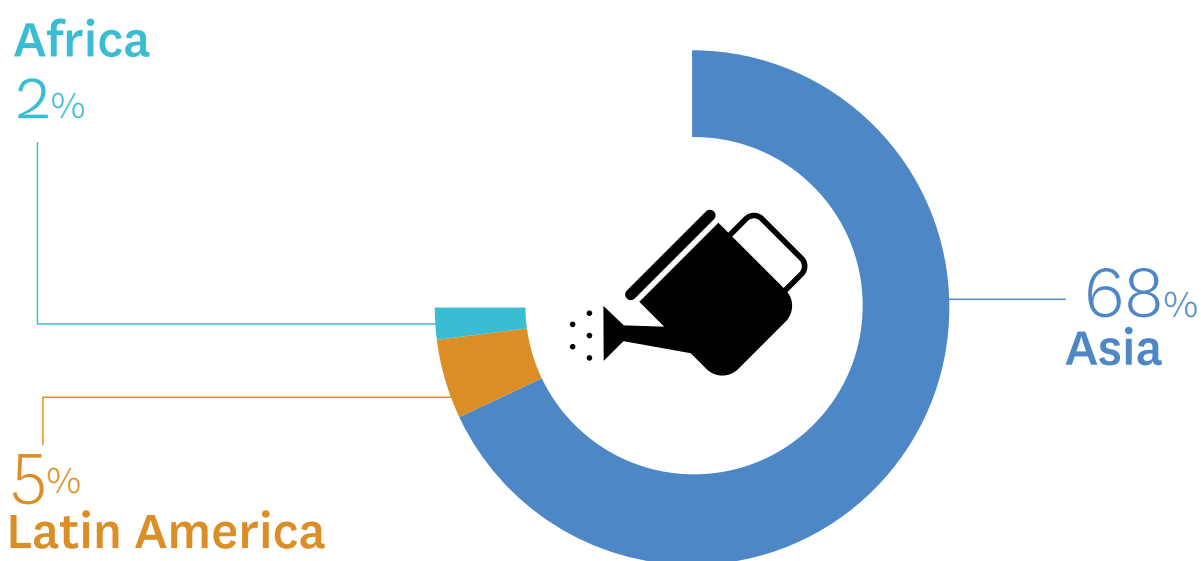
Importance of irrigation

Irrigation has been a critical element of agriculture for thousands of years. Many ancient civilizations (e.g., in Mesopotamia, Egypt, Sudan, India, Southeast Asia, China, Sri Lanka and tropical America) depended on irrigation. Increasing irrigation was a key factor in the success of the Green Revolution from the 1950s to the 1970s, which brought very significant increases in global food production. This helped to avert major famines and starvation, despite a rapidly increasing human population (Fitzgerald-Moore and Parai, 1996).

Globally, the irrigated area has approximately doubled in the last 50 years (Foley *et al.*, 2011). In 2012, over 324 million hectares (Mha) were equipped for irrigation, of which about 85 percent (275 Mha) was actually irrigated (FAO, 2014a). However, there are significant differences between regions (Figure 2).

About 68 percent of the irrigated areas are in Asia (~220 Mha equipped for irrigation), of which 45 percent is concentrated in two countries: China (69.4 Mha equipped) and India (66.7 Mha equipped). In Latin America, 16 Mha are equipped for irrigation (14 percent of the cultivated area). In contrast, it is estimated that 7.7 Mha in Africa are equipped for irrigation (just over 6 percent of the cultivated area). Of this area, more than two-thirds are concentrated in five countries: Egypt, Algeria, Morocco, South Africa and Sudan (Malabo Montpellier Panel, 2018). There is considerable uncertainty in these figures, which rely primarily on census data that are infrequently updated and often fail to capture small-scale, community-managed systems, as well as ‘informal’, individual (also called ‘farmer-led’) irrigation development (Bowers *et al.*, Forthcoming; Woodhouse *et al.*, 2017).

Figure 2. Irrigated area in three regions: comparative percentages of the global irrigated area



Source: adapted from AGRA, 2017.

Although climate change may lead to a reversion from irrigated to rain-fed agriculture in some places (e.g., parts of China and India), a significant net increase in irrigation is anticipated globally. There is potential to expand the irrigated area in all regions of the world. Investments to upgrade and rehabilitate obsolete or degraded irrigation systems can generate many benefits.

Irrigation and fisheries

There is considerable scope to optimize the benefits derived from irrigation systems by integrating fisheries from the outset of project planning and design through to operation and management. It may be possible to prevent or mitigate the negative impacts and enhance fisheries, without undermining the primary purpose of the irrigation scheme. Taking this approach may also avoid or minimize the disputes and conflicts that often delay implementation of water management projects, and reduce their operating efficiency, sustainability and economic benefits.

Irrigation proponents should not perceive fisheries as a problem or a threat. Rather, the integration of fisheries provides an opportunity to enhance and sustain the benefits of irrigation projects and reduce negative externalities.

Target audience, purpose and scope of this guide

This is a user-friendly guide to assist the development and implementation of improved, sustainable irrigation systems. It is mainly for water planners, water managers and civil engineers responsible for the design, construction, operation and maintenance of irrigation systems.

The guide aims to provide practical ways to integrate fisheries into the planning, design, construction, operation and management of irrigation systems to increase their benefits and sustainability, and to enhance fisheries-dependent livelihoods and the services provided by aquatic ecosystems. This will be achieved by improving the understanding of the following:

- Importance of integrating fisheries into the planning, design, construction, operation and management of irrigation systems in Africa and Asia (noting that these examples can be translated to other regions where there are similar problems).
- Potential impacts of irrigation on aquatic resources, ecosystems and fisheries.
- Technical, management and governance options for the planning, design, construction, operation and management of irrigation systems that can prevent or mitigate the negative impacts and enhance fisheries.

How should you use and navigate this guide?

This guide comprises two parts. **Part I** generally explains WHY irrigation systems impact fisheries, but conversely can also provide opportunities for their development. This part aims to improve the knowledge and understanding of (i) fisheries and irrigation systems, and (ii) the mechanisms of positive and negative impacts of irrigation on fisheries.

Part II provides operational guidance on HOW to integrate fisheries into irrigation systems to mitigate the negative impacts of irrigation on fisheries and optimize the benefits derived from both sectors. This operational part of the guide could be used independently in the field provided that the impacts and the mechanisms of positive and negative impacts are well known and understood.



Photo: Michael Akester,
WorldFish, Yangon, Myanmar.

PART I

Understanding the impacts of irrigation systems on fisheries and some potential opportunities

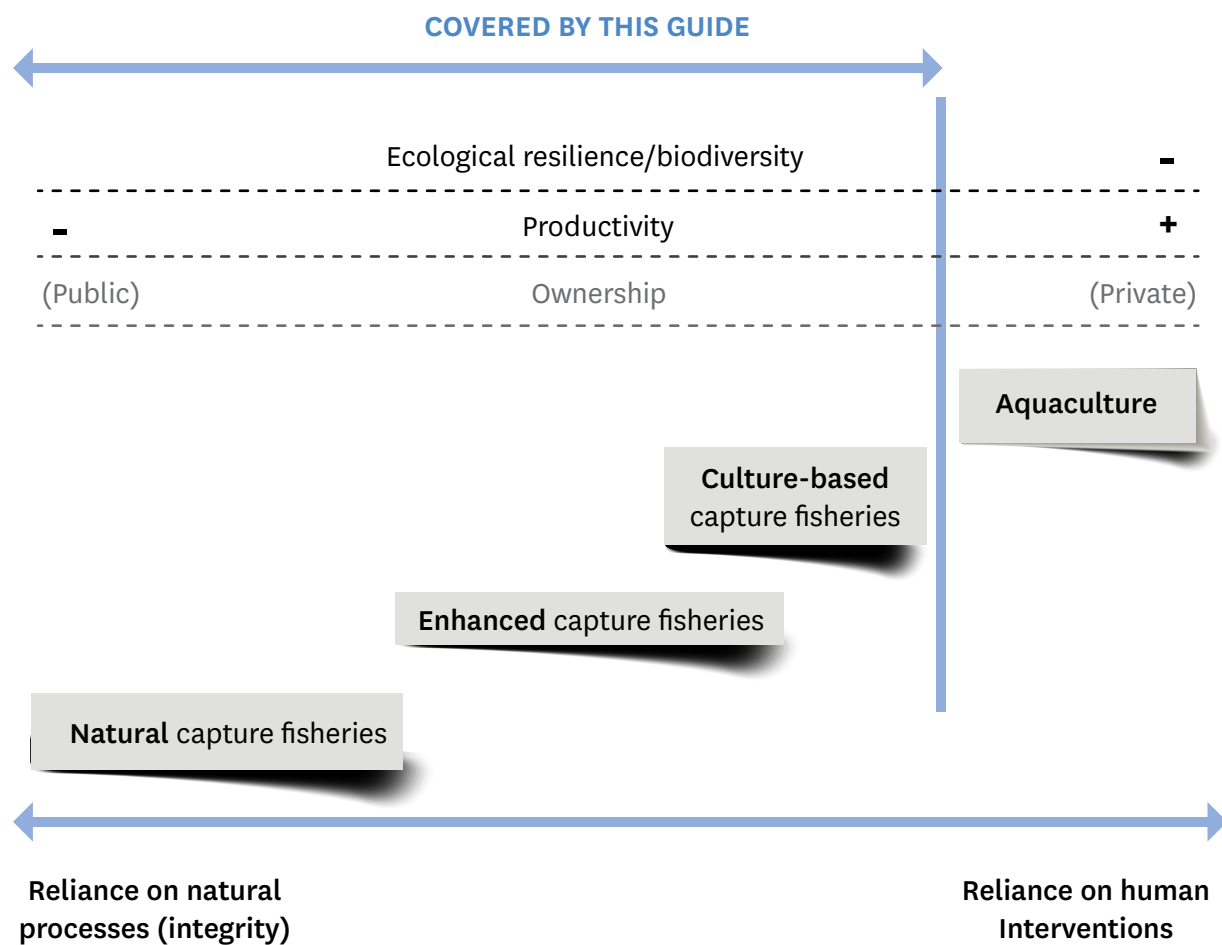
Successful exploitation of fish and aquatic resources in irrigation systems requires a good understanding of their needs in terms of water resources and the health of aquatic ecosystems, as well as the complex interrelationships between irrigation systems and fisheries.

1. Key characteristics of fisheries and irrigation systems

1.1 Fisheries

This guide focuses principally on **fisheries**, i.e., the removal of fish and other aquatic organisms for which the stock is maintained by natural reproduction or fish stock enhancement. This activity can be qualified as natural, enhanced or culture-based capture fisheries – noting that the last category is often considered to be a form of aquaculture. The range of aquatic animal production systems from natural capture fisheries to aquaculture is best considered as a continuum (Figure 3).

Figure 3. Continuum from natural capture fisheries to aquaculture



Source: Adapted from Welcomme and Bartley, 1998.

Definitions

- Natural capture fisheries: fish stock maintained by natural reproduction, with no human intervention.
- Enhanced capture fisheries: fish stock enhanced by the addition of feed or modification of habitat to increase biomass production or ease capture (e.g., isolating part of a reservoir to trap fish and then feeding these fish before capture).
- Culture-based capture fisheries: fish stock enhanced by the addition of fry or fingerlings that are ‘cultured’ specifically for this purpose (e.g., addition of fingerlings grown in ponds to a reservoir or irrigation canals).

While overlap exists between these production systems, it is important to understand the gradients of productivity, ownership of resources, and biological resilience in relation to the increasing human intervention across the continuum. The impacts on each of these systems or the opportunities provided by irrigation will differ, and priorities and trade-offs will vary (see Part II, Step 4).

The resources harvested by capture fisheries are the result of biological production. Therefore, the activity strongly depends on the quality and amount of primary nutrients available in the aquatic environment. These nutrients are delivered from the decay of plant and animal biomass, sediment deposition and fertilization from runoff. The distribution and recharge of these nutrients may be modified by habitat fragmentation, changes in river connectivity and land use in the watershed. While the production and consumption of fish is a primary concern for food and nutrition security, and livelihoods, it is never the only consideration.

Fish species differ in their value as food and marketable commodities, and their dissimilar life cycles and migration patterns imply different water resources and habitat requirements. At the ecosystem level, inter-species interactions may provide compensatory mechanisms, i.e., if the abundance of one species is depressed, the abundance of its prey and/or its competitors may increase and maintain the combined biomass of aquatic animals (Lorenzen *et al.*, 2007). Therefore, **the ecology, biodiversity and production of fisheries are strongly influenced by the health of their supporting ecosystem.**

Another important characteristic of capture fisheries is that, although pre- and post-harvest activities (e.g., fish meal production for feed and ice for storage) may consume small amounts of water, the activity itself **does not consume water**, i.e., it does not withdraw or degrade water resources. However, the water requirements for fish stocks in terms of quality, timing of availability and volume **can nevertheless compromise other water uses.**

Uses that modify the location and timing of releases, change the temperature or alter the quality of water may prevent that water from being used effectively for fish production. Likewise, the water requirements for fish production may be considered wasteful, such as the need for continuous flows (sometimes even outside of the cropping season), which may exceed the requirements for irrigating crops. This underscores the importance of determining environmental flows for all components of the ecosystem to optimize overall productivity.

Assuming that the water requirements to sustain capture fisheries can be satisfied, the activity can provide significant potential for increasing irrigation benefits. Ideally, **integration of fisheries into irrigation systems should be addressed at the scale of the river basin ecosystem (or an area broader than the immediate irrigation command area), and should simultaneously aim at enhancing fisheries production, and sustaining the aquatic ecosystem and its biodiversity.** It is recognized that this may not always be possible at the broader scale, but this should not deter efforts to achieve some degree of mitigation or improvement within a smaller watershed or irrigation command area.

In rural communities, capture fisheries can play different roles: (i) a specialist occupation; (ii) part of a diversified accumulation strategy; (iii) part of a diversified semi-subsistence livelihood; and (iv) a primary, subsistence livelihood (Table 1).

1.2 Irrigation systems

An irrigation system is composed of WCI and its command area, i.e., the cropping area serviced by irrigation water, as detailed in Box 1 and Annex 1. There are many types of irrigation systems, including gravity fed and pumped surface water systems with water supplied from large and small reservoirs and/or diverted or lifted from rivers using a range of technologies. In the past, irrigation systems were often developed by governments. More recently, there has been an increase in the number of irrigation systems initiated

and developed by private entrepreneurs and farmers, either autonomously or with little support from the government and/or non-governmental organizations (NGOs).

Table 1. Livelihood functions of fishing

Livelihood strategy	Livelihood functions of fishing
‘Specialization’ (as fishers)	<ul style="list-style-type: none"> ▪ Market production and income ▪ Accumulation strategies that aim to improve living standards and can be used to reduce risks when they occur
‘Diversification for accumulation’	<ul style="list-style-type: none"> ▪ Accumulation strategies (as defined above) ▪ Retention in a diversified accumulation strategy ▪ Recreation
‘Semi-subsistence’ diversification	<ul style="list-style-type: none"> ▪ Own consumption – food and nutrition security ▪ Complementarities in labor use with farming ▪ Means for barter, or for participation in reciprocal exchange and social networks ▪ Occasional source of income ▪ Diversification for: <ul style="list-style-type: none"> ▫ labor and consumption ‘smoothing’ ▫ risk reduction ▫ as a coping strategy/buffering against shocks
‘Survival’	<ul style="list-style-type: none"> ▪ Primary reliance for subsistence (food production and income) ▪ Nutrition – protein, micronutrients, vitamins

Source: Adapted from Smith, Nguyen Khoa and Lorenzen, 2005.

Irrigation often occurs in the uplands of catchments, but topographic constraints usually mean that such systems are relatively small (< 500 ha). Much larger irrigation systems (often > 1 000 ha) have been developed on flat river valleys and alluvial plains of lowlands, usually with public funds, e.g., for irrigated rice farming in Asia. In this region, polder systems using embankments are common in deltas² to protect crops from both flooding and saltwater intrusion.

Irrigation systems usually create new aquatic habitats, such as reservoirs, irrigation canals, drainage canals, and irrigated and drainage areas. They can also modify aquatic habitats by altering flow and flooding regimes, and for example, transforming brackish water into freshwater ecosystems by the use of tidal barrages. In order to properly assess the relationships between capture fisheries and irrigation systems, it is necessary to extend the spatial scope of the conventional irrigation command area. This broader scope includes the upstream and downstream water bodies connected to a source of irrigation water, including other water sources that join and mix with the irrigation water and can be referred to as the ‘**extended command area (ECA)**’ (Gregory, Funge-Smith and Baumgartner, 2018).

² Especially in the Mekong, Red, Ganges and Ayeyarwady deltas.

BOX 1 Common components of irrigation systems (see also Figure 4)

1. Infrastructure

- Diversion weirs or barrages*
- Water gates and distribution system
- Irrigation canals: main canal, secondary, tertiary
- Drainage canals

2. Command area

- Storage reservoirs*
- Crop fields
- Wetlands and floodplain water bodies
- Depressions
- Downstream rivers

3. Extended command area

- Upstream and downstream water bodies
- Waterlogged areas outside the command area
- Associated/connected wetlands/swamps and aquatic habitats

* Such structures may also serve other purposes, such as potable water supply, hydropower and flood regulation.

2. Mechanisms of impacts of irrigation on fisheries

Water control infrastructure (WCI), built to control and distribute water, changes the biophysical and ecological characteristics of the area under control, as well as management and governance of the water resource. These changes have wide-ranging and often complex impacts: modifying ecosystem functions (including ecology, and primary and secondary production), the productivity of fisheries, its contribution to rural livelihoods, and the governance of water and fisheries.

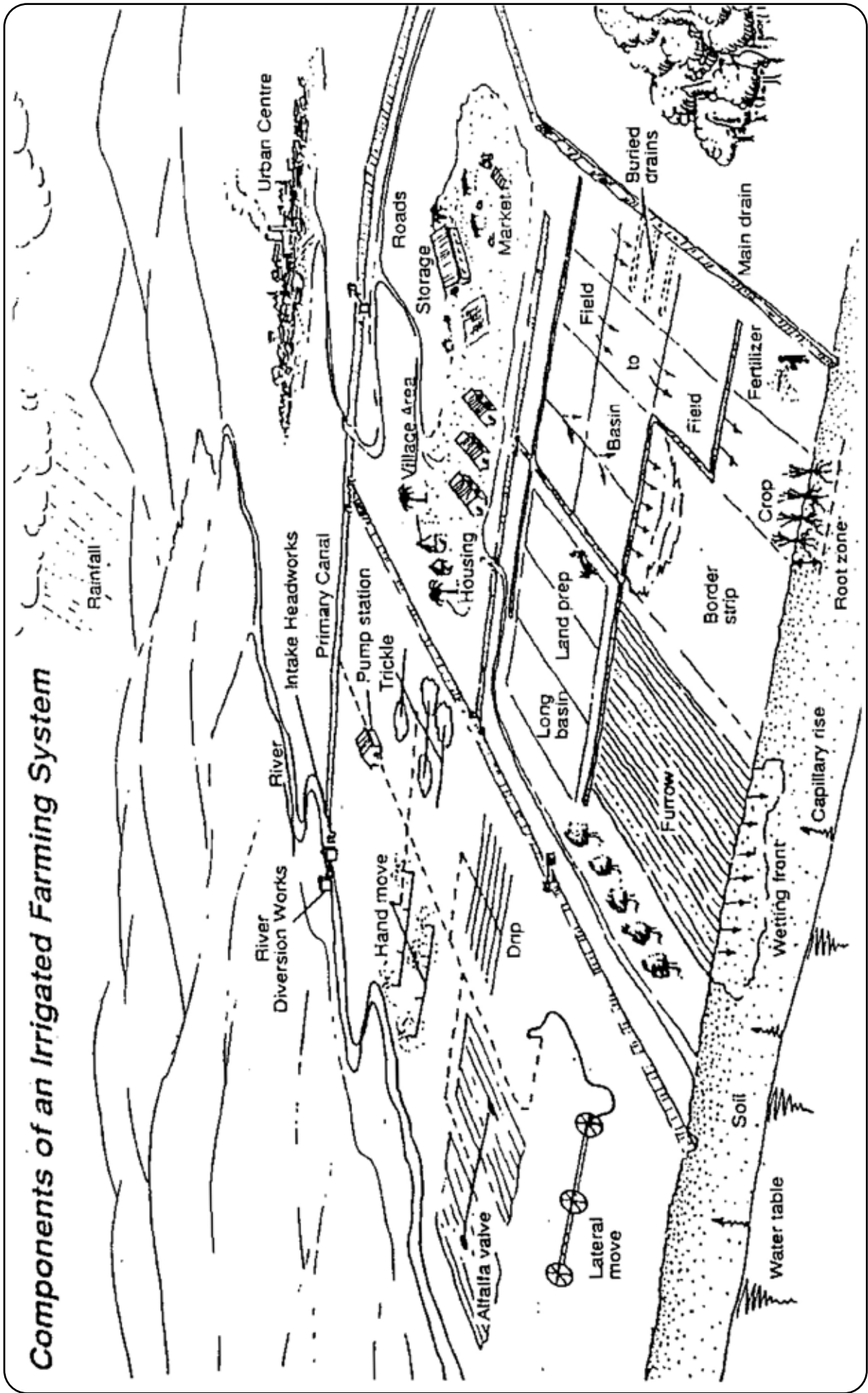
All irrigation systems potentially impact fisheries, but the manner in which they do and the nature of impacts vary considerably. Impacts depend on both the biophysical context in which the irrigation scheme is located and the exact manner in which it is operated and managed.

