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AN ECOSYSTEM APPROACH TO PROMOTE THE INTEGRATION AND COEXISTENCE OF FISHERIES WITHIN IRRIGATION SYSTEMS

Cover photograph: Low head tropical fishway, Pak Peung, Lao PDR (Lee Baumgartner)

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AN ECOSYSTEM APPROACH TO PROMOTE THE INTEGRATION AND COEXISTENCE OF FISHERIES WITHIN IRRIGATION SYSTEMS

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PREPARATION OF THIS DOCUMENT

This document was prepared to support the work of FAO Fisheries and Aquaculture Department to develop tools and approaches for the improved management of fisheries and aquaculture. The review is intended to provide guidance on how to understand the needs of fisheries and aquaculture within the context of irrigation water systems and to enable fisheries stakeholders to cooperate effectively on the integration opportunities that irrigation presents for inland fisheries and aquaculture. It also aims to provide some examples of how to find ways to mitigate the impacts on fisheries that result from irrigation water management and its water control structures. The review describes how planning process of an ecosystem approach to fisheries can be adapted to work closely with other planning frameworks, used to evaluate irrigation system function and management. The intention is that this can be used to develop recommendations and strategies for modernization of irrigation systems, such that their impacts on fisheries are mitigated and potential opportunities for fish production can be effectively incorporated into the design and operation. The authors are grateful to our colleague Robina Wahaj, Land and Water Officer, FAO Land and Water Division, in explaining the FAO MASSCOTE irrigation modernization planning approach and relevant aspects of irrigation system design and operation.

ABSTRACT

This document has been developed in recognition of the increasingly diverse demands for water from irrigation systems and the need to introduce more holistic land uses into conventional irrigation management. Despite historical precedents the potential for the integration of fish production (capture fisheries and aquaculture) and irrigation systems has yet to be fully realized. Capturing these underutilized opportunities for the integration of fisheries and aquaculture could significantly increase local economies, food security, household incomes and livelihood diversity within irrigated agriculture systems.

To re-examine the potential of fisheries in irrigation systems, the concept of the extended command area (ECA) is used, expanding the conventional definition of an agriculture irrigation command area. This expanded definition recognizes that all elements of an irrigation system, from upstream dam storage to downstream drainage areas, offer opportunities for increasing fish production. Many of these opportunities may be realized at no additional cost to the main irrigated crop.

This document provides an introduction to the ways fisheries and aquaculture already co-exist with irrigation and explores the threats and opportunities that arise from this. A key concept for sustaining and enhancing inland capture fisheries is "connectivity"– a fundamental basis for ensuring adequate environmental conditions to allow fish to flourish within an aquatic ecosystem such as a river, lake, or wetland. Improving connectivity within an ECA can restore elements of ecological services that may have been compromised or degraded through irrigation, water management or through other rural infrastructure development such as road construction.

Practical application of the integration of fisheries and irrigation systems is explored through the use of the Ecosystem Approach to Fisheries (EAF) in the context of irrigation systems. The proposed process links the development of an EAF management plan for fisheries to irrigation system operation and is given the acronym EAFm-i. A key part of this linkage is an assessment of water resources in the system and the management of water for delivery to fisheries. Additional tools to support the EAFm-i process are also described.

This document is intended to encourage fisheries and irrigation specialists to communicate and cooperate to improve the integration of fisheries into irrigation planning and to support piloting of an EAFm-i process. Although the experience and approach are drawn largely from irrigation systems and inland capture fisheries in Southeast Asia, the application of the ECA concept and approach will be relevant to any irrigation or water management system where there is potential for the closer integration and harmonization of fisheries and irrigation systems and where water users are interested in realizing this potential.

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1.1 LINKAGES BETWEEN IRRIGATION AND FISHERIES

1.1.1 GLOBAL IRRIGATION AND WATER DEVELOPMENT IS EXPANDING

Worldwide, the development of irrigation has increased exponentially over the past 50 years (Fernando and Halwart, 2000). This has been crucial to enhance global food production, but has had a substantial impact on river flows and ecological processes (Davies *et al.*, 2000).

Irrigation typically requires the regulation of river flows through water impoundment, diversion and abstraction. This is widespread wherever irrigation occurs, but the impact tends to be most severe in regions with highly variable flow regimes (Dudgeon *et al.* 2006; Vörösmarty *et al.*, 2000).

By 2050, it has been estimated that the world will require 1 500 percent more energy and 70 percent more agricultural production (Zarfle *et al.*, 2014; Bruinsma, 2009). Increased future demand for irrigated production requires increased irrigation infrastructure to deliver more water from rivers. It is estimated that every 1 000 ha of irrigated land requires the creation of 2.5 km of large irrigation channels and 10 km of smaller tributary channels (Redding and Midlen, 1991).

Figure 1: Many irrigation systems are designed solely for irrigation of a single type of field crop (e.g. rice) and do not consider fish and fisheries in their design and operation. (Photo credit: Ariel Javellana, International Rice Research Institute)

The expansion of irrigation networks is therefore inevitable for most of the world's river basins and systems (Ellis, 2011). In the interests of expanding food production many governments continue to subsidize irrigation schemes through charging water users nominal fees for water and infrastructure maintenance, or by subsidizing fuel or electricity for agriculture use. In many cases, these incentives have led to the expanded cultivation of water-intensive crops using inefficient technologies, and have led to surface water, groundwater and energy resources becoming depleted. An unavoidable consequence of this has increased competition over limited resources, conflicts and environmental degradation. Impending climate-change scenarios are also demanding improved water efficiency, enhanced food production and more sustainable environmental outcomes. To meet these demands and mitigate the impacts, irrigated agriculture will need to be extended, however outdated designs and operational practices will also need to be modernised (Doll, 2002).

Irrigation modernisation is a global phenomenon, many existing dams, weirs and channels were constructed from 1950 onwards, but some date from 200 years ago. Most structures are now in disrepair and governments are investing substantial amounts of public money in replacements and upgrades. Large multilateral donors (including the World Bank, Asian Development Bank and International Monetary Fund) are investing billions of dollars in a new wave of refurbishment, or modernization, of failing irrigation infrastructure.

Many irrigation systems were designed solely for irrigation of a single type of field crop (e.g. rice), but have not been able to fulfil their design expectations (Figure 1), leading to sub-optimal operational management (Renault, Facon and Wahaj, 2007).

A number of common problems in irrigation schemes include: a lack of integration of planners, designers, managers and beneficiaries; a failure to improve design standards; difficulties in maintaining control of water in canal structures; a lack of buffers and regulatory reservoirs; inflexible operation schedules; poorly paid field level managers and operators; and an incomplete understanding of water balance and efficiency (FAO, 2007). External threats such as rapid urbanization and industrialization have also degraded many areas once serviced by rural irrigation systems.

This era of irrigation modernization is compelling decision-makers to devise progressive policies that address environmental sustainability, food security, economic and social wellbeing issues created by the nature and speed of change. In order to ensure sustainable, long-term development objectives, there is a major global challenge to balance social, economic and ecological benefits, across critical ecological thresholds. Irrigation modernization can meet this challenge, but will require improved design and operations of water delivery and water management, capable of responding to this broader range of outcomes, beyond the traditional requirement of delivery of water to a field crop.

1.1.2 THERE IS A LONG TRADITION OF INTEGRATION BETWEEN FISHERIES AND FLOODPLAIN CROP PRODUCTION

Rice and fish have been dietary staples for many of the world's people for countless generations. Their importance is reflected culturally with several Asian countries using a traditional expression along the lines of, "