2.1 Irrigation infrastructure and management

The infrastructure built to control and distribute water resources for irrigation can result in the following (Figure 4):

- Creation of artificial water bodies (within or external to a river)
- Barriers to longitudinal river flow (weirs, dams and barrages, pumps)
- Barriers to lateral river flow and floodplain inundation (embankments/levees, canals)
- Controls to river and canal flow for regulation of flow or diversions (spillways, gates/regulators)
- Abstraction and reduced flow (pumps or gravity feed)
- Conveyance of water (canals, channels, pipes, culverts and drainage ditches)
- Settlement of nutrients in reservoirs (reducing the primary productivity of water)
- Disruption of natural sediment (and therefore nutrient) deposition processes, reducing natural productivity of the command area
- Increased sedimentation and reduced water depth within the river and canals

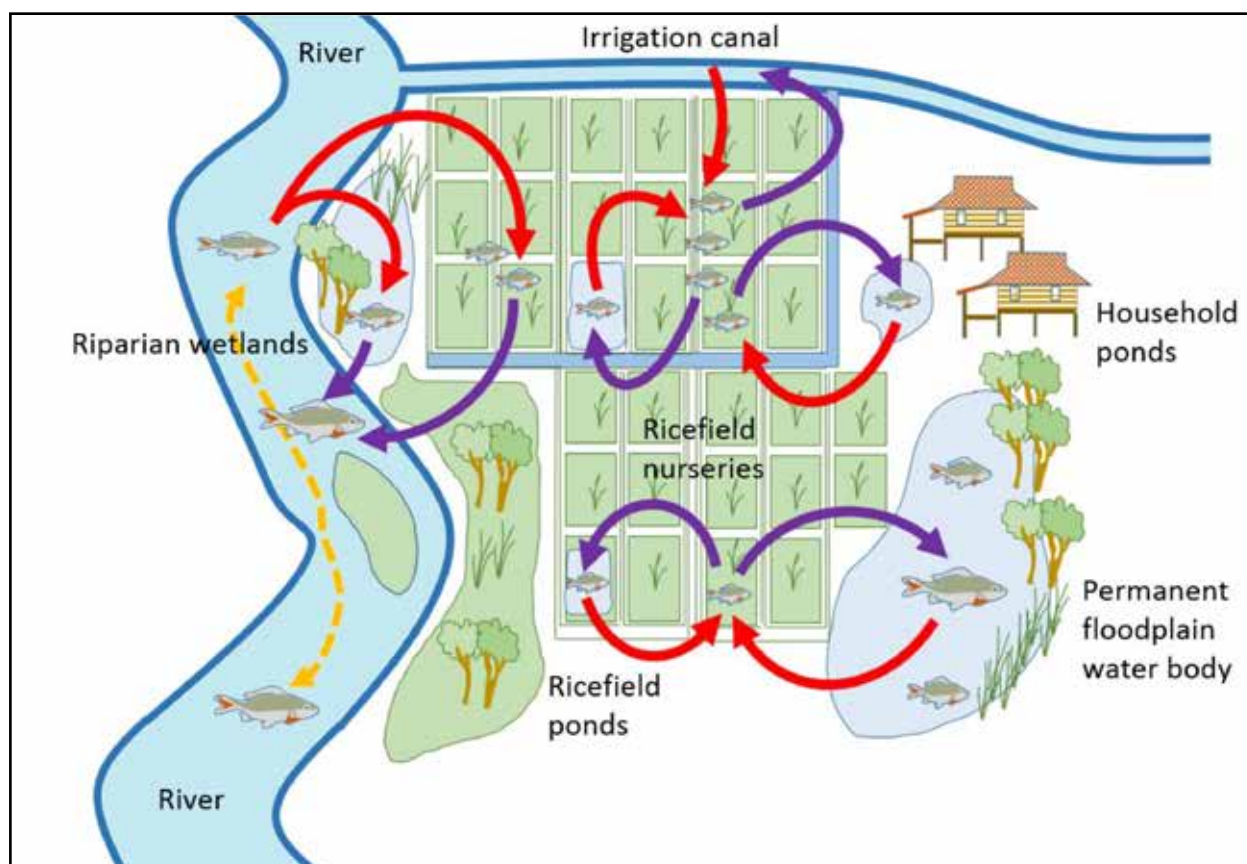
Figure 4. Layout of a typical irrigation and drainage system



Source: Lorenzen et al., 2007.

Given the potential to alter water flows, WCI and water management can also alter fish movement, both in the riverine environment and between water bodies and other aquatic habitats (e.g., floodplains) (Figure 5).

Figure 5. Seasonal movements of fish in irrigation systems



Source: Gregory, Funge-Smith and Baumgartner, 2018.

Note: The figure shows the movements of fish between rivers, floodplains, water bodies, rice fields and irrigation systems. Red arrows show lateral migrations during the rainy season. Purple arrows show lateral migrations that occur at the onset of the dry season. The yellow dashed line indicates the upstream and downstream migration of riverine fish.

In many instances, lowland irrigation systems have a greater impact on fish and fisheries than upland systems. This is not only because the fish tend to be larger in lowland systems, but often the construction of canals, gates and roads disconnects and fragments low-lying floodplains which are vital for fish breeding and feeding (see example in Box 2).

BOX 2 Reduced connectivity in Bangladesh floodplains

While an increasing number of farmers in Bangladesh are enclosing lowland floodplains with polders to better control their farmlands, they simultaneously block the access of many migratory fish species to large areas of floodplains. The net result of this is reduced fish catches, as fewer fish migrate to the floodplain farmland and associated water bodies.

The wide range of impacts arising from changes in water availability and flows, water quality, biodiversity, connectivity between habitats, and drainage of land, and resulting changes in fisheries production are listed in Table 2.

Table 2. Potential negative (-) and positive (+) impacts of irrigation on capture fisheries

Issues	Impact on capture fisheries	(-) / (+)
Water availability	Reduced water storage capacity in wetlands	(-)
	Increased evapotranspiration	(-)
	Reduction in the level of the water table (e.g., tube well irrigation)	(-)
	Increased evaporation	(-)
	Modified river hydrology, aquatic habitats and ecology	(-)
	Control of flood levels	(-)
	Control of extent and intensity of flooding	(-)
	Creation of reservoirs	(+/-)
	Improved groundwater recharge through seepage	(+/-)
	Unintended creation of refuges and wetlands	(+)
	Increased water availability in the dry season	(+)
Water flow	Erratic changes in water levels	(-)
	Irregular flows causing the drying out of some areas	(-)
	Short periods of high velocity flows	(-)
	Irrigation dam pulse releases leave fish stranded and damages gear	(-)
	Poorly sited culverts constrain the movement of fish stocks, creating bottlenecks exploited by fishers	(-)
	Decreased frequency, duration and magnitude of floods	(-)
	Blocked flow by increased sedimentation	(-)
	Protection from extreme or flash floods	(+/-)
	Stabilization of downstream flows (especially in the dry season)	(+)
Water quality	Increased pesticide and herbicide residues	(-)
	Increased salinization through waterlogging	(-)
	Increased siltation from agricultural intensification	(-)
	Reduced water turbidity	(-)
	Eutrophic conditions and low oxygen levels, especially during dry seasons	(-)
Biodiversity	Reduced species richness and diversity	(-)
	Spread of alien species, e.g., golden apple snail and tilapia	(-)
	Proliferation of alien species in reservoirs	(-)

(Continued)

Table 2. Potential negative (-) and positive (+) impacts of irrigation on capture fisheries (Continued)

Issues	Impact on capture fisheries	(-) / (+)
Habitat	Loss of habitat, and foraging and breeding areas for fish	(-)
	Land reclamation and drainage for agriculture causes reduced wetland habitat area, quality and connectivity	(-)
	Decrease in natural sediment and nutrient deposition, reducing natural productivity	(-)
	Lack of habitat variation in canal type environments	(-)
	Extension of habitat variation in canal type environments	(+)
Connectivity and fish migration	Reduced floodplain connectivity	(-)
	Weirs and barrages prevent the movement of fish stocks	(-)
	Habitat partitioning through roads and dikes	(-)
	Removal of spawning stimuli through water flow regulation and flood control measures	(-)
Fishing pressure	Increased potential to catch fish in bottlenecked areas	(-)
	Increased pressure on local resources due to a rise in the number of people supported by irrigated agriculture	(-)
	Increased fishing livelihood options	(+)
	Reduced access to irrigated areas can restrict fishing activities	(-)
Drainage	Discharge of poor quality water affects downstream sites	(-)
	Possible salinization of drainage water can increase salinity of water in estuaries and lagoons	(-)
	Increased dry-season runoff of high-nutrient and turbid water	(+)

Source: Adapted from Gregory, Funge-Smith and Baumgartner, 2018.

The impacts of irrigation on capture fisheries are mostly negative, as shown in Table 2. However, the impacts can be positive in the following instances:

- The new aquatic habitat created by irrigation may provide opportunities for new fisheries.
- At the catchment level, aggregated fish production may increase and improve the livelihoods of fishing communities, as is the case in some irrigated rice farming systems (Nguyen Khoa et al. 2005a).

The potential for achieving positive impacts highlights the scope for increasing the benefits derived from investment in irrigation. However, aggregated impacts cannot be limited to a list of positive and negative outcomes. The benefits will be gained by people in different locations of the irrigation system, and they will respond to different objectives of the project (e.g., economic profitability, food and nutrition security, equity). The distribution of positive and negative impacts will often result in conflicts around the use and management of water, for example, between the requirements for agriculture and fisheries development (see Part II, Step 2). The various trade-offs resulting from the achievement (or not) of different objectives and the resulting impacts, therefore, need to be assessed (see Part II, Step 4).

2.2 Role of fisheries in rural livelihoods

The ecology and productivity of aquatic systems and associated resources will influence fisheries (e.g., frequency, duration, location, gear/equipment used), the benefits derived from these activities in terms of income and/or food security, and the role played by fisheries in livelihood strategies (Smith, Nguyen Khoa and Lorenzen, 2005).

Understanding the potential impacts of irrigation and opportunities for fisheries livelihoods should consider the following three aspects (Lorenzen *et al.*, 2007):

1. What livelihood changes (impoverishments or improvements) may result from a change in actual or potential productivity of the fishery?
2. What livelihood changes may result from any change in patterns of access to the fishery for some or all households?
3. How will livelihood changes be distributed between households and individuals?

For example, irrigation development has the potential to expand the non-farm labor market through the stimulus it provides to the rural economy, with new opportunities for livelihood diversification. This can create opportunities and incentives that draw labor away from fishing, or may provide income that compensates for the lost or reduced fishing activity.

Although there may be overall benefits to many rural households, poor households (possibly dependent on fishing) without access to the benefits of irrigation and intensified farming may be economically and socially marginalized by irrigation development. Such households may be driven to rely (even) more heavily on fishing as one element of a less diversified survival strategy. At the same time, the productivity of natural and enhanced capture fisheries may decline due to reduced connectivity of water resources in the landscape. These households are also the least likely to have access to or benefit from alternative employment, except for off-farm labor migration.

The distribution of benefits from fishing may also change. For example, flooded rice fields, canals and reservoirs can provide habitat for fish and catches that compensate, in whole or in part, for reduced productivity of the floodplain and the main river channel downstream. This may mean that some groups that fish mainly downstream tend to lose, while other groups may gain from access to the new habitats created by irrigation development. Similarly, a polder system in the lower area of a delta, designed to provide irrigation water while reducing the tidal impact (salinity), increases agricultural production and could possibly create opportunities for rice-fish farming. However, this may cause declines in capture fisheries in the previously productive estuarine environment.

Rules and regulations may determine who has access to new habitats (as discussed below), but other factors may also influence accessibility for different groups. For example, a new reservoir habitat may support a productive fishery, but may only be accessible to people who are strong, mobile and able to use boats, and have the financial resources to engage in these activities. In contrast, natural streams and flooded rice fields may be important to older people and children, who are less mobile, and to women, because of their proximity and ease of access using traditional fishing gear, such as baskets, nets, hook and lines, and fish traps.

2.3 Governance of water and fisheries

In the context of water and exploitation of aquatic resources, governance can be defined as the organizations and institutions, laws and rules that regulate access to and use of natural resources. Governance

arrangements influence how well irrigation is managed and thus its productivity and efficiency. These arrangements also influence the impacts of irrigation on the productivity and sustainability of fisheries, both before and after irrigation development or rehabilitation. Critically, governance will determine who can access fisheries and where, when and how they can engage in these activities.

Many inland fisheries are open access systems with no regulation on who participates and how much they harvest. Such systems can work effectively, but depending on the ecology of the system, excessive fishing can result in the depletion of fish stocks, boom-and-bust cycles, and dissipation of economic profits. Sustainability and the equitable distribution of benefits from fisheries often depend on the establishment of institutions, policies and processes through which fisheries are managed.

Legislation on fisheries and environmental conservation is often both incomplete (outdated) and poorly enforced. Even where it exists, there is often limited local capacity to effectively implement and enforce legislation in a fair and transparent manner. A similar situation may exist for wider measures aimed at water management. More clearly defined policies and legislation for the abstraction, distribution and use of water usually exist, but may be subject to similar deficiencies in implementation.

Existing legislation and policies for fisheries, water resources management and environmental conservation may also be contradictory, resulting in perverse incentives that can encourage the overexploitation of fisheries, or the modification or destruction of fisheries habitat. For example, in Myanmar, an 88 percent loss of mangroves (i.e., 191 122 ha were lost between 2000 and 2014) was due to the expansion of rice cultivation. Such a loss of habitat has a significant impact on fisheries. Therefore, the ambition should be for integrated assessment and management of land and water resources at catchment and landscape scales, and improved harmonization of sector policies and legislation for fisheries, water resources and the environment.

Table 3 summarizes the key institutional arrangements in place for activities related to irrigation and fisheries, and the linkages and pathways leading to positive and negative impacts from irrigation. The third column in Table 3 – ‘Institutional arrangements’ – provides a guide and checklist for assessment. However, a detailed qualitative assessment is needed to identify how arrangements have developed and performed in any given location. Institutional arrangements may be both formal and informal. How they perform and their outcomes will depend on the local context.

Institutional development is thus a complex and time-intensive social enterprise. Some of the arrangements in Table 3 represent complex social interactions. For example, membership of a fisheries or water management group is an outcome of several factors, such as the influence of stakeholders relative to each other, their ability to meet membership criteria and to contribute to the definition of these criteria. Even if membership is achieved, social differences and the ability to influence are likely to persist. Similarly, deciding what type of equipment is allowed will strongly influence who can and cannot fish, for example, by determining which households can afford the permitted equipment. This complexity means that the most marginalized households may be further sidelined unless institutional development has been embedded in a process of stakeholder engagement that is sensitive to such social diversity. Ideally, this process will lead to co-creation of new or modified institutions with the participation of all stakeholders.

Irrigation planners and managers need to be proactive and responsible to ensure appropriate outcomes from their decisions and actions within the prevailing or often modified governance arrangements for fisheries, water resources and the environment. Since information to fully assess the potential impacts of irrigation development on fisheries will almost always be lacking, it is essential to engage in inclusive consultation and engagement with communities, including fishers.

Table 3. Key local institutional arrangements for irrigation and fisheries

Types of rules	Activity to control	Institutional arrangements
Operational rules	Regulating fish allocation and withdrawal	<p>Who can fish?</p> <ul style="list-style-type: none"> ▪ Community-based organizations (CBOs) ▪ Co-management groups⁺ ▪ Licensing ▪ Leasing ▪ Membership of fisher associations ▪ Informal institutions ▪ Irrigation management agencies
	Regulating fishing methods and timing	<p>Limit the timing, amount and type of fishing</p> <ul style="list-style-type: none"> ▪ Area restrictions, e.g., reserves ▪ Seasonal restrictions, e.g., closed seasons ▪ Licensing of permissible gear and catch (quotas)
	Regulating water distribution	<p>Who can withdraw water?</p> <ul style="list-style-type: none"> ▪ Membership ▪ Permits ▪ Riparian rights <p>Water distribution method, for example:</p> <ul style="list-style-type: none"> ▪ On demand/semi-demand ▪ Canal rotation ▪ Continuous flow ▪ Reservoir releases ▪ Provision for environmental flows
	System maintenance (irrigation)	<p>Maintenance of, for example:</p> <ul style="list-style-type: none"> ▪ Dams and reservoirs ▪ Irrigation network ▪ Drainage network ▪ Flood protection dikes ▪ Fish passages, fishways <p>Who is responsible? For example:</p> <ul style="list-style-type: none"> ▪ Department of Irrigation ▪ Irrigation system manager ▪ Water User Groups ▪ Private operators ▪ Co-management groups
	Monitoring operational rules	<p>Who monitors compliance?</p> <ul style="list-style-type: none"> ▪ Agencies are responsible ▪ Are resources available?
	Enforcement of operational rules	<p>Who enforces regulations?</p> <ul style="list-style-type: none"> ▪ Presence of fines, social sanctioning ▪ Extent to which rules are enforceable and legally binding, e.g., presence of bylaws

(Continued)

Table 3. Key local institutional arrangements for irrigation and fisheries (Continued)

Types of rules	Activity to control	Institutional arrangements
Collective choice rules	Who can, cannot or must make the decisions?	Which organizations and personnel? for example: <ul style="list-style-type: none"> ▪ Traditional community leaders ▪ User community involvement (co-management group) ▪ Cross-sectoral representation ▪ Cross-discipline representation ▪ Government/NGO representation
	What procedures are considered compulsory, advisable or voluntary?	Consultation <ul style="list-style-type: none"> ▪ Stakeholder analysis/participation ▪ Problem identification ▪ Possibly, co-creation of institutions (de Silva <i>et al.</i>, 2019) Information gathering, for example: <ul style="list-style-type: none"> ▪ Indigenous knowledge ▪ Environmental impact assessment ▪ Social impact assessment ▪ Catch monitoring, stock assessment (fisheries) ▪ Migration study (fisheries) ▪ Site survey
	What rules are used to finalize decision-making?	Example: majority vote, unanimous vote, right of veto
	What information must be made available to decision-makers?	Refer to <i>'Information gathering'</i> above
	Monitoring collective choice rules	Formal and informal processes
	Enforcement of collective choice rules	<ul style="list-style-type: none"> ▪ Presence of fines or other forms of sanctioning for breaking rules ▪ Extent to which rules are enforceable and legally binding, e.g., presence of bylaws

Source: Adapted from Lorenzen *et al.*, 2007.

Note: *Co-management groups usually involve some form of partnership with the government and/or civil society organization (CSO), while this is not necessarily the case with CBOs.

However, consultation alone is unlikely to generate representative institutions with stakeholder buy-in. From the very first step of the process, stakeholder engagement aims to define the problems and co-create the necessary institutional arrangements, where relevant. The arrangements should reflect inclusive negotiation and consensus among stakeholder groups, community leaders and government agencies.

Given the specialized nature of such a social enterprise, irrigation planners and managers should cover the appropriate set of skills as much as possible and include institutional development specialists.

3. Trends and opportunities in fisheries and irrigation

3.1 Fisheries: Trends and opportunities

An undervalued contribution to food and nutrition security, economies and livelihoods

Inland fisheries are central to livelihoods and represent the main source of animal protein in rural diets in many countries facing endemic food and nutritional deficits (Funge-Smith and Bennett, 2019). These resources depend on the integrity of river and floodplain systems and, as outlined above, are often degraded by the construction of WCI.

Despite evidence to the contrary, capture fisheries are often presented in debates as being marginal and a last resort of the poorest that can be relatively easily sacrificed in the interest of national economic development. The reality is that inland fisheries are often very productive and an important resource that cannot be easily replaced for millions of people. In many places (e.g., throughout much of rural southeast Asia), it is only the presence of fish that makes livelihoods viable (Arthur and Friend, 2011).

Drivers of change

By far, the greatest threats to fisheries and aquatic ecosystems come from changes in land use and water developments that degrade habitats and alter the natural hydrological dynamics of water resources (Lorenzen *et al.*, 2007). In particular, WCI for irrigation (and also for hydropower and water supply), as well as the construction of levees and polders (to control flooding for urban development and agriculture), affect hydrological regimes, and habitat availability and connectivity (see *Glossary*), which in turn affect fisheries. Waste, pollution and climate change are also important drivers of change.

Future trajectory

Uncertainty regarding catches hinders the understanding of catch trends in inland fisheries. The trend in global-aggregated catch indicates that inland fisheries catch has risen more or less linearly over the past 20 years increasing by 2.3 percent per year. However, this global trend masks significant differences with some countries reporting declines and others rapid increases (Funge-Smith and Bennett, 2019). Furthermore, it is difficult to know whether recent apparent increases in catch are actual increases or rather the result of improvements in reporting and estimation. Estimating trends in future catch, with a huge uncertainty in how different conflicting drivers will play out, is even more difficult.

Climate change is expected to have an increasing effect on fish catch levels over the coming decades. While, globally, catch is expected to vary by less than 10 percent (FAO, 2018a), a significant redistribution of where fish are caught is expected. Considering that all but four of the 30 countries most dependent on fish as a source of protein are developing countries (Garcia and Grainger, 2005), increasing their resilience through the promotion of more integrated fish and food production systems utilizing multi-purpose WCI would appear to be both a climate-smart and poverty-aligned water use option.

3.2 Irrigation: Trends and opportunities

Irrigation can, when adequately planned and managed, contribute not only to significant increases in agricultural production but also to food security, poverty alleviation, rural employment, improved diets and economic development. Governments also recognize that under changing climatic conditions, investments in irrigation can represent a pragmatic form of adaptation. This reflects demands from households that often list irrigation as their most preferred – but not implemented – adaptation strategy. Where individual farmers lack the financial resources and knowledge to access water from rivers and streams or shallow groundwater, support is needed from the government, or NGOs, to invest in WCI.

Drivers of change

Potential still exists to expand the irrigated area in all regions of the world, and many governments continue to invest in irrigation as a cornerstone of food security and rural development. Furthermore, there is a rise in investment in both formal and informal irrigation by the private sector, increasingly by farmers themselves (de Bont *et al.*, 2019).

Many of the influences that drove past irrigation development (e.g., population growth, poverty alleviation and economic development) continue to be priorities. However, recent calls for healthier and more sustainable food systems (Willet *et al.*, 2019) are placing new demands on how irrigation is developed and managed. At the same time, growing pressures from competing water uses in the domestic and industrial sectors, and an increasing recognition of environmental flow requirements, have led investors in irrigation and voices in other water sectors to demand improvements in irrigation performance (Molle and Berkoff, 2006). Irrigation is increasingly required to not only increase food production, but to also deliver acceptable returns on investment, improve rural livelihoods and support environmental conservation. The need to cope with the impacts of climate change further increases the complexities of planning, design, construction, operation and management of irrigation systems.

Against this background, there is increasing recognition that **the focus of irrigation needs to change from simply maximizing crop yields to a much more ambitious approach of maximizing net benefits across a range of uses of irrigation water**. Also, this must be done within a total envelope of net irrigation consumption appropriate to the river basin in which the irrigation system is located. This is a much more challenging concept, in which multiple objectives need to be considered and the opportunity costs of water, including for fisheries, need to be explicitly factored into analyses (English, Solomon and Hoffman, 2002).

Future trajectory

Under business as usual, the total harvested irrigated area³ is expected to increase by 12 percent to 394 Mha by 2030, with the largest increase (44 percent) projected for sub-Saharan Africa, followed by South Asia, and Latin America and the Caribbean (15 percent each) (Ringler, 2017). Approximately 90 percent (39 Mha) of the total increase in harvested irrigated area between 2010 and 2030 is expected to be in developing countries. Average annual costs of expanding irrigation across all developing countries are estimated at USD 7.87 billion (Ringler, 2017). Due to its many benefits, there are advocates for accelerated investment in irrigation, particularly in Africa, where net food imports are rapidly increasing (Malabo Montpellier Panel, 2018; Xie *et al.*, 2018). A scenario of increases in irrigation by an additional 20 Mha and consumptive water-use efficiency at the river basin level by 15 percent beyond business-as-usual levels requires an estimated additional investment of USD 8.1 billion a year. This would result in an estimated 26.2 million fewer people at risk of hunger than under the business as usual scenario (Ringler, 2017).

3.3 Opportunities for fisheries in irrigation

Harvesting fish in irrigation systems, sometimes involving some forms of enhancement, is a practice that dates back millennia. Although seldom recorded, it seems to have been widespread in the tropics and subtropics, especially in rice fields. However, with the advent of the Green Revolution, the focus has largely been on improved water management for agricultural production alone and fisheries have been widely neglected. The area under irrigation has increased over the past 50 years, but for the most part, fisheries within irrigation systems have not been encouraged. While opportunistic fishing does occur, there remains huge potential for enhancing fisheries (and the wide range of benefits they bring) within irrigation systems.

³ In some places, it is possible to cultivate the same area more than once a year due to irrigation. Global average cropping intensity is estimated at 130 percent. Hence, in 2011, the total harvested irrigated area was approximately 350 Mha (FAO, 2014b).

The whole range of aquatic habitats created by irrigation systems can be integrated with fisheries (Lorenzen *et al.*, 2007; Gregory, Funge-Smith and Baumgartner, 2018). Small and large irrigation reservoirs, the extensive network of irrigation canals, the irrigated fields, and the adjacent ponds or aquatic refuges of various types are all potential habitats for fish at different stages of their life cycle. If a pragmatic and flexible approach is adopted to use all habitats for fish production, opportunities for enhanced fisheries are extensive.

Studies indicate that management to enhance fisheries can lead to increased incomes. In rice-fish farming systems, the economic value of fish often exceeds the value of the rice grown. For example, in southeast Cambodia, the value of the wild fish caught from low-yielding rice fields was the equivalent of 85-125 percent of the value of rice harvested from the same area (Gregory and Guttman, 2002). There is evidence from other studies that integrating fisheries into irrigation systems can increase rice yields by 5-30 percent, in addition to providing a second source of income from fisheries (WorldFish, 2017). An important factor in the increase in profits earned by rice-fish farmers has been the reduced use of fertilizers and pesticides, which can contribute to and/or affect the conservation of aquatic ecosystems and reduce the impacts on downstream fisheries.

Irrigation modernization, widely promoted as a new paradigm for enhanced irrigation, is defined as *technical and managerial upgrading (as opposed to mere rehabilitation) of irrigation schemes with the objective to improve resources utilization (labor, water, economics, environmental) and water service for farmers* (FAO, 2018b). To date, irrigation modernization programs have generally been narrowly interpreted, and focused primarily on improving infrastructure and operations to increase traditional irrigation performance. There has been insufficient consideration of the broader requirements such as the provision of water for ecosystems and fisheries. Nevertheless, irrigation modernization, if interpreted appropriately, provides an opportunity for fundamental transformation of irrigated agriculture, and better integration of fisheries would be a way to achieve the broader objectives demanded of future irrigation (McCartney *et al.*, 2019b).

PART II

Integrating fisheries into irrigation systems

This guide aims to optimize and broaden the range of irrigation benefits by better integrating fisheries into irrigation systems. Drawing from knowledge of the potential impacts of irrigation on fisheries summarized in Part I, Part II provides practical ways to integrate fisheries into the planning, design, construction, operation and management of irrigation systems. A participatory integrated approach and a sequential, stepped process are recommended.

The process framework requires the following:

1. **Inclusive engagement of stakeholder representatives** from the fishing sector and irrigation water users throughout the process.
2. **Participatory integrated assessment and management** of the impacts of, and opportunities for, integrating fisheries into irrigation systems.
3. **Commitment** to implement and **monitor** the management measures.
4. **Adaptive management** of implementation.

Stakeholders are individuals, groups or any organizations that have some interest or ‘stake’ in the intervention (in this case, irrigation development or rehabilitation), and can affect or be affected by it. Stakeholders of irrigation interventions typically include the following:

1. Local resource users, not only fishers and farmers but also other individuals or groups that may lose access to natural resources.
2. Representatives of organizations, including CBOs and other sources of local authority (e.g., village leaders, Buddhist monks).
3. Representatives of line agencies and local government (e.g., irrigation, agriculture, fisheries, rural development).

Throughout the process, stakeholders can inform, assist and help better understand how different options translate at ground level. Ideally their engagement in the decision-making process should lead to the co-assessment and management of impacts and opportunities, and where relevant, to the co-creation of institutions needed.

The defined **irrigation system** should be assessed and managed within the context of its catchment or river basin. At this scale, the water cycle and related water resources can be understood holistically, and different uses of land and water resources can be considered together. The boundaries of the irrigation system will be drawn along the relevant **aquatic ecosystem boundaries** (see rationale in Part I, Section 1.2) rather than along administrative or political boundaries.

Combining the key principles of integrated water resources management (e.g., integrated catchment management, integrated water resources management [IWRM]) **and the ecosystem-based approach**, the process framework aligns with the ecosystem approach to fisheries management (EAFM) developed by FAO (Gregory, Funge-Smith and Baumgartner, 2018; Staples *et al.*, 2014). The outcomes of the process can contribute to catchment or river basin planning and management, including an environmental impact assessment (EIA) commonly conducted for large irrigation schemes. This will facilitate systematic integration of fisheries into assessments and evaluations of irrigation investments throughout the traditional project life cycle.

1 Understanding the context and engaging with stakeholders

2 Assessing the key impacts and opportunities

3 Screening and scoping preliminary measures

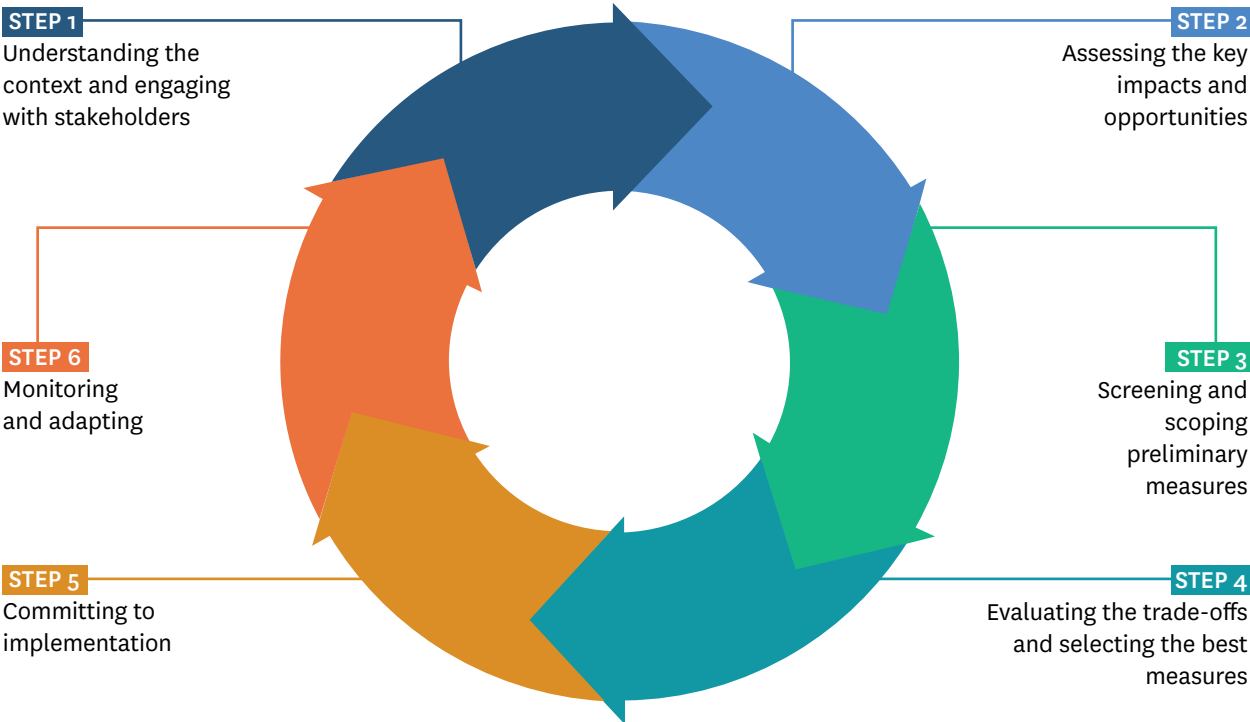
4 Evaluating the trade-offs and selecting the best measures

5 Committing to implementation

6 Monitoring and adapting

The process is operationalized through the following steps (see Figure 6):

Figure 6. Integrated and participatory process for integrating fisheries into irrigation systems



After step 1, stakeholders will remain engaged throughout the process.

Where relevant, some steps can be conducted in parallel (e.g., steps 1 and 2), sometimes iteratively or recursively. The cycle should be repeated for continuous learning and adaptation, and long-term improvement.

Necessary distinctions between planning of new irrigation schemes and modernization of existing schemes will be made, notably in Step 2: ex-ante assessments for new schemes and ex-post assessments for existing schemes.

Selected tools and methodologies with varying degrees of complexity are proposed to support each step (see the following guidance per step).

The assistance of social scientists and institutional development specialists is recommended.

STEP 1

Understanding the context and engaging with stakeholders

1. Understanding the context

1.1 The irrigation system

The first step is to understand national and, where appropriate, local government policies and strategies, not only for irrigation and fisheries but also more broadly for water, food and nutrition security, climate and the environment. These policies and strategies will often support the achievement of multiple objectives (e.g., enhanced nutrition, food security, diversified and improved rural livelihoods, ecosystem health, and increased resilience to climate shocks). Better integration of fisheries into irrigation systems will often contribute to achieving these objectives.

Within this context, the objectives of the irrigation project and its key features are defined as follows:

- Specify the nature of the intervention:
 - **Creation of a new scheme: there are more opportunities** for influencing the design and operation of the irrigation system and fisheries enhancement measures.
 - **Modernization of an existing scheme: there are possibilities** for retrofitting fisheries measures, e.g., fish passages, constructed habitats, improved gates.
 - **Rehabilitation of an existing scheme: there are fewer opportunities** for retrofitting fisheries measures, but there could be operational and management options, e.g., timed water release or the creation of permanently flooded refuge areas.
- Explain the objectives of the irrigation project. This will help later to evaluate management measures such as the allocation of water that can be set aside for fisheries or the trade-offs that may be required, e.g., lower crop yields and/or decreased irrigated area.
- Describe the key features of the irrigation system, composed of WCI, and the command area, as indicated in Toolbox 1.

TOOLBOX 1 Characterizing the key features of irrigation systems

- The irrigation scheme (see Part I, Section 1.2).
- The extended command area.
- Location and type of WCI, reservoirs and other potential habitats.
- Changes to the pattern of river flow due to water diverted for irrigation (how much water is abstracted, when and where it goes).
- Crop area and crop types.
- Irrigation method(s).
- Drainage flows.
- Direct impacts on natural drainage and streamflow.
- Direct impacts on the floodplain area.

1.2 Biophysical context

- Map and characterize water resources (see Toolbox 2 and example in Box 3).
- Map aquatic habitats and their role in supporting aquatic organisms and fisheries production, before and after the project.
- Identify the locations where fisheries activities are taking place.
- Identify existing and planned WCI in the catchment, and their potential cumulative impact on the irrigation system under study.

TOOLBOX 2 Identifying, characterizing and mapping aquatic habitats

Even where detailed topographic maps are available these are unlikely to provide a good picture of aquatic habitats. It is, therefore, important to consult with aquatic resource users to identify and characterize aquatic habitats.

1. Groups of aquatic resource users (include all users: men, women *and* children) can be asked to map aquatic habitats, characterize them and possibly rank their importance for different aquatic resource uses (reflecting both habitat quality, and ease of access and capture for users).
2. Visits to selected habitats should be undertaken to cross-check information and carry out measurements.

The mapped habitats should be characterized according to the following attributes:

A. Physical characteristics of habitats

- Natural or man-made
- Lake/wetland/floodplain water area (wet and dry season)
- Channel width (rivers/streams, wet and dry season)
- Channel slope
- Sinuosity ('wigglyness', measured as channel distance divided by down-valley distance)
- Water depth (wet and dry season)
- Flow velocity (wet and dry season)
- Macrophyte cover

B. Hydrological processes maintaining habitats

- Irrigation supply
- Seepage/waterlogging
- Drainage
- Runoff and natural flooding

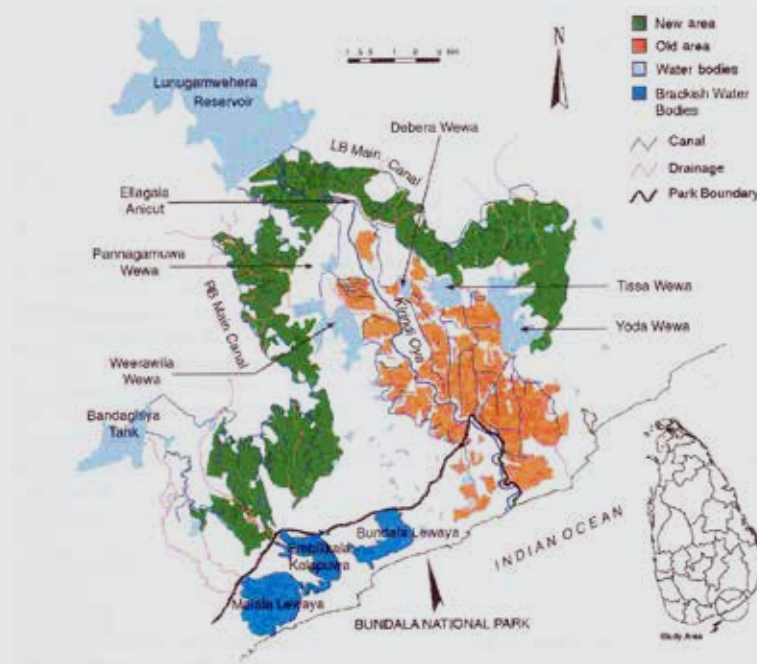
C. Connectivity between habitats

- Natural and man-made barriers disrupt connectivity for fish movement

Tabulate habitat characteristics by water body and summarize the extent of different habitat types (e.g., temporary floodplain, stream, etc.). The summary may be used later to identify the habitat types that will be most affected by irrigation development, and whether certain types will be lost altogether, thus reducing the local diversity of habitat.

Source: Lorenzen *et al.*, 2007.

BOX 3 An example of an irrigation scheme and water resources mapping: Kirindi Oya, Sri Lanka



Source: Nguyen-Khoa, Smith and Lorenzen, 2005b.

Note: The 'extended area' considered is the Kirindi Oya Basin downstream of the Lunugamwehera Reservoir, the irrigation scheme and the lagoons receiving drainage water in a neighboring watershed.

1.3 Socioeconomic and livelihoods context

Drawing from the understanding of the biophysical context and changes in access to resources, irrigation professionals need to understand how fishers and farmers use different parts of the irrigation system – for what, by whom, when, and what contributions are made to livelihood strategies. A socioeconomic profile will reveal sources and extent of socioeconomic differentiation within the potentially affected population. Sources of differentiation may include caste, class, social status, age, gender, language, religion, ethnicity and mobility.

A preliminary socioeconomic profile of the area can be prepared (see Box 4) using secondary information, direct observations and reconnaissance field visits, and discussions held with stakeholders and key informants (e.g., local government officials, merchants, school teachers, NGO representatives, etc.). More refined information may be obtained using methods of wealth ranking or other participatory and/or rapid rural appraisal techniques, such as focus group discussions, semi-structured interviews with key informants who are representative of different socioeconomic groups, and resource use mapping.

Where the above still leaves data inadequate for differentiation of livelihood assets, or livelihood options and labor allocation, or for the purposes of carrying out a full detailed assessment, then a well-focused formal household survey may be required (Lorenzen *et al.*, 2007).

BOX 4 Outline of a socioeconomic profile

A. Location and physical characteristics

- Description of location
- Sketch map (better if) showing roads, land use, water bodies, rivers, bridges, major settlement areas

B. Demographic

- Age/sex/family size
- Health and nutrition
- Migration (in and out)
- Single parent households
- Gender differentiation of households
- Ethnicity, language, religion

C. Economic

- Use and access to marketing services
- Use and access to commercial inputs
- Use and access to livelihood assets – natural, physical, financial, human and social capital
- Employment and allocation of labor
- Types of livelihood activities and their diversity

Source: Adapted from Lorenzen *et al.*, 2007.

Understanding how the different patterns of use vary for different groups will be key to determining who will be particularly affected by changes in the irrigation system (see Toolbox 3).

TOOLBOX 3 A framework for analysis of rural livelihoods

Assets	for which access is modified by	in a context of	resulting in strategies	composed of activities	with outcomes in terms of
<p><u>Natural</u> e.g., land, water, fish stocks, forest</p> <p><u>Physical</u> Infrastructure, tools and buildings</p> <p><u>Human</u> Skills, knowledge and health</p> <p><u>Financial</u> Income flows, savings, credit</p> <p><u>Social</u> Kinship networks, associations, trust, access to wider institutions</p>	<p><u>Social relations</u></p> <ul style="list-style-type: none"> ▪ Gender ▪ Wealth rank ▪ Class ▪ Age ▪ Ethnicity <p><u>Institutions</u></p> <ul style="list-style-type: none"> ▪ Customary ▪ Land and water tenure ▪ Markets <p><u>Organizations</u></p> <ul style="list-style-type: none"> ▪ Associations ▪ NGOs ▪ Local administrations ▪ State agencies 	<p><u>Trends</u></p> <ul style="list-style-type: none"> ▪ Population ▪ Migration ▪ Technological change ▪ Relative prices ▪ Macro policy <p><u>National and world market trends</u></p> <p><u>Shocks</u></p> <ul style="list-style-type: none"> ▪ Climatic ▪ Market ▪ Disease ▪ Conflict 	<p>Livelihood strategies</p>	<ul style="list-style-type: none"> ▪ Fishing ▪ Cultivation (non-market) ▪ Cultivation (market) ▪ Livestock ▪ Other hunting and gathering ▪ Rural manufacture ▪ Rural trade ▪ Services ▪ Farm labor ▪ Non-farm labor ▪ Migration ▪ Remittances ▪ Other transfers 	<p><u>Livelihood security</u></p> <ul style="list-style-type: none"> ▪ Income level ▪ Income stability ▪ Seasonality ▪ Vulnerability <p><u>Environmental sustainability</u></p> <ul style="list-style-type: none"> ▪ Soil and land quality ▪ Water ▪ Fish stocks ▪ Forests ▪ Biodiversity
Resource endowment	Institutional and policy environment, and vulnerability context		Household choices and resource allocation		Outcomes

Source: Adapted from Smith, Nguyen Khoa and Lorenzen, 2005; modified from Allison and Ellis, 2001.

1.4 Governance context

Governance arrangements for fisheries, water resources and the environment are inevitably diverse and complex as they encompass agencies and institutions that are both multi-level and multi-scale, as well as formal and informal. There may be several types of organizations tasked with issues related to water management, fisheries and local government. Ideally, all these functions are integrated into a coordinated arrangement, but this is rarely, if ever, the case.

At irrigation system level, irrigation planners may seek assistance from institutional development specialists to understand the following three aspects of governance: local institutional arrangements, national legislation for fisheries and water resources, and coordination between institutions and potential for local partnerships or co-management.

1.4.1 Local institutional arrangements

Implementation of an irrigation project is not just a technical intervention, it is also a set of rules or institutions that aim to facilitate the implementation, performance and sustainability of the scheme. **At the outset of irrigation projects, these rules rarely include provisions to protect and sustain fisheries.** Attempts should be made to identify such gaps.

Frequently, there is a difference between what institutions prescribe and what people do. These need to be understood when investigating the existence and effectiveness of institutions. The following three nested levels are commonly recognized for institutional arrangements:

- The **operational level** and operational rules that relate to day-to-day actions and resource use.
- The **collective choice level** and collective choice rules that relate to how operational rules are decided and enforced for an irrigation scheme or fishery at the local level.
- At the **constitutional level**, rules are set at a higher level by provincial, national or international authorities.

It is, therefore, important to understand the following:

- **Interactions between the operational, collective choice and constitutional levels.** Unexpected or undesirable outcomes can result from the way operational rules are made rather than the rules themselves. Decision-making regarding an irrigation scheme often occurs without consulting people who understand and can predict the possible impacts of irrigation on fisheries. An example is the operational decision for managing gates for irrigation water rotations, which may dry out some channels or fields, thereby negatively impacting fish. This problem lies at the collective choice level.
- **Where rules are made and by whom.** The operational rules that determine who, where and how someone can fish may have come from a mixture of, sometimes conflicting, government legislation, local customary rules and community organizations.

Annex 2 summarizes key local institutional arrangements set out as operational and collective choice rules that need to be understood during irrigation scheme planning. Because such institutional arrangements may be formal or informal, and involve several levels of organizations, information must be obtained from a range of stakeholders. For example:

- **From the government at national and local levels:** e.g., for formal rules governing the use of fisheries (e.g., gear or seasonal restrictions), and the rights of resource users to make local operational rules.
- **From resource users:** e.g., who can fish, where, when and how? Local customary rules may seem natural and obvious to local people, and it may be necessary to ask a range of probing questions to gain such information.

1.4.2 National legislation for fisheries, water resources, irrigation and the environment (constitutional rules)

A review of the relevant policies, strategies and, most importantly, legislation should be undertaken to understand potential constraints, contradictions and gaps over the use of water, and identify possibilities to integrate fisheries conservation into integrated water resources management. There is a particular need to identify perverse policies and incentives as considered in Part I, Section 2.3. For example, those that can result in the degradation or destruction of fisheries habitat.

Ideally, irrigation planners and managers will be held accountable by the stakeholders (see Step 5). In many instances, irrigation planners and managers will need to adopt a precautionary approach⁴ within the context of an inadequate or dysfunctional regulatory environment that is unlikely to adequately protect the interests of the most vulnerable groups in society.

At a higher level, policy reform and new legislation may be required (Box 5). Immediate solutions can rarely be expected, but the needs identified at project level can inform the development of longer-term national policy aimed at integrating land and water resources management for fisheries and irrigated agriculture.

BOX 5

Examples of policy and legislative reforms, and harmonization of integrated water resources management for fisheries and irrigated agriculture

- Strategies that value the transition from single-use to multi-use natural resources systems, often linked to food security, health and growth-oriented policies.
- Allowing capture fisheries in irrigation canals and rice paddies.
- Allowing irrigation water to be used for aquaculture inside the irrigation command area.
- Allowing the use of man-made water bodies for fisheries.
- Restrictions on drainage or conversion of wetlands (seen as unproductive when fisheries and other ecosystem services are ignored) to farmland or urban development.
- Mandatory requirements for EIAs and effective public participation to screen and identify significant potential impacts on fisheries and the environment.
- Legislation requiring effective mitigation measures for the implementation of irrigation infrastructure and its operation, which is applicable for all investments in irrigation development and rehabilitation.
- Environmental legislation for the protection of environmental flows and ecosystem services.

In the short term, locally-applicable solutions can be sought through stakeholder consultation and working in partnerships, legitimized by local agreement and endorsement by a higher authority (or through powers delegated to local authorities). Such local agreements can ultimately inform and promote the need for mainstreaming reform at the national level.

1.4.3 Coordination between institutions, local partnerships and co-management

Identification, design and implementation of effective mitigation measures to protect fisheries from the negative impacts of irrigation development, and to exploit and enhance positive impacts will often best be achieved through working in partnership with relevant government agencies and CBOs. This can lead to the development of co-management arrangements and community-based management plans for the implementation of measures that both enhance irrigation performance and agricultural productivity and protect and sustain fisheries (see example in Box 6).

⁴ The precautionary approach defines the scope for action when there is uncertainty and potential for harm. The approach implies that there is a social responsibility to protect the public from exposure to harm, when scientific investigation has found a plausible risk.

BOX 6 Successful examples of fisheries co-management

In Lao People's Democratic Republic, development of the first national fishery law specifically enshrined the role of resource users to form groups to manage their resources and to have this legally recognized. It has empowered them to develop management plans for fisheries, on which they depend.

Allison and Badjeck (2004) provided details of other best practices in inland fishery co-management. Pomeroy, Katon and Harkes (2001) listed the criteria for successful co-management and community management of fisheries.

Effective and inclusive stakeholder engagement (see Section 2) can provide the foundation for development of such arrangements. These may later need provision in policy and/or law to confirm their legitimacy and status.

The absence of effective governance arrangements to protect the environment and vulnerable groups does not absolve irrigation planners and managers from responsibility. On the contrary, it enhances the need for them to act conscientiously, through public and stakeholder consultation, in partnership with relevant government agencies and communities, and based on the best available data and scientific understanding.

2. Engaging with stakeholders

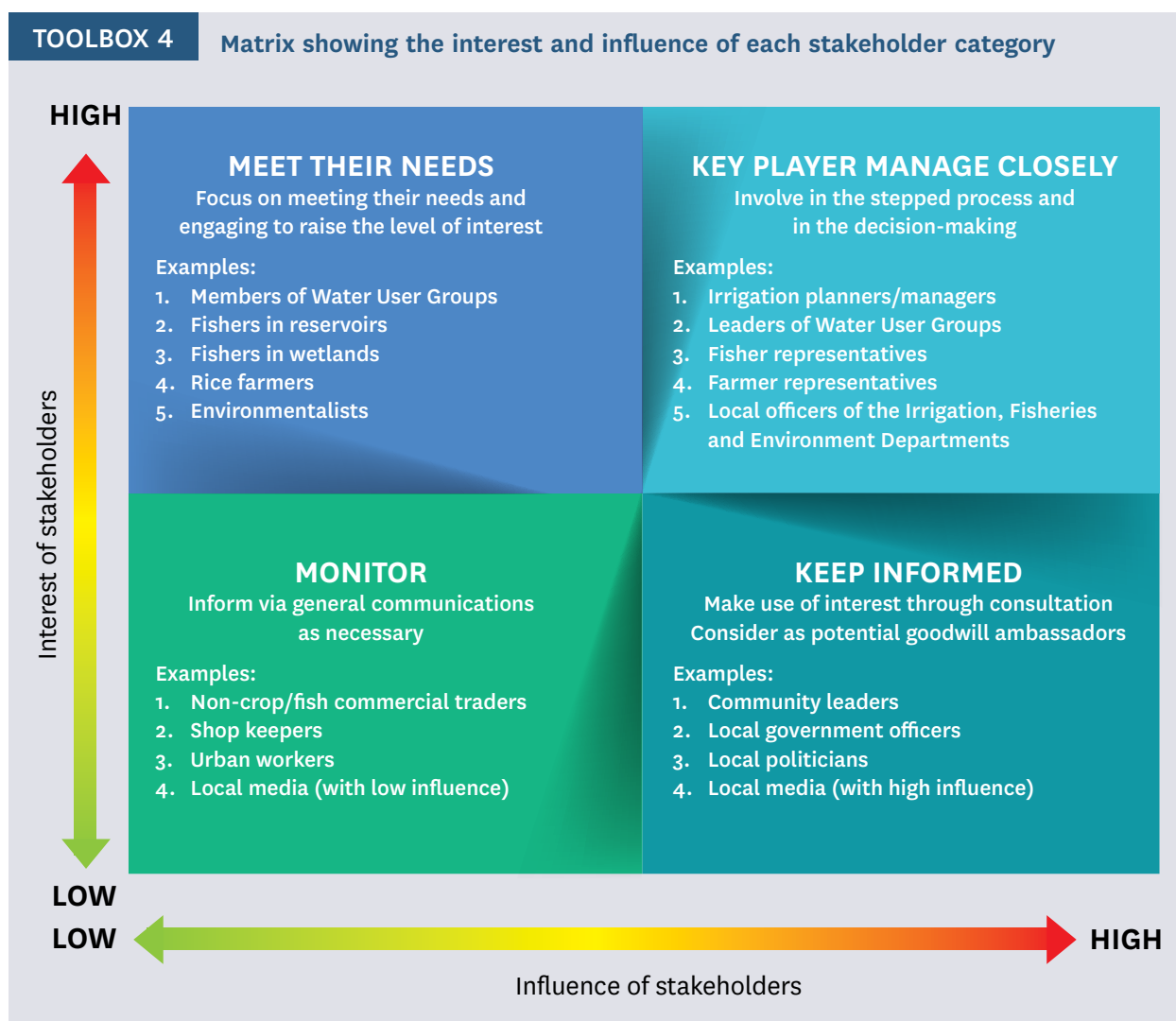
Engaging with stakeholders first requires understanding the range of stakeholders within and downstream of the irrigation system. Different forms of engagement are proposed. It must be noted that the process of engaging may raise tensions or even conflicts between stakeholders, and the irrigation professionals assisted by social scientists should be prepared to help resolve these.

2.1 Stakeholder identification, mapping and analysis

1. Identify all relevant stakeholders, i.e., all persons, groups and organizations with a stake in fisheries and/or the irrigation system:
 - Distinguish primary stakeholders (those directly affected, primarily those deriving at least part of their livelihoods from the system) from secondary stakeholders (those involved in managing the fishery or irrigation system but not directly affected, e.g., government departments or NGOs).
 - The identified stakeholders may need to be subdivided further, for example, by a range of social identities such as wealth, gender, occupational group, ethnicity and even age.
 - *Link and review during the livelihood analysis in Step 3.*
 - Assess whether new stakeholders are likely to emerge as a result of irrigation development (e.g., specialized reservoir fishers).
2. Assess the vulnerability of the groups to biophysical, ecological and socioeconomic changes as a result of the irrigation system.
3. For each stakeholder category, evaluate their interest, influence and power in the fisheries-irrigation system, and create a simple matrix (see Toolbox 4). Some individuals are likely to fit into more than one of the categories, e.g., the village leaders who are major landowners and dominate Water User Groups.

TOOLBOX 4

Matrix showing the interest and influence of each stakeholder category



4. Map stakeholder vulnerability drawing from the matrix showing their interest and influence (Toolbox 4). This includes the position of the stakeholder to influence the management of, and benefit from, new opportunities for integrating fisheries in the irrigation system.
5. Assess the responsibilities and capacities of relevant government agencies, CBOs and NGOs that are potential partners for fisheries and irrigation development/management. This will support the analysis of required coordination between governance actors (see Section 1.3).
6. Appraise the political economy to be aware of potential vested interests. Informal and often less visible factors may shape institutional performance and resource management. For example, rent-seeking by the Department of Fisheries in Myanmar through the auctioning of monsoon season fish lots in open access areas.

2.2 Mechanisms for stakeholder engagement

- Drawing from the stakeholder analysis, invite representatives of the 'key players' to engage in the stepped process.
- Define the type of engagement with each stakeholder representative:
 - **Partnership:** work together as equal partners to address a common water challenge.
 - **Involvement:** support the contribution of stakeholders having a joint interest.
 - **Consultation:** actively meet or discuss proposed actions.

- **Information:** inform stakeholders about the progress in the stepped process, and allow them to ask questions or raise concerns, if needed.

In a co-development process, a multi-actor process will facilitate discussion and negotiation to generate the institutional architecture.

- Create a committee with decision-making authority.
Since the institution needs to fit and respond to the level of complexity of the irrigation system, there may be more than one committee in a nested governance structure. For example, see de Silva *et al.* (2019).
 - Refer to *Governance of water and fisheries - Part I, Section 2.3.*
- Define roles and responsibilities, including those of irrigation planners and managers, for co-management.

2.3 Potential conflicts raised by irrigation systems

Often it is the emergence of conflicts surrounding the construction and operation of irrigation schemes that leads to the first calls for more effective integration of fisheries. Conflict should be viewed as an opportunity for change. Working through conflicts often leads to greater commitment to addressing issues and implementing consensual measures.

2.3.1 Typology of conflicts

Irrigation development often initiates conflicts typically between different water users due to competing needs and interests within and outside of the command area. It must be noted that irrigation development may also raise or intensify conflicts between different types of fisheries activities (especially capture fisheries and aquaculture) and among fishers themselves (see Box 7).

Conflicts may also arise because stakeholders are brought into the process too late. While stakeholder engagement in large schemes is extremely complex, it may be possible to revisit the objectives and drive the design of smaller irrigation schemes as part of the co-development process. Failure to involve users of the scheme in the design can complicate institutional development by creating problems (e.g., poor water delivery).

Conflicts between fisheries and irrigated agriculture

The following could be the source of such conflicts:

1. **Physical system:** water storage, water diversion, flood protection, change in land use, water delivery, water removal, excessive nutrient enrichment.
2. **Operation of the scheme:** irrigation scheduling, maintenance of waterways and embankments, land use.

For example:

- Draining down of small reservoirs to secure rice, at the expense of wild or stocked fishery.
- Draining down of rice paddies for harvest.
- Draining and drying out of the main canals in the distribution system.
- Dry-season irrigation versus supplemental irrigation in the wet season.
- Diversion of water from rivers or inadequate flow releases from dams to sustain river fisheries and fish migrations.
- Excessive short-term variation in water levels either within the irrigation system or in the river downstream.

- Operation of saline barrages preventing fish migrations.
- Opening of polders to allow fish to enter into the system versus storage of freshwater.

3. Production of crops

Irrigation may lead to changes in cropping and farming patterns, often towards more controlled and productive patterns, such as the following:

- Shifting to short stem rice or lower water-consuming varieties. The introduction of short stem and faster-growing rice (e.g., system of rice intensification [SRI]) affects rice-fish farming as the irrigation period is shortened.
- Change in rice varieties that require higher applications of fertilizer or pesticide⁵.
- Shifting from rice to other (often higher value) irrigated crops that need less water.

Conflicts between fishers

Purposively or not, irrigation development leads to changes in the pre-project fisheries activities in terms of access to aquatic habitat, productivity and distribution of benefits (see Part I, Section 2). These changes, if not properly managed, often lead to tensions or conflicts, such as the following:

- Fishers gain access to improved fishing at choke points or barriers (e.g., weirs, water gates or in front of dams).
- Non-traditional fishers move to and access a new reservoir, and original river fishers lose out as their fishery declines after damming and loss of connectivity.
- Women and men lose fish catches from a river or rice fields due to changes in water flow and connectivity.
- People lose access to fishing areas formerly under common property arrangements.

These examples illustrate the challenges of elite capture and other forms of inequity, and underline the need for co-development of structures, rules and processes through consensus building.

2.3.2 Conflict resolution: from conflict to consensus?

Opportunities for conflict resolution occur primarily at four stages of the irrigation project cycle:

1. Characterization of the irrigation project and understanding different stakeholder needs and interests in terms of water requirements, and potential impacts on their respective well-being in the scheme; important information that should shape choices made during scheme design.
2. Design, planning and operation processes for multiple water users and uses.
3. Operation of the irrigation project, especially if agreements such as gate operation or prevention of fishing directly adjacent to these gates are not adhered to (see also Part I, Section 2.2).
4. Rehabilitation of the scheme, when there is an opportunity or a new chance to resolve long-lasting conflicts.

Steps towards a resolution

Conflict resolution can be understood along a spectrum of approaches from ‘public involvement’ at one end to negotiation and arbitration at the other. The former is oriented to building consensus through mechanisms such as advisory groups and public meetings, with the aim of increasing the legitimacy of final decisions. Conflict management is an approach that avoids either extreme and aims to reach a middle ground through workshops and collaborative problem solving. At the other end of the spectrum, negotiation is not aimed at building consensus, but rather attempts to deliver mutually agreeable solutions to satisfy

⁵ Pesticides may poison fish directly or kill the insects on which they depend for food.

BOX 7 Typical scenarios of conflict

Less of a problem

When a Water User Group is also the fishery/aquaculture stakeholder group, the issue of conflict resolution is internalized within the group. An example of this is community irrigation groups that pump or abstract water from a natural water body or small irrigation reservoir, which is used as a stocked fishery. Decisions on using water for irrigation or sustaining the fishery are made among the users within the group.

More of a problem

More typically, a fishery group may be located outside the command area and may not even be from the same community. An example of this is fishing communities using large reservoirs while the Water User Groups are based within the command area. In these situations, decisions on the management of the reservoir and its drawdown can have impacts on fisheries, but there may be little or no accountability. Such impacts can lead to conflicts over the operation of WCI.

each party's underlying interests by proposing alternative actions; the ideal being win-win solutions as opposed to zero-sum situations, but often this involves trade-offs or concessions by some or all of the parties involved (see Box 8).

The majority of conflicts that emerge are social rather than technical in nature. Whatever the approach, a key aspect is the engagement of a diverse group of water user representatives to deliberate on the issues that the design, operation and management of the irrigation project can help to solve (Toolbox 5); for further details, refer to, for example, de Silva *et al.* (2019). These agreements are often mediated by a third party and work best if documented in the form of a resolution agreement or plan or institutional design with a clear mechanism for enforcement. It is also important to evaluate the impacts of the agreements according to an agreed schedule and, if necessary, update the agreements to reflect any emergent issues.

BOX 8 An example of conflict resolution

The Pak Mun Dam in Thailand was initially constructed as a multi-purpose dam, primarily for hydroelectric power generation and secondarily for irrigation. During its construction, the dam became the focus of considerable conflicts with fishers who had lost fishery opportunities due to disrupted connectivity with the Mun River. This was due to the construction of the dam and failure in the design of the associated fish passage.



Photo: Michael Akester, WorldFish, Yangon, Myanmar.

Following years of protest and negotiation, a redesign of the operation based on evidence from community research delivered several mitigating actions to ameliorate this impact. These measures included the seasonal opening of the dam gates for three months to enable fish migrations up the river; and stocking of the water body behind the dam to establish a higher-value freshwater prawn fishery to increase fishers' incomes. This model took a partnership approach with communities and civil society groups working together to resolve conflicts.



Photos: Michael Akester, WorldFish, Yangon, Myanmar.

Component 1 (Conflicts): Discussions with specific stakeholder groups will be needed to gain an in-depth understanding of their views, vulnerabilities, opportunities and ideas. These discussions should then lead to the multi-stakeholder dialogues, where an understanding of each stakeholder’s situation helps the project mediate the process.

Placing the outcomes of the analysis (e.g., what could result in key conflicts and why) within the physical and administrative landscapes is important to understand the effectiveness of the institutional structure.

Component 2 (Conflict resolution and system design): Responses take shape as a result of the enhanced understanding and reflection in Component 1.

Deliberations will need to cover both technical and social aspects since they are interlinked, and some solutions may need adjustments in both domains.

Component 3 (Conflicts are resolved or mitigated): The analysis and negotiations will usually lead to new or modified institutional arrangements, and possibly modifications in irrigation system design and/or its operational rules.

STEP 2

Assessing the key impacts and opportunities

A good understanding of the context of the irrigation project, acquired in Step 1, will help to pursue the following activities with stakeholders engaged in the process:

- Clarify the objectives and benefits of both irrigation and fisheries in the defined system.
- Prioritize the impacts and opportunities through risk assessment.
- Assess these priority impacts and opportunities.

1. Objectives and benefits of irrigation and fisheries

The objectives of the irrigation project, defined in Step 1, are put in perspective with the objectives of fisheries pre- and post-intervention. The latter should be expressed not only in terms of additional fish production or livelihood benefits, especially for the more marginal groups with limited livelihood options, but also in terms of restoration of aquatic habitat and biodiversity, and associated ecosystem services.

2. Prioritizing impacts and opportunities through risk assessment

Risk assessment helps to prioritize irrigation impacts and opportunities (Toolbox 6 and Annex 3). For new irrigation schemes, this can also help optimize the type of intervention and/or its location. Such assessment can be qualitative and opinion-based where there is little monitoring data but good local ecological knowledge of fisheries. It can also be quantitative and based on data where there are sufficient data on fish location and movements. A stakeholder-centered process utilizes local knowledge and allows differently positioned and capacitated stakeholders to articulate the risks due to potential changes.

A risk assessment typically seeks answers to the following questions (FAO, 2019):

1. What can go wrong in the system to have negative impacts on fisheries? (the risk)
2. How likely is this to happen, or how frequently does this occur? (the likelihood)
3. What is the consequence of this occurrence? (the impact)
4. What can be done to reduce either the likelihood or the consequences of things going wrong? (the action)

TOOLBOX 6 Semi-quantitative risk assessment

A risk matrix can be used to define the level of risk by considering the category of probability or likelihood of occurrence against the category of consequence (or impact) severity. This is a simple mechanism to increase the visibility of **risks** and assist management decision-making.

	Consequence				
Consequence	Insignificant	Minor	Moderate	Major	Severe
Almost certain	Medium	High	High	Extreme	Extreme
Likely	Medium	Medium	High	Extreme	Extreme
Possible	Medium	Medium	High	High	Extreme
Unlikely	Low	Medium	Medium	High	High
Rare	Low	Low	Medium	High	High

The 'likelihood' is the probability of occurrence and the consequence is the severity of impacts if the change occurs. Priority issues are those that have a high likelihood of occurring and for which consequences (negative or positive) are high or extreme. These priorities are the most important issues that require assessment and mitigation or enhancement.

The key consequences generally cover the following areas (see Part I, Section 2):

1. Biophysical: physical habitats, fisheries ecology and yields.
2. Fisheries production and livelihoods.
3. Governance of water resources and fisheries.

3. Assessing the priority consequences

The assessment is based on the comparison with a situation 'without a project':

1. **A new scheme:** the situation before implementation of the project.
2. **Rehabilitation of an existing scheme:** a 'control' area that had similar pre-project conditions and has not been subjected to irrigation development.
3. **If (1) and (2) above are not possible:** evaluate pre-project trends for key variables and assess the extent to which these may have continued in the scenario 'without a project'.

Priorities will be defined according to the perspectives of multiple stakeholders (as defined in the introduction in Part II). In all cases, flexibility is needed to allow investigation of any new significant issues identified during the impact assessment.

3.1 Biophysical impacts

Biophysical impacts on capture fisheries may be caused by WCI and/or its operation and management. Annex 4 provides a typology of impacts for each root cause, which is essentially the following:

- Barriers to longitudinal river flow (weirs, dams and barrages)
- Barriers to lateral river flow (embankments/levees)
- Controls to river flow/diversions (gates/regulators)
- Pumps and turbines
- Off-river water storage (ponds)
- Conveyance of water (channels, pipes, culverts and drainage ditches).

For each issue or root cause of impact, Annex 4 provides insights on the following factors:

- Risks and opportunities
- Consequences
- WCI options
- Operation and management options

3.2 Impacts on fisheries production and livelihoods

Impacts and opportunities can be assessed through an analysis of the primary stakeholders' livelihoods, holistic assessment of household livelihood strategies, and prediction of trajectories of change in livelihoods due to irrigation development.

Principles of the livelihood analysis are given below (see also Toolbox 3):

1. **Appraise the five types of livelihood assets:** natural, physical, human, social (including indigenous user rights) and financial (for further details, see DFID, 2000).
2. **Understand how people use these assets** through a range of activities to achieve positive livelihood outcomes.
3. **Consider linkages between activities at macro and micro levels**, and the importance of the policy and institutional environment in influencing chosen livelihood strategies and outcomes.
4. **Assess** how biophysical and socioeconomic changes as a result of irrigation development will (or have) **change(d) access to livelihood assets and activities, and resulting outcomes**. In the assessment, consider the resilience and sensitivity of livelihoods, the most vulnerable households being those with low resilience and high sensitivity to change or external shocks.

The assessment must be people-centered, holistic and dynamic in seeking to understand and build upon processes of change.

Using Toolbox 3 and Annex 3 to identify data needs and issues to be considered, the following must be assessed:

1. Where and how will actual or potential productivity of fisheries change, what livelihood impoverishments or improvements are likely to result from this, and which households will be positively or negatively affected by these changes?
2. Where and how will patterns of access to the fishery change, and what livelihood changes are likely to result from this for some or all households?
3. How will predicted livelihood changes be distributed between groups, households and individuals (including between men and women, and young and old)?

STEP 3 | Screening and scoping preliminary measures

Based on an understanding of the biophysical, socioeconomics and livelihoods, and governance contexts of the irrigation project as well as its major impacts on fisheries, a range of potential measures for mitigating negative or enhancing positive impacts can be screened, and the most adequate measures should be preliminarily selected. Whatever the type of irrigation system, and wherever it is located within a catchment, selected measures will only be successful if carefully tailored to the biophysical, ecological and socioeconomic context of the irrigation system.

1. Screening the potential measures

The potential measures for mitigating negative or enhancing positive impacts essentially target the following objectives:

1. Minimizing loss and degradation of existing aquatic habitat.
2. Maintaining ecological connectivity.
3. Compensating for losses (or offsetting losses with alternative fishing options).
4. Developing new aquatic habitat.

While, ideally, all four of the above objectives should be considered together, priorities will depend on local circumstances, stakeholders' preferences and trade-offs between these objectives (see Step 4). Figure 7 illustrates a range of measures to mitigate negative impacts and enhance fisheries in irrigation systems.

For each impact identified in Step 2, several measures are proposed and evaluated according to their risks, costs and benefits (see Annex 4).

1.1 Mitigation

Mitigation measures center around the principles of maintaining aquatic habitats and their connectivity.

1. Maintain aquatic habitats: preserve these habitats from (wet)land drainage or infilling, and prevent or mitigate loss or degradation of habitats from land use.
2. Maintain connectivity between water bodies and habitats: there are two basic options to maintain connectivity, i.e., the use of fishways, and the manner in which WCI is operated. Placing a fishway on every water regulator would be too costly and would typically result in water flows that could not be sustained in the system. Therefore, the best sites for setting up a limited number of fishways should be determined to achieve both biological optimization and minimal impact (see Gregory, Funge-Smith and Baumgartner, 2018). Water gate management is a complementary or alternative option, where gates are opened at critical periods to enhance migration and movement of fish in the system.

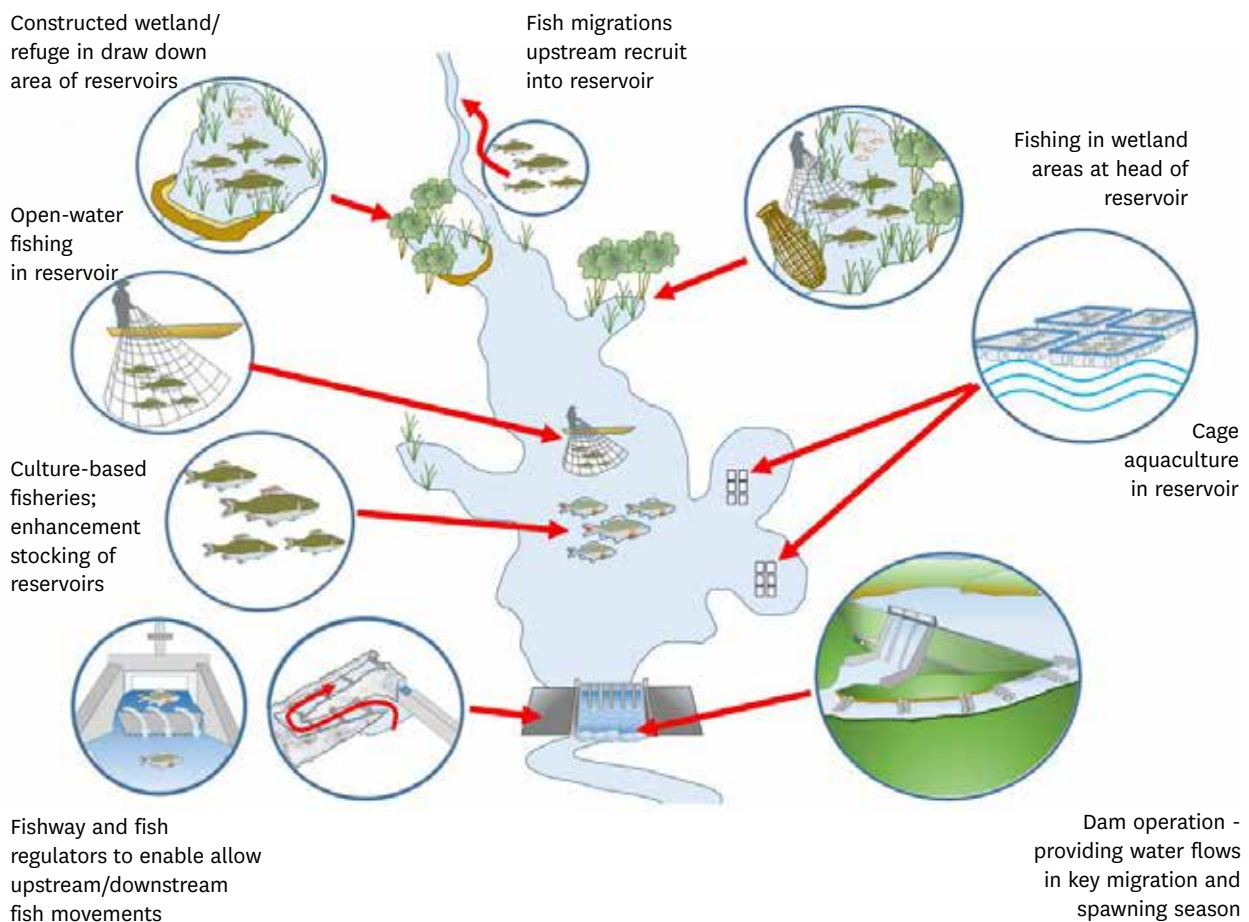
1.2 Enhancement or improvements

Enhancement measures focus on developing fisheries in newly created habitat, increasing fisheries production and improving the supply chain.

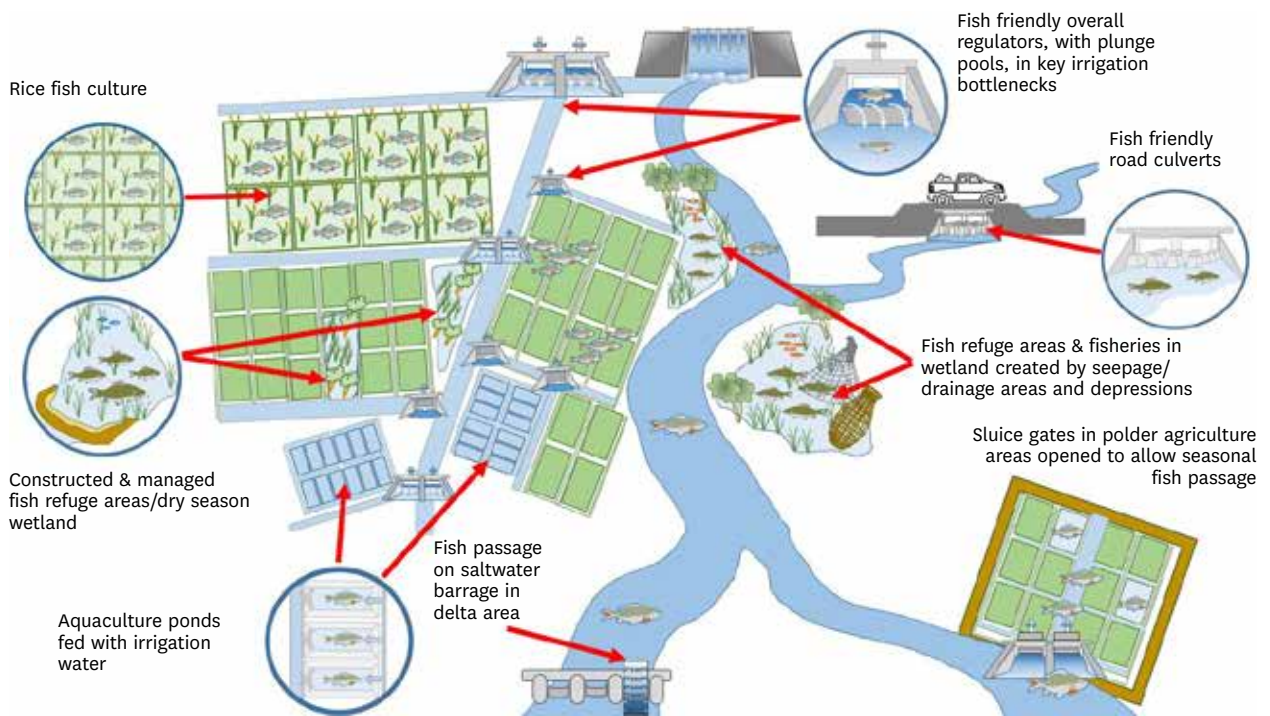
1. **Fisheries in newly created habitats:** the irrigation system often creates reservoirs, and irrigation and drainage canals. Compared to river fisheries, large reservoir fisheries tend to be less dependent on seasons and provide opportunities for economies of scale. This often leads to the emergence of full-time professional fishers using more efficient equipment (such as motor boats, gill nets, seines and large lift nets) and are likely to be better-off than the most-affected fishers. This may require fishers to move location and often results in the establishment of new communities. There is also the possibility of developing fisheries in smaller irrigation reservoirs and ponds, irrigation canals, irrigated fields, as well as in adjacent ponds or aquatic refuges. If adequately managed, all these are potential habitats for fish and hence opportunities for fisheries.
2. **Increasing fisheries production:** besides fishing in the new habitats, moving along the fisheries continuum towards stock enhancement and culture-based fisheries can increase fish production. There are also opportunities to enhance or improve the habitat within water bodies through the creation of refuge areas and planting of vegetation. This can encourage fish breeding or increase the survival of early stages of fish development (e.g., fry and fingerlings (FAO, 2015)).
3. **Improving the supply chain:** post-harvest technologies, marketing and the development of fishermen's organizations can improve the supply chain. This is typically only viable where there is a high volume of production and focused landing sites. This situation usually occurs only in reservoir fisheries.

Figure 7. A range of measures to enhance fisheries in irrigation systems

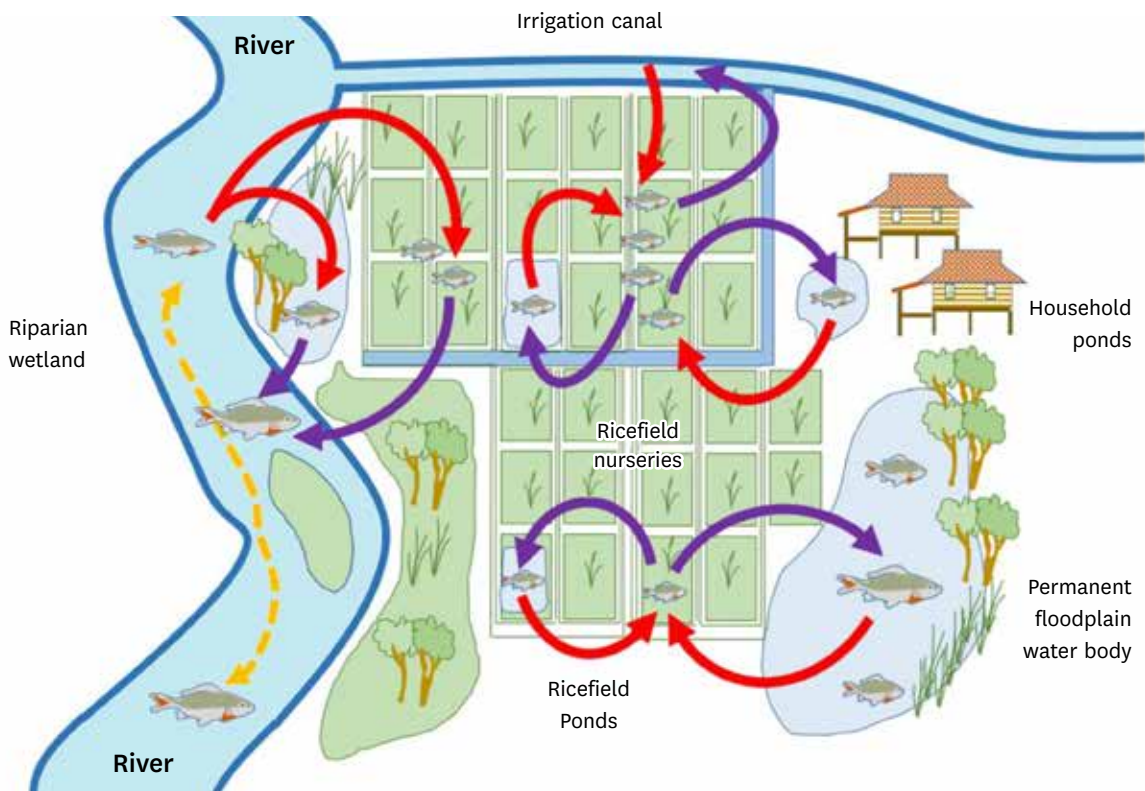
1. Upstream of a dam



2. Downstream of a dam



3. Polders and floodplain systems



Source: Gregory, Funge-Smith and Baumgartner, 2018.

Notes: Movements of fish between rivers, floodplains, water bodies, rice fields and irrigation systems. Red arrows show lateral migrations during the rainy season. Purple arrows show lateral migrations that occur at the onset of the dry season. The yellow dashed line indicates the upstream and downstream migration of riverine fish.

2. Scoping and selecting preliminary measures

Preliminary measures are selected from the wide range of available measures as follows:

1. Define the main objectives of the irrigation and fisheries measures to be integrated.
2. Assess the annual costs of non-mitigated negative impacts on fisheries production. Such costs need to be compared to costs of mitigation and enhancement measures. It must be noted that social and environmental impacts are unlikely to be fully accounted for in monetary terms, and hence it will be best to ensure decision-making is based on multi-criteria analysis (MCA) as considered in Step 4 (Section 2).
3. Assess the mitigation and enhancement measures against a series of qualitative or semi-qualitative criteria to facilitate choice. These criteria are as follows:
 - **Suitability:** How well does the measure fit into the system, landscape or biophysical and socioeconomic context?
 - **Feasibility:** How easy will it be to design and construct or retrofit the fishery enhancement measure? What changes in user behavior are needed? How easy will it be to manage or change user behavior?
 - **Cost of measures and technical requirements:** Details of low to higher technological measures are provided in Box 9. For example, the cost of measures could be: Very low (< USD 1 000), Low (< USD 10 000), Medium (< USD 50 000), High (< USD 100 000), and Very high (> USD 100 000).
 - **Effectiveness:** How effective will the measure be for enhancing the fishery and its contribution towards achieving the objectives, including greater food security and poverty alleviation? Stakeholders will contribute to defining how to achieve the objectives and who should be targeted. In some cases, effectiveness may be known from experiences in other locations. In other cases, e.g., fishways, the effectiveness will have to be estimated. Assessing the likely effectiveness of a measure often requires the input of a fisheries specialist.
 - **Implications:** Does the enhancement measure have implications for water allocation and use, including new trade-offs between irrigation and fisheries? Does the measure have other environmental or social impacts? If yes, these should be described and quantified to the extent possible.
 - **Management requirements:** Does the enhancement measure have specific management requirements for both water resources and fisheries? If yes, these should be described.

These criteria may be assessed on a scale of Very high (5), High (4), Medium (3), Low (2) to Very low (1) in a scoring matrix.

BOX 9 Cost of measures and technical requirements

Low technology: Reserving an area for construction or modification of seepage/waterlogged area to function as a constructed wetland/refuge. The costs include some minor earthworks, perhaps some channel connectivity, and the cost of the extra water allocated.

Medium technology: Stock enhancement requires recurrent investment costs and a hatchery, maybe on a cost recovery basis for small water bodies in developed countries. Associated costs include water to ensure environmental flows, water releases to maintain levels in refuges, gate opening to allow migration/movement of fish at critical periods, and other minor operational costs/complexities.

Higher technology: Infrastructure modifications of sluice gates to overshot gates with plunge pools and the larger tropical fish ladders. Associated costs include water to ensure flows and other minor operational costs/complexities.

Three practical scenarios are proposed in Annex 5. They typically aim to achieve the following objectives:

1. Sustain or enhance reservoir fisheries or capture fisheries within the irrigation command area (canals, small reservoirs and ponds or fields) to support the livelihoods of local communities, including, if appropriate, resettled villages.
2. Maintain some level of fish productivity below the irrigation scheme to support the livelihoods of downstream communities.
3. Create or enhance opportunities for capture fisheries in and around the irrigation scheme to add to its value and bring benefits to local communities.

STEP 4 | Evaluating the trade-offs and selecting the best measures

Integrating fisheries into irrigation systems often leads to trade-offs between competing objectives and stakeholder interests, as well as between the measures identified to satisfy these. Irrigation professionals often face challenges when selecting the most appropriate measures. This necessitates an analytical decision-making process.

Given the significant range of trade-offs between fisheries and irrigation, these first need to be fully understood, identified and then evaluated against the criteria selected with the stakeholders.

1. Identifying the trade-offs

Trade-offs between water requirements for irrigation and fisheries will arise throughout the planning, design, construction, operation and management phases of the project. The different types of trade-offs should be identified before selecting those that are acceptable. It must be noted that trade-offs arise even between the objectives of fisheries (conservation versus production and productivity) and the livelihoods functions that are targeted (income generating versus poverty alleviation versus food/nutrition security).

When the targeted objectives have been clarified (Step 1), trade-offs may arise between water requirements for irrigation and fisheries (e.g., Table 4).

Table 4. Typical trade-offs between water requirements for irrigation and fisheries

	Agriculture requirements	Capture fisheries requirements	Aquaculture requirements
Reservoir management	Reservoirs supply water especially during the dry season	Water drawdown changes fisheries productivity, especially under a certain water level threshold Fish migrations in the early onset of the monsoon season require flowing waters	Minimum drawdown or fair warning agreements for small/shallow reservoirs
Dam operation	Alter water availability	Fish-friendly flows (as part of environmental flows) downstream of the dam	N/A
Fish passes, fishways	Alter water availability	Migration of fish across infrastructure (upstream-downstream or laterally) requires fish passes/fishways	N/A
Gate operation	Storing water requires closing the gates	Opening to maintain habitats and connectivity	N/A
Water distribution	Diversion from some agricultural fields and crops	Water for fish in critical habitats or connectivity points	Reuse of crops requires careful planning or supplemental pumping

(Continued)

Table 4. Typical trade-offs between water requirements for irrigation and fisheries (Continued)

	Agriculture requirements	Capture fisheries requirements	Aquaculture requirements
Flood control	Opening a gate to drain water and prevent flooding	Fish migration requires opening of the gate	Rapid discharges downstream may impact water quality or damage fish habitat
Rice paddy	Reduction of water consumption (or increase in water productivity) for rice production, e.g., through SRI	Fish cannot survive in rice paddies that are dried out, unless refuge areas are provided within the paddy	Fish ponds associated with rice paddy may dry out or not receive adequate water exchange during low or zero flow periods
Draining	Draining and drying of the system are required before the harvest to dry off the field crops	Minimum water levels in channels are needed to provide water for fish, unless refuge areas are constructed	Optimum time for harvesting fish may not coincide with field crops, and water flows may not be sufficient in the drying out period

Note: N/A – Not applicable.

2. Evaluating the trade-offs

The preliminary measures and resulting trade-offs are evaluated simultaneously to ensure the following:

1. The appropriate balance between the competing objectives, requirements and interests is determined.
2. The measures that are deemed the most adequate for the irrigation system, overall, are selected.

Trade-off analysis (TOA) will support the assessment of the pros and cons of the preliminary measures selected to explicitly determine what choices are made and why. This will help decision-makers understand the roots of potential conflict and stakeholders’ preferences for the management of irrigation impacts.

While the trade-off analyses vary from simple to complex levels, such as multi-criteria analysis (MCA) (see example in Box 10) and its computerized models, the depth of analysis required will depend primarily on the issues to be addressed, and on the data and research resources available.

Often, simpler versions of TOA will be conducted (see Toolbox 7).

BOX 10 Multi-criteria optimization in the Tana River

Traditional methods of informing the design and operation of WCI lack the capability to incorporate non-market benefits accruing from rivers, including, very often, those from fisheries. However, in recent years, simulation and multi-criteria optimization methods have been developed for water resources planning and management. In Kenya, such an approach was used in decision-making for the inclusion of ecosystem services, including fisheries, in the Tana River Basin. Within the basin, fisheries occur in reservoirs, on the floodplains downstream of the dams, and in the estuary and nearshore marine environment close to the river mouth. All these provide benefits to different groups of people, and all are affected by variability in hydrology and the operation of dams. The different types of fisheries were considered in the multi-criteria modelling and optimization, in conjunction with a range of other ecosystem services as well as hydropower production and irrigation.

For more information, refer to McCartney *et al.*, (2019a) and Hurford *et al.*, (2020).

TOOLBOX 7 Simple trade-off analysis

1. List the preliminary options for mitigating negative and enhancing positive impacts.
2. Identify the criteria against which to assess these impacts.
3. Conduct a simple MCA and rank options/measures from the least preferred to the most preferred outcome.
4. Seek final decisions on preferred options through review and iteration of the analysis with stakeholders, often using trust and consensus building techniques.

Outcomes will be a combination of scientific results, stakeholder preferences and national policy priorities. Depending on their scale and significance, decisions may nevertheless be subject to final political approval at ministerial or parliamentary level.

Where conflicts exist (see also Step 1, Section 2.3), stakeholders should be facilitated to review their prioritization in the ranking of alternatives in the light of others' priorities. The aim is to reveal areas of consensus on alternatives that can bring benefits to all, and alternatives that are least damaging, or where trade-offs provide acceptable compensation and conflict resolution.

STEP 5

Committing to implementation

1. Formalizing the agreement

Once the options and measures for modification of the design, operation, management and governance of the irrigation system have been agreed between the project team and the relevant stakeholders, an agreement needs to be formalized to ensure that the respective stakeholders are committed to implementing the agreed changes.

Typical agreements and commitments often refer to the following:

- Timing and duration of water releases across a regulator to enable fish migration.
- Timing of opening water gates to allow natural movement of fish through water gate infrastructure.
- Maintenance of minimum water levels in a critical habitat (wetlands, ponds, channels or reservoir).
- Non-targeting of fishing effort on the entry and exit points of fishways or regulators.
- Modification of a structure to improve its performance for fisheries.

The formalization of the agreements may be undertaken under the following scope:

1. As part of a water management plan and a water delivery agreement established by an irrigation or water management body.
2. Within the framework of local government powers, i.e., endorsed and recognized by subdistrict- or district-level agriculture, irrigation and fisheries units.

In the context of inadequate legislation, it may be difficult to fully formalize agreements. The use of a memorandum of agreement (MOA) or memorandum of understanding (MOU) could provide an interim solution and a useful semi-formal instrument.

2. Committing to the implementation of measures

The stakeholder representatives signing the commitment should be in a position to guarantee the necessary human and financial resources to implement and, to the extent possible, monitor and adapt the measures (see Step 6).

Once established, a formal agreement provides the following benefits:

1. As a written or endorsed plan, it allows some recourse by a stakeholder when there is non-compliance.
2. It provides some basis to prevent stakeholders from insisting on additional measures that may be unreasonable beyond those negotiated.
3. It provides the negotiated basis for the use of budgetary resources to undertake construction work or other measures.
4. It may also include any commitments of time or resources to be provided by community groups, fisheries or Water User Groups.

STEP 6

Monitoring and adapting

Given the complex changes required to integrate fisheries into irrigation systems, effective monitoring and evaluation, and adaptation are necessary throughout the process. Implementation of the selected management measures is likely to be subject to significant uncertainty due to internal and external factors. In the long-term, this uncertainty may be reduced, and the effectiveness of measures increased, if impacts are monitored and measures are adapted accordingly.

1. Monitoring and evaluation

Monitoring and evaluation (M&E) aims to check whether (a) the selected options and measures are providing the expected benefits, and (b) the objectives are achieved through implementation. The indicators, which are developed during the assessment phase of the project (Step 2), should be SMART, i.e., specific, measurable, attainable, relevant and time-bound.

Monitoring indicators should encompass all key features and functions of the fisheries system:

1. Biophysical: habitat, flow and flooding patterns, level of exploitation, fisheries production and exploitation level (a simple indicator of status of resources), species composition of catches (as an indicator of biodiversity and of the status of resources).
2. Livelihoods: assets and livelihood functions of fisheries at a stakeholder-disaggregated scale; conflicts arising (if any).
3. Socioeconomic: fisheries supply chain, including markets and prices by species, transport, fish consumption considering social and cultural norms, etc.
4. Governance: adherence to agreements and commitments, institutional performance, establishment and compliance with rules and regulations pertaining to fishing and aquatic habitat management.

While carried out throughout implementation of the management measures, the frequency of monitoring will depend on the selected indicators (some are monthly, seasonally or annually). Because indicators may change for reasons unrelated to irrigation (e.g., natural events or economic trends), it is recommended to monitor not only the target site, but also a control site that is not subjected to irrigation, and ensure this is done both before and after implementation of the project. The method of monitoring would preferably utilize a mix of quantitative and qualitative/participatory (including self-monitoring) approaches.

2. Managing adaptively

Based on the M&E results, implementation of the integrated and participatory process and its outcomes (the selected management measures) will need to be periodically adapted taking into consideration lessons, iteration and feedback mechanisms. The process should effectively 'learn through doing', remain flexible and be able to adapt when things go wrong or capitalize on opportunities when they arise (see Toolbox 8).

TOOLBOX 8 Operational steps for adaptive management

1. Identify/clarify the management options to be implemented experimentally.
2. Identify specific and measurable criteria for success of the intervention (e.g., increase in yield by at least 20 percent; distribution of fish production is spread across stakeholder groups, including women, youth and vulnerable people).
3. Decide on an experimental design and monitoring program.
4. The key issues are as follows:
 - Replication - ideally, this should be temporal (before and after the intervention) as well as spatial (parallel measurements at similar sites where no intervention has been carried out).
 - Contrast - the intervention should be substantial in order to have a measurable effect.
 - Sampling effort - each replicate unit must be sampled with sufficient intensity to allow detection of an impact of the expected magnitude.
4. Calculate and compare costs and expected benefits of experimental management.

Source: After Lorenzen *et al.*, 2007.

Concluding remarks

Irrigation has been, and will remain, instrumental in addressing several of the United Nations Sustainable Development Goals (SDGs): water security (SDG 6), food insecurity (SDG 2) and poverty (SDG 1). However, the global context in which irrigation takes place is changing rapidly. A call for healthier and more sustainable food systems is placing new demands on how irrigation is developed and managed. At the same time, growing pressures from competing water uses in the domestic and industrial sectors, and a growing recognition of environmental flow requirements, have led investors in irrigation and voices in other water sectors to demand improvements in irrigation performance. Irrigation is increasingly required to not only increase food production, but to also deliver acceptable returns on investment, improve rural livelihoods and support environmental conservation. One important way to achieve this is through the better integration of fisheries into the planning, design, construction, operation and management of irrigation systems. This involves institutions that (i) help manage the schemes as multiple-use systems, and (ii) ensure benefits from integration are socially inclusive and environmentally sustainable. This way, the integration of fisheries in irrigation can contribute to the achievement of the multiple objectives that irrigation is expected to deliver.

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Glossary

Adaptive management: A systematic process for continually improving management by learning from the outcomes of implemented management measures or options.

Aquaculture: The farming of aquatic organisms, including fish and other aquatic organisms, with some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding and protection from predators. Farming also implies individual or corporate ownership of the stock being cultivated.

Biodiversity: The variety of living organisms, most commonly measured as the number of species present in a particular location (species richness).

Capture fisheries: Fishing for naturally occurring fish using a variety of gear and methods.

Catchment or Watershed: The geographical zone in which water is captured, flows through and eventually discharges at one or more points. Smaller areas of land defined by the sub-basins of tributaries within a river basin are commonly referred to as a 'catchment' or 'watershed'. The river basin terminology tends to be used interchangeably and at different geographical scales to refer to a drainage basin, a catchment, a drainage area, a river basin, a water basin and a watershed. In some countries, including the United States of America and Canada, the terms catchment and watershed are also applied to the river basin itself.

Co-management: Partnership arrangements between key stakeholders and the government to share the responsibility and authority of management, with various degrees of power sharing.

Connectivity: Links between aquatic habitats that allow aquatic organisms (mainly fish) to move between them.

Culture-based fishery: "A fishery in which the use of aquaculture facilities is involved in the production of at least a part of the life cycle of a conventionally fished resource. Aquaculture is usually the initial hatchery phase that produces larvae or juveniles for release into natural or modified habitats" (FAO, 2015).

Ecosystem: An ecosystem can be defined as a relatively self-contained system that contains plants, animals (including humans), micro-organisms and non-living components of the environment, as well as the interactions between them.

Ecosystem approach to fisheries management (EAFM): A more holistic approach representing a move away from fisheries management systems that focus only on the sustainable harvesting of target species. EAFM aims for systems and decision-making processes that balance ecological well-being with human and societal well-being within improved governance frameworks.

Ecosystem health: The health status of an ecosystem depends on the selected health metrics and societal aspirations underlying the assessment. Therefore, there is no universally accepted benchmark for a 'healthy ecosystem'. While the term 'health' has the advantage of being simple to communicate, this construct can be subjective and value laden.

Ecosystem services: The benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as flood and disease control; supporting services such as nutrient cycling or waste degradation; and cultural services such as spiritual or customary benefits.

Enhanced fisheries: Fisheries that are supported by "activities aimed at supplementing or sustaining the recruitment of one or more aquatic organisms and raising the total production or the production of selected elements of a fishery beyond a level which is sustainable by natural processes" (FAO, 1997).

Fishways: Channels built around or through an obstruction to allow fish to swim across and pass with undue stress. Fishways are effectively used to maintain pathways for migratory fish.

Food security: "The availability of consistent and sufficient quantities of food, access to appropriate and sufficient foods and consumption or appropriate use of basic nutrition and food preparation" (Staples *et al.*, 2014).

Habitat: "The environment in which fish and other living marine resources live, including everything that surrounds and affects their life, e.g., water quality, bottom vegetation, associated species (including food supplies)" (Staples *et al.*, 2014).

Resilience: "The ability of an ecosystem to maintain key functions and processes in the face of (human or natural) stresses or pressures, either by resisting or adapting to change" (Staples *et al.*, 2014).

Stakeholder: Individuals, groups or any organizations that have some interest or 'stake' in the intervention (in this case, irrigation development or rehabilitation), and can affect or be affected by it. The four main categories of stakeholders are (1) those who have an impact on the organization; (2) those on whom the organization has (or is perceived to have) an impact; (3) those who have a common interest; and (4) neutral - those with no specific link, but with whom it is relevant to inform. Of most relevance to water stewardship are stakeholders associated with water use and dependency, but engagement should not be limited to these.

Annex 1. Physical components of irrigation, flood control and drainage schemes.

Component	Levels	Purpose
Canals	Primary, secondary, tertiary, quaternary	Convey irrigation water to the fields
Drains	Main, collector, field	Convey irrigation water or rainfall away from the field
River weir	River	Maintain the required water level to command the system, and divert and control irrigation water supplies
Embankment	River	Prevent flooding of irrigated areas
Pump station	Main canal Main drain	Lift water to command level for gravity irrigation, or lift and pressurize water for piped distribution Remove water from drainage channels below a river or natural drainage level
Cross regulator	Primary and secondary canals	Raise and maintain water surface at the required elevation at control and division points in the system
Head regulator	Primary, secondary and tertiary canals	Regulate discharge entering a canal, usually by means of a gate
Measuring structure	Primary, secondary and tertiary canals	Measure discharge entering a canal
Aqueduct	All levels of canal	Pass the canal over an obstruction (another canal, a drainage channel, road, etc.)
Culvert	All levels of canal or drain	Pass the canal or drain under an obstruction (road, drainage channel, etc.), or pass an obstruction under the canal (usually a drain)
Drop structure	All levels of canal or drain	“Drop” the canal or drain bed level in a safe manner. Used to slacken canal or drain slopes on steep land to avoid erosion
Escape structure	All levels of canals	Used to divert water safely from a canal into the drainage network in the event of oversupply
Syphon underpass	All levels of canals	Used to pass the canal below an obstruction such as a road or drainage channel
Distribution box	Quaternary canal	Simple distribution structure to distribute the water between quaternary channels
Night storage reservoir	Main canal or on-farm premises	Reservoir to store irrigation water during the night. Main canals thus operate 24 hours/day while lower order canals can be operated during the daytime
Tube well	On-farm premises	Abstraction of groundwater for irrigation. Can be used in conjunction with a surface water system
Bridges	Road bridges Foot bridges	Allow human and animal traffic over the canal or drain
Roads	Inspection roads Access roads	Gain access to the irrigation system and villages for inspection and maintenance
Fields	Within tertiary unit	Land prepared for crop cultivation, allowing for different methods of irrigation (basin, furrow, sprinkler, etc.)
Access points	Main canals	Access points into the canal for human and animal traffic for the purposes of obtaining water, washing, etc.

Source: Lorenzen *et al.*, 2007.

Annex 2. Governance of natural resource use and possible impacts of irrigation development.

Issue	Key governance attributes	Possible impacts of irrigation development
Water access and use		
Water rights	<p>Formal water rights are usually only recognized for irrigation and domestic water supply.</p> <p>Complex informal or customary water rights and uses also usually exist, for example, for fishing, domestic uses, gardens, watering livestock and artisanal industry.</p> <p>Formal water rights tend to apply even during periods of scarcity (e.g., dry seasons and drought years), but informal rights may be denied when water is scarce.</p>	<p>Together with the generally increasing competition for water, irrigation development may involve formalization, allocation and/or reallocation of water rights.</p> <p>Informal rights and existing practices for other water uses, including fisheries, are often ignored, resulting in loss of water access and use for vulnerable groups.</p> <p>Such loss and negative impacts may be exacerbated by seasonal and/or annual water scarcity.</p>
Use of preexisting water bodies	<p>Access for fishing is often unregulated (i.e., open access) or regulated by informal local community-based institutions.</p> <p>Open access resources tend to become overexploited, resulting in economic inefficiency and degradation of the resource.</p>	<p>Irrigation development may impact water availability and quality, habitats and biodiversity (Table 2).</p> <p>Overexploitation and degradation of open access resources may be further exacerbated.</p> <p>Informal institutions may lack the knowledge and capacity to respond effectively to the need to conserve resources and manage access by vulnerable groups.</p>
Use of newly created water bodies	<p>Lack of institutions to sanction, monitor and regulate fishing (and other water uses), or new institutions that are not sufficiently inclusive.</p> <p>Lack of knowledge and managerial capacity to ensure sustainable use of new water resources and fisheries.</p>	<p>Reservoirs and other new water bodies may provide habitats and opportunities for fishing (Table 2).</p> <p>Formal institutions established to regulate access may be ‘captured’ by local elites or neglectful of the interests of vulnerable groups.</p> <p>New local agreements and informal institutions are possible but may lack permanence, particularly during periods of water scarcity.</p> <p>Deficiencies in local managerial capacity may result in poor sustainability.</p>
Water charges	<p>Lack of a policy and mechanisms for collecting fees for water uses, excluding irrigation and formalized domestic use.</p> <p>This may exacerbate uncertainty of access and weaken sustainability of any associated infrastructure (including regulatory institutions) through the lack of cost recovery.</p>	<p>Further uncertainty and lack of sustainability for other water uses.</p> <p>Any introduction of fees for water use must consider affordability for vulnerable groups.</p>

(Continued)

Issue	Key governance attributes	Possible impacts of irrigation development
Environmental impacts		
<p>Environmental flows and ecosystem conservation</p>	<p>A lack of information on the environmental flows and habitats needed to sustain fisheries.</p> <p>Usually an absence of, or unclear, legislation on water allocation to sustain environmental flows.</p> <p>Similarly, a lack of formal requirements to maintain water flows and habitat connectivity (and control the introduction of alien species).</p> <p>Poor compliance, monitoring and enforcement even if requirements for the above exist.</p> <p>No mandatory requirement to mitigate the impacts of irrigation development on water flows and habitat connectivity.</p>	<p>Lack of budget and technical capacity to gather information, engage with stakeholders, and to design and implement effective mitigation measures.</p> <p>Therefore, non-mitigated impacts on water flows, habitats and biodiversity (as shown in Table 2).</p> <p>Failure to implement possible mitigation measures, including:</p> <ul style="list-style-type: none"> ▪ management of reservoir releases to maintain minimum water levels for reservoir habitats and downstream environmental flows; and ▪ actions to maintain habitat connectivity (e.g., fish passages) for the conservation of biodiversity and sustained fisheries.
<p>EIA and corresponding mitigation measures</p>	<p>Lack of, or unenforced, requirements for mandatory environmental and social impact assessments of new and rehabilitated irrigation infrastructure.</p> <p>Similarly, mandatory requirements for stakeholder engagement and participation in planning and decision-making processes.</p> <p>Similarly, mandatory requirements for mitigation of impacts.</p>	<p>Likelihood of the lack of, or inadequate, mitigation measures as identified and specified by an EIA for the design and implementation of the irrigation scheme.</p> <p>Likelihood of inappropriate and poorly designed and located mitigation measures resulting from inadequate stakeholder engagement and influence on planning and decision-making.</p> <p>Failure to exploit the potential of co-management for planning and implementing mitigation measures, and ongoing management of water and fishery resources.</p>
Fisheries and poverty		
<p>Access to fisheries</p>	<p>Opportunistic fishing in open access (unregulated) water bodies, whether natural or constructed, is often an economic activity of last resort for poor people, including women.</p> <p>It can also provide for valuable diversification of livelihoods and nutrition for small farmers and landless laborers, including women.</p> <p>Effective governance of fisheries to account for the aspirations and needs of rural populations that depend on aquatic resources for their livelihoods is the exception rather than the norm in many developing countries.</p>	<p>Restrictions on access to fishing/fisheries without knowledge or consideration of consequent impacts on the poorest and most vulnerable groups in a locality.</p> <p>Inaction and non-mitigation of impacts due to a lack of understanding of why such groups are marginalized and thus dependent on fishing.</p>

Annex 3. Prioritizing issues associated with risks.

A number of tools support the prioritization of issues associated with risks, as indicated in the table below.

Name	Description	Implementation
<i>Non-formal risk categories</i>	The risk associated with each identified issue is directly assigned to one of three categories – high, medium or low risk, with the descriptions incorporating both the consequence (impact) and the likelihood of occurrence.	Easy
<i>Semi-quantitative risk assessment</i>		
<i>Qualitative risk analysis (impact/likelihood matrix)</i>	All stakeholders place issues on the 2 x 2 matrix with two variables of likelihood and impact, and two to six categories of likelihood and two to six levels of consequence (impact). Each identified issue is rated accordingly and plotted on the matrix.	Moderate
<i>Dot ranked informal vote ranking</i>	All stakeholders identify issues which they think are high priority. The final count shows the issues that are high priority to that group of stakeholders.	Easy
<i>Pair-wise ranking</i>	All stakeholders list up to five issues on cards on both vertical and horizontal axes of a matrix, in the same sequence. Compare each pair and agree on which is the higher risk. Repeat this process until all possible combinations have been filled. List the results in rank order by sorting the cards in order of priority.	Easy

Source: Staples et al., 2014.

Annex 4. Typology of issues: risks and opportunities-consequences-WCI options-operational and management options.

Typology 1. Barriers to longitudinal river flow (weirs, dams and barrages).

Biophysical issue	Risk and opportunity	Consequences	WCI options	Operational and management options
<p>Reservoir creation</p>	<p>Standing water bodies are different to flowing water bodies in terms of hydrology, productivity, habitat type, etc.</p>	<p>Riverine fish eggs require flowing water (lotic) habitats. The impoundment of rivers may totally preclude riverine fishes that are dependent on flowing water conditions for their ecological requirements, and species that are only able to live in flowing water may be eliminated.</p>	<p>Need to facilitate upstream and downstream movements of fish. Fish passages to facilitate upward migration of brood fish and downstream flow of eggs and larvae.</p>	<p>Pre-impoundment vegetation clearing – needs to be designed taking into consideration fish habitats. Maintenance of return flows to maintain larvae in suspension at 0.3 m/second to allow downstream larval drift (throughout the length of the reservoir). Protect inflow streams to the reservoir, critical habitats (spawning and nursery). Enhancement/protection of headwaters for breeders and juveniles. Hatcheries and fish restocking programs. water gate opening, timing and duration.</p>
		<p>River species generally decline in abundance due to the inability to complete their life cycle, and are replaced by species that are tolerant and able to exploit static water conditions. Species composition of the catchment may change. Generally, the fishery moves towards lesser catches of smaller, non-migratory species of lower economic value or non-native species.</p>	<p>Six main types of fish passes: pool and weir, baffled, fish locks, pre-barrage, rock ramp, and bypass channels. Need sufficient water to operate during key migration periods (especially at the onset of the flood cycle). Correct location of fish pass entrance and flow dynamics to attract fish. Correct design of pass for all species and sizes expected to use the irrigation area (gradient, hydraulics, dimensions, etc.).</p>	

(Continued)

Typology 1. Barriers to longitudinal river flow (weirs, dams and barrages). (Continued)

Biophysical issue	Risk and opportunity	Consequences	WCI options	Operational and management options
Reservoir creation (Continued)	<p>Desirable migratory fish species replaced by species more suited to lacustrine environments. This may lead to reductions in fish biodiversity and the monetary value of the fishery. It can also result in the invasion of exotic fish species.</p>	<p>Water quality in the reservoir may become oligotrophic and unproductive for fish.</p>	<p>Pre-impoundment</p>	<p>Introduction of juveniles or lacustrine fish species.</p>
	<p>Deep pools, which are complex hydraulic refugia, are inundated and simplified.</p>	<p>Deep pools in reservoirs no longer work as fish refuges.</p>	<p>Create new fish habitats upstream of the reservoir or command areas as refuges.</p>	<p>Pre-impoundment vegetation clearing – needs to be designed taking into consideration fish habitats.</p>
	<p>Impoundment may drown out spawning and nursery areas, and habitats for riverine species typically found in rapids and glides, i.e., rhithron species.</p>	<p>Rhithron species are eliminated from communities, resulting in loss of biodiversity and replacement by species that are tolerant and able to exploit static water conditions.</p>	<p>Low-head obstacles in areas upstream of reservoirs can often be overcome relatively easily.</p>	<p>Hatcheries and restocking programs (potentially in combination with other measures).</p>
	<p>Creation of new water bodies for capture fisheries and aquaculture.</p>	<p>New fisheries livelihood opportunities for some local people.</p>	<p>Promotion of capture fisheries, sport fishing, culture-based fisheries (CBF) (likely to be more successful in small reservoirs).</p>	<p>Regular restocking of reservoir with desirable fish species (CBF). Introduction of fish species more suited to lacustrine environments. Cage and pen aquaculture⁶.</p>

(Continued)

⁶ Two forms of aquaculture. A cage is totally enclosed on all, or all but the top, sides by a mesh or netting, whereas in pen culture, the bottom of the enclosure is formed by the bottom of the lake, pond or reservoir.

Typology 1. Barriers to longitudinal river flow (weirs, dams and barrages). (Continued)

Biophysical issue	Risk and opportunity	Consequences	WCI options	Operational and management options
<p>Turbines and pumps</p>	<p>Large numbers of larvae and juveniles drift passively downstream from spawning grounds upstream and are drawn either into the intake of generating turbines or over the dam's spillway.</p> <p>Adults passing downstream actively seek flowing water and are drawn to turbine intakes or spillways</p>	<p>Both routes can cause high mortality rates with consequences on the recruitment of fish to populations downstream of the dam.</p> <p>Fish drawn to pumps disrupt life cycles, and lead to injury and mortality.</p>	<p>Dedicated design and operational choices for structures such as the turbine and gates.</p> <p>Use of screens and other barrier technologies (e.g., light, acoustic) to direct fish away from areas of high mortality risk.</p> <p>Spillways.</p>	
<p>Mortality and injury in spillways</p>	<p>While moving downstream, fish will either pass over the spillway through specially engineered bypass channels or be drawn into the turbine intakes and then through the turbines themselves.</p>	<p>Fish moving over the spillway can be injured or killed, if the design of the spillway does not take fish passage into account.</p> <p>If the flow is too strong, fish may not be able to avoid collisions with energy dissipating structures or flow detectors. They suffer abrasion against spillway walls and floor (shear), if the water is too shallow, and may suffer 'gas bubble disease' and barotrauma, if the plunge pool is too deep. Turbulent flow in the spillway basin can disorientate fish, slowing their downstream movement, and exposing them to predatory fish and birds.</p>	<p>Spillway design.</p>	

(Continued)

Typology 1. Barriers to longitudinal river flow (weirs, dams and barrages). (Continued)

Biophysical issue	Risk and opportunity	Consequences	WCI options	Operational and management options
<p>Flow regime modified</p> <p>The impoundment changes the hydrodynamics from a complex flowing water habitat to a uniform slower flowing habitat.</p> <p>Seasonal flooding patterns can be modified, resulting in deterioration of downstream habitat, and disruption of longitudinal and lateral migrations.</p> <p>Flows in the downstream reaches of the river are depleted, leading to loss of natural habitat and ecosystem functioning, especially in the command area.</p>	<p>In some cases, longitudinal migration of fishes is also compromised because environmental cues for migration (trigger floods) are lost, and passage over rapids, falls and other natural and partial obstructions to fish are disrupted.</p>	<p>Siting of the project site to ensure downstream impacts are reduced due to river configuration or by entering tributaries to ameliorate impacts.</p>	<p>Project-specific operating rules to minimize flow fluctuations downstream of the dam: establish an environmental flow regime for the benefit of fisheries and aquatic ecosystem functioning. Operating rules to ensure harmonized operations.</p>	
<p>Reduced connectivity</p> <p>Migratory fish species are unable to move from downstream areas into the reservoir.</p> <p>Impoundments also present problems for downstream migrating fishes. Downstream migration involves all life history stages, including eggs and larvae, which drift in the current, juveniles with limited swimming ability and adult fish.</p>	<p>May lead to the loss of fish species due to the inability to complete their life cycles, usually because they are isolated from their spawning and nursery areas.</p> <p>Ultimately, disruption of downstream migration may lead to loss of fish species due to the inability to complete their life cycles, usually because they are isolated from their nursery and feeding areas.</p>	<p>Fish passage facilities. 8 m head limitations.</p> <p>Fish lifts – high investment – unproven in tropical multi-species fisheries.</p> <p>Overshot versus undershot gates.</p>	<p>Periodic opening of water gates during peak migration periods.</p>	

(Continued)

Typology 1. Barriers to longitudinal river flow (weirs, dams and barrages). (Continued)

Biophysical issue	Risk and opportunity	Consequences	WCI options	Operational and management options
Block sediment	The impoundment may reduce the volume of sediments and associated nutrients passing downstream.	The productivity of the system declines, especially in downstream floodplains.		Watershed management - forest conservation, reforestation, sediment management measures, catchment sensitive farming regulations, buffer strips.
Modify downstream temperature/water quality	The quality/characteristics of water stored in reservoirs may fundamentally change.	In some cases, longitudinal migration of fishes may be compromised because environmental/water quality cues for migration are altered.		Discharge of water from reservoirs should consider downstream fish migration requirements.
Reservoir drawdown and refill	Water level fluctuations caused by impoundment impinge on the capacity for certain fish species to breed and grow in the impounded area.	Compromises capacity to replace lost fisheries production caused by impoundment of the river system.	Modification of reservoir terrain – Check dams within reservoir areas.	Discharge of water from reservoirs should consider fisheries requirements. Scheduling of amounts of reservoir water discharged. Management of water level fluctuations in the reservoir (daily, seasonally) to mitigate the effects on spawning in drawdown areas.

Typology 2. Barriers to lateral river flow (embankments/levees).

Biophysical issue	Risk and opportunity	Consequences	WCI options	Operational and management options
Reduced connectivity	Infrastructure can constrain the movement of fish to and from the floodplain.	Reduced distribution of adults and juveniles from the floodplain, leading to lost fisheries production levels.	Community refuge ponds with enhanced connectivity through culverts and channels.	
	Floodplains can be permanently inundated by an impoundment or disconnected by development.	Lost functions in the ecosystem and fisheries-related services.		Need to facilitate movements into and from floodplains and wetlands.
Reduced water and sediment transport into floodplains	Embankments and levees may reduce the volume of sediments and associated nutrients passing into the floodplain.	The productivity of the floodplains declines, especially in downstream floodplains and coastal regions.		

Typology 3. Controls to river flow/diversions (gates/regulators).

Biophysical issue	Risk and opportunity	Consequences	WCI options	Operational and management options
Physical barrier to fish migration	Sluice gates are often operated for a single water use; crop production.	<p>This can block fish due to the inability to complete part of their life cycle, specifically migration for feeding and spawning.</p> <p>This is of importance to water engineers and planners, as this single use approach misses an opportunity for increasing water productivity for the benefit of people and the environment.</p>	Sluice gates are modified to allow for fish migration.	Timing of the operation of sluice gates to coincide with anticipated fish migrations.
Modifies the flow regime	Irrigation water flows may not coincide with seasonal water flows.	May confuse or retard lateral or longitudinal fish migrations.		
Diverts a proportion of river flow into the irrigation system	Reduces the availability of water for riverine fish species.	Degradation of aquatic and riparian habitats. Increased predation of fish. Declines in fish production.		Maintain downstream environmental flows.

Typology 4. Pumps and turbines.

Biophysical issue	Risk and opportunity	Consequences	WCI options	Operational and management options
Water movement	Fish entering pumps and turbines are exposed to a variety of physical stresses that cause injury and death. These include pressure changes (barotrauma), and shear and strike by the turbine blades.	Eggs and yolk-sac larvae are susceptible to shear and strike by the turbine blades, while fish with closed (physoclistous) or chambered (carp species) swim bladders are susceptible to pressure impacts. Large fish are susceptible to shear/blade strike.	Fish-friendly turbines is a misinterpretation of impact and all turbines can typically have a significant effect on individual fish, resulting in high injury or mortality rates, often up to several days after passing through the turbines or pumps.	
May pollute water	Oil spills from pumps or greased machinery can enter into watercourses.	Local deterioration in water quality and possible negative impacts on aquatic fauna.		Efforts made to reduce spillage of oil from irrigation structures or equipment.

Typology 5. Off-river water storage (ponds).

Biophysical issue	Risk and opportunity	Consequences	WCI options	Operational and management options
Relatively shallow water bodies created	Creation of new water bodies with potential for fisheries.	Fisheries-related livelihood opportunities enhanced. Fish refuge/conservation areas created.	Culvert of pipe connectivity between irrigation system and off-river storage ponds.	Community fish refuges, recreational areas, cage and pen aquaculture.

Typology 6. Conveyance of water (channels, pipes, culverts and drainage ditches).

Biophysical issue	Risk and opportunity	Consequences	WCI options	Operational and management options
Creates new habitats directly and in seepage areas	Creation of new water bodies with potential for fisheries.	Fisheries-related livelihood opportunities enhanced. Fish refuge/conservation areas created.	Canals can act as fish habitats or fish highways, allowing lateral migrations.	Create fish habitats during the dry season and rice harvesting time. Community agreed management of fishing activities in and around canals, culverts, fish passes and refuge habitats.
Pipes and culverts disrupt fish movement	The poor siting (or lack) of pipes and culverts may constrain the lateral migration of fish.	Can delay population of floodplains and inundated areas, resulting in reduced fish productivity and biodiversity.	Pipes and culverts are modified to allow for migrating fish to rest. Pipes and culverts are modified to prevent easy capture by local fishers.	Pipes and culverts are protected during lateral out-migrations.

Scenario 1 – Objective: Sustain or enhance reservoir fisheries or capture fisheries within the irrigation command area (canals, small reservoirs and ponds or fields) to support the livelihoods of local communities, including, if appropriate, resettled villages.

User: Irrigation/Hydropower developer or project manager.

Rationale: Why do they want to consider the integration of fisheries in their project?

When creating a new reservoir, the following factors need to be taken into consideration in the design of the structure, in order to sustain some level of fisheries productivity in the water body.

1. Reservoir itself to function as a healthy ecosystem that provides good habitats for fish.
2. Reservoir to maintain connectivity with rivers and streams downstream and upstream, so that fish can complete their life cycle by migrating across the connected habitats.
3. Reservoir and its vicinity to provide a variety of wetland habitats for fish to be used for spawning, and as nurseries and dry season refuges.
4. Governance and management arrangements planned to support sustainable and equitable fisheries in the reservoir.

1. Reservoir itself to function as a healthy ecosystem that provides good habitats for fish.⁷

- 1.1 Of the fish species present in the river before impoundment, identify those that have potential for survival in the modified environment where the reservoir replaces the river. Identify management objectives and priority for reservoir fishery development, based on stakeholder consultation.
- 1.2 Pre-impoundment vegetation clearing – needs to be carried out taking into consideration the creation of fish habitats in the reservoir and water quality conditions suitable for the survival of fish.
- 1.3 During planning, a watershed management plan – forest conservation, reforestation, sediment management measures, catchment sensitive farming regulations, buffer strips – needs to be developed to ensure that the quality of water in the reservoir can be maintained at an acceptable level.
- 1.4 During planning, a dam operation plan needs to consider how to limit annual and daily water level fluctuations and drawdown rates in the reservoir, in order to prevent disturbing fish spawning and nursery habitats in drawdown areas during the spawning season.

2. Reservoir to maintain connectivity with rivers and streams downstream and upstream, so that fish can complete their life cycle by migrating across the connected habitats.⁸

- 2.1 Identify tributaries upstream of the reservoir that provide spawning habitats for the fish, and institute conservation/fisheries management measures to protect them. Ensure the connectivity between these habitats and the reservoir by avoiding/removing obstacles for fish movement.⁹

⁷ The potential fisheries yield of reservoirs is a function of size, depth, availability of habitats and natural food for fish. Fluxes of organisms, detritus, nutrients and other materials into the reservoir strongly affect primary productivity (not least through impacts on turbidity), and hence food webs and fisheries productivity. Smaller, shallower reservoirs tend to be more productive than those that are large and deep (Jackson and Marmulla, 2001).

⁸ Many fish species in rivers need to be able to migrate upstream and downstream to reach spawning and nursery habitats. It is important to facilitate upstream and downstream movements of fish through the dam, reservoir and tributaries upstream of reservoir, in order to enable the reproductive cycle of existing fish species in the reservoir.

⁹ Protection of the spawning native brood fish is perhaps the most important management intervention for sustaining reservoir fisheries. In Ubolratana Reservoir in Thailand, a substantial increase in fish production was recorded after inflowing streams came under management protection during the spawning season (Bernacsek, 1997). The Nam Ngum 1 hydropower reservoir

- 2.2 Consider installing fish passages to facilitate connectivity between the reservoir and river downstream. Some fish passage options for facilitating upward migration of brood fish are available and have been proven to be effective in cases where the height of the dam is less than 8 m.
 - 2.3 Plan for suitable water releases into fish passages, so that fish passes can actually function as intended. A rule of thumb is that fish passes need 10 percent of Q_{95} minimum flow to allow fish to use it. However, this has to be done based on the timing of seasonal fish movements.
 - 2.4 Ideally, downstream flow of eggs and larvae across the reservoir and to the river below the dam need to be facilitated. However, technologies for enabling this are not yet available.¹⁰
- 3. Reservoir and its vicinity to provide a variety of wetland habitats for fish to be used for spawning, and nurseries and dry season refuges.¹¹**
- 3.1 Identify and protect existing critical wetland habitats to be used for spawning and as nurseries, and sustain the connectivity between the reservoir and these wetland habitats.
 - 3.2 Identify potential areas for new habitat creation based on projected reservoir extent and water levels in different seasons/operational stage.
 - 3.3 Protect inflow streams to the reservoir and other fish migration bottlenecks from fishing activities, and prevent/remove obstructions to fish movements.
 - 3.4 Create new fish habitats upstream of the reservoir or in drawdown areas as refuges during the dry season as well as rapid drawdown of reservoir water level.
- 4. Governance and management arrangements planned to support sustainable and equitable fisheries in the reservoir.**
- 4.1 Establish management rules for fishing activities in the reservoir and associated fish habitats to prevent overfishing and destructive fishing practices.
 - 4.2 Stocking of native fish species can be considered if recurrent costs can be covered, either through government or external assistance, or through own cost recovery schemes, such as collective marketing of harvested fish and fishing access fees.
 - 4.3 Institutional arrangements to support the implementation of above during the operational phase, e.g., local fishers' organizations, fishing access rights, watershed management incentive schemes.

¹⁰ Downward flows of reservoir surface water to maintain larvae in suspension is at 0.3 m/second to allow downstream larval drift (throughout the length of the reservoir). However, it is unrealistic to operate and manage water storage infrastructure in this way.

¹¹ Some fish species need to migrate into and off floodplains and wetlands to complete their life cycle. These habitats are also useful for creating dry season refuge habitats for fish, and can also serve as fishing grounds that are easily accessible to local communities.

Screening matrix

Screening criterion	Fishery enhancement option		
	Pre-impoundment vegetation clearing	Fish passage to facilitate connectivity between the reservoir and river downstream	Identify and protect existing critical wetland habitats for spawning
Suitability – How well does the option fit the situation?	Some vegetation clearance is expected, especially removal of high-value timber, and to reduce adverse water quality issues and greenhouse gas emissions, and for ease of boat movement. However, leaving some standing trees and vegetation in place can be beneficial for creating refuges and habitats for fish in the reservoir.	Suitability of the fish passage depends on the height of the dam. High dams pose significant problems for effective fish passage. The fish passage needs to be well designed to cover the sizes and swimming abilities of fish species found in the river.	Within the area to be inundated, there will be several places where wetland habitats either existed before or can be created. Deep pools in the river will probably not continue to operate after inundation, but the confluences with small streams entering the river may continue to be suitable locations for fish spawning.
Feasibility – How easy will the option be to implement?	Leaving some trees and vegetation standing is easy. However, some insight into the functioning of the reservoir habitats is needed to identify the areas where trees are to be left standing.	Choosing the right design, siting, length and slope for the fish passage will depend on the location and topography. Fish passes can be retrofitted to existing weirs and barrages, but it is better to build into the design of new infrastructure.	The identification of such habitats will require an initial survey before inundation, and to predict what will happen both hydrologically and hydraulically after inundation. New habitats, such as the laying down of gravel or sand beds, may be considered, together with the planting of riparian and aquatic plants.
Cost - Very low (< USD 1 000) Low (< USD 10 000) Medium (< USD 50 000) High (< USD 100 000) Very high (> USD 100 000)	Cost of full clearance is avoided, so the cost saving may be significant. Maintenance costs are very small.	An effective fish pass may have a high or very high cost, depending on its size.	Depending on the level of active habitat creation required, this may be low to medium cost.
Effectiveness – How effective will the option be for enhancing the fishery	Leaving some areas with standing trees has been found to be effective at creating habitats for fish.	Fish passes around low dams and weirs can be effective, but the effectiveness of fish passing upstream decreases as dams get higher.	Wetland habitat protection and creation is probably one of the most effective measures for enhancing a reservoir fishery.

(Continued)

Screening criterion	Fishery enhancement option		
	Pre-impoundment vegetation clearing	Fish passage to facilitate connectivity between the reservoir and river downstream	Identify and protect existing critical wetland habitats for spawning
Implications – for water allocation, and social and environmental impacts	There are no implications for water allocation. There may be visual impacts of dead trees throughout the reservoir. Navigation and fishing in these areas will be difficult, but this helps to protect the habitat as a fish refuge.	Water will have to be diverted through the fish pass, and this water will not be available for hydropower and may not be available for irrigation. The water allocation depends on the original flow in the river. It may be possible to operate the fish pass only during the fish migration season	There are very low implications for water allocation, except when water is trapped in the wetland areas at times when the reservoir water level is very low,
Management requirements – What will it take to manage the option successfully	After impoundment, there is no further management requirement. The areas where standing trees are left should be declared as fish protection areas.	Fish passes act as aggregating devices for fish. Therefore, all fishing activities must be restricted at the entrance and exit of the fish passage.	These habitats where fish spawn should be protected and fishing prohibited, at least during the spawning season.
Conclusion – Can the option be considered further?	-----	-----	-----

Scenario 2 - Objective: Maintain some level of fish productivity below the irrigation scheme to support the livelihoods of downstream communities.

User: Irrigation/Hydropower developer or project manager

Rationale: Why do they want to consider the integration of fisheries in their project?

Options:

1. Environmental flows
 - Create a reservoir regulator below the hydropower dam to mitigate daily flow fluctuations (e.g., Nam Theun 2 [NT2] Lao).
 - Manage water releases to mimic seasonal flow fluctuations.
 - Create peak flows to trigger fish migration.
2. Enhance river habitats downstream
 - Construct riverbed diversification downstream to restrict fast flowing water eroding the riverbed as water rises, and to create deeper areas of the river when the water levels fall.
 - Create riparian wetlands as fish refuges ('monkey cheeks').

Screening matrix

Screening criterion	Fishery enhancement option		
	Pre-impoundment vegetation clearing	Fish passage to facilitate connectivity between the reservoir and river downstream	Identify and protect existing critical wetland habitats for spawning
Suitability – How well does the option fit the situation?	Only possible in certain situations, usually at the end of a cascade of dams, which are used for hydropeaking. Regulating dams and reservoirs provide sufficient storage to balance out the changes in daily flows.	Seasonal flow changes imply releasing more water at certain times of the year. To some extent, this happens anyway, but usually only when the reservoir is full and the spillways are operating. In this case, the normal seasonal flow is delayed by one or two months. If early wet season releases are planned, this can only be done by early opening of spillway gates. It cannot be done with a fixed sill overflow.	Several measures for downstream habitat enhancement can be envisaged for most rivers. The aim of these measures is to reduce the impacts of rapidly changing flow rates, riverbed erosion, sedimentation and water levels, so that river habitats are more stable. Essentially, this means creating areas that are relatively protected from the extremes of flow, and provide refuges for fish during times of very low flow.
Feasibility – How easy will the option be to implement	Regulating reservoirs is usually considered during the design of the lowest dam, but can be constructed later, depending on site suitability.	In the case of opening spillway gates, this is an operational decision, which will be taken depending on the rating curve for the reservoir. The curve would have to be revised to take into account seasonal releases. The aim would be to mimic early wet season flushes down the river to encourage fish migration, and may only last a few days.	Feasibility of habitat improvements depends on the topography, riverbed and riverbank geomorphology. These improvements may include check dams, groins and gabions inserted into the riverbed and riverbanks to create different protective habitats, or wetlands on the riverbanks that flood during high flows and retain water during low flows.
Cost - Very low (< USD 1 000) Low (< USD 10 000) Medium (< USD 50 000) High (< USD 100 000) Very high (> USD 100 000)	Cost is likely to be very high.	The cost is likely to be high in terms of water lost for hydropower generation and irrigation.	Cost could be low to medium depending on the situation.
Effectiveness – How effective will the option be for enhancing the fishery	Regulating dams produces more balanced flows in the river downstream. So, the river is not exposed to the extremes of daily flow changes. The river downstream is more natural and provides a better environment for fish. Regulating dams cannot rebalance the seasonal flow changes.	The enhancement of fish migration through early wet seasonal flow releases would aim to increase the performance of the fish passage. Releasing seasonal flows also encourages migration of fish for spawning in tributaries downstream of a dam, i.e., moving into rivers and streams before they get to the dam.	Any measures to improve the stability and diversity of the downstream habitats will enhance the fishery.

(Continued)

Screening criterion	Fishery enhancement option		
	Pre-impoundment vegetation clearing	Fish passage to facilitate connectivity between the reservoir and river downstream	Identify and protect existing critical wetland habitats for spawning
Implications – for water allocation, and social and environmental impacts	Regulating ponds or reservoirs does not affect the water allocation in upstream dams. It may be possible to divert water from regulating ponds for some baseload hydropower or for irrigation.	Loss of water that would otherwise be stored and used for hydropower or irrigation.	There are no implications for water allocation. The measures could also be helpful in reducing riverbank erosion downstream.
Management requirements – What will it take to manage the option successfully	The flows entering the regulating pond need to be released evenly throughout the day and night. Therefore, flow releases need to be carefully managed.	Requires careful management of the seasonal flow releases, both in terms of quantity and duration.	Requires careful design and siting of such measures, and monitoring to determine their effectiveness and continuity.
Conclusion – Can the option be considered further?	-----	-----	-----

Scenario 3 – Objective: Create or enhance opportunities for capture fisheries in and around the irrigation scheme to add to its value and bring benefits to local communities.

User: Irrigation developer or project manager

Rationale: Why do they want to consider the integration of fisheries in their project?

Irrigation schemes have multiple domains where fish-friendly interventions can be implemented.

- Reservoir (see Scenario 1)
- Distribution
- Primary canal
- Secondary/tertiary canals
- Rice fields
- Associated wetlands

The following are entry points for creating/enhancing fisheries in the irrigation scheme:

1. Allow fish to enter the irrigation scheme and move across different habitats within and outside of the scheme to complete their life cycle.¹²

¹² A study by Halls (2005) in Bangladesh concluded that irrigation system operators should aim to:

- maximize the water flow into irrigated areas during the rising flood period;
- open the sluice gates as frequently as possible;
- avoid creating flow rates in excess of 1 m/s; and
- close the gates towards the end of the wet season in order to retain as much water in the system as possible for the next dry season.

2. Increase the area of aquatic habitats fish can use (and people can use to catch the fish).
 - 2.1 Assess the current use of the irrigation scheme and extended command area (ECA) for fishing purposes, and map water distribution structures, including the location of control gates and culverts.
 - 2.2 Identify areas where fisheries can be enhanced through the above interventions, e.g., known fish migration blockages and obstacles.
 - 2.3 Consult local villages regarding priority fish species and fishing grounds, and suitable access regime and management rules.
 - 2.4 Depending on locations where connectivity needs to be established, select suitable measures and tools to facilitate fish movements across habitats, e.g., fish passes, sluice gates, culverts.¹³
 - 2.5 Design an operational module for water and sluice gate management to facilitate migration of priority fish when it is needed (e.g., at the beginning and the end of the rainy season).
 - 2.6 Identify areas where additional fish habitats can ensure the survival of some fish in the dry season/rice harvesting time.
 - 2.7 Review the current water distribution and consider requirements for modification to facilitate the changes described above (i.e., 2.4 to 2.6) while avoiding conflict with the main crop production cycle.
 - 2.8 Institutional arrangements to support implementation of the above during the operational phase. For example, local fishers' organizations, establish fishing access regime, and reorganization of irrigation management committees to ensure fisheries interests are represented.

¹³ See Gregory, Funge-Smith and Baumgartner (2018) for detailed description of engineering design options for fish passes, sluice gates/weirs and culverts, and their suitability for different domains in the irrigation scheme.

Screening matrix

Screening criterion	Fishery enhancement option		
	Pre-impoundment vegetation clearing	Fish passage to facilitate connectivity between the reservoir and river downstream	Identify and protect existing critical wetland habitats for spawning
Suitability – How well does the option fit the situation?	The different options for facilitating lateral fish movements include fish passes, sluice gates and culverts. Each option is suitable depending on location and operation.	Maximize the water flow into irrigated areas during the rising flood period. Open the sluice gates as frequently as possible. Avoid creating flow rates in excess of 1 m/s. Close the gates towards the end of the wet season in order to retain as much water in the system as possible for the next dry season.	Some depressions, wetlands and deep pits in and around the rice fields serve as refuges and breeding sites for fish in the dry season.
Feasibility – How easy will the option be to implement	Fish passes around weirs and barrages will require careful design and construction.	Sluice gates and culverts may already be included in the system, and may need to be adapted or operated to enhance fisheries.	These potential refuges should be identified through a study of the topography and natural habitats in the area. They may remain as they are or may need to be enhanced, e.g., by digging deeper, preparing low dykes or by protecting the natural vegetation.
Cost - Very low (< USD 1 000) Low (< USD 10 000) Medium (< USD 50 000) High (< USD 100 000) Very high (> USD 100 000)	Fish passes can be high or very high cost.	Sluice gates and culverts can be low or medium cost.	Such enhancement of fish refuges in and around the rice fields can be very low, low or medium cost.
Effectiveness – How effective will the option be for enhancing the fishery	To be effective, several fish movement measures may need to be included to ensure that fish reach all parts of the irrigation system.		Fish refuges in the rice fields are very effective, providing additional incomes for the rice farmers, and maintaining breeding fish in the system.

(Continued)

Screening criterion	Fishery enhancement option		
	Pre-impoundment vegetation clearing	Fish passage to facilitate connectivity between the reservoir and river downstream	Identify and protect existing critical wetland habitats for spawning
Implications – for water allocation, and social and environmental impacts	Fish passes around weirs will require diversion of some water, but usually this could be as water released down the river (i.e., the minimum flow release).	Sluice gates will require operational opening for fish movements that may not coincide with the timing for releasing water for irrigation. Culverts would be open access and not have any implications for water allocation.	There are no implications for water allocation associated with these refuges. Indeed, during periods of drought, these depressions or deep pits may retain water for longer. While deep pits within the rice field may take up land depressions, wetlands are often less productive as agricultural land.
Management requirements – What will it take to manage the option successfully	Once installed, fish passes would require little management of flows.	Opening sluice gates for fish management would require careful timing for the best enhancement of fisheries. Culverts would not require special management, except for normal maintenance to ensure they are kept open for fish movement.	Deep pits may require maintenance and cleaning to ensure they do not silt up. Depressions and wetlands can largely maintain themselves, although some clearance of vegetation may be needed to maintain water-holding capacity.
Conclusion – Can the option be considered further?	-----	-----	-----

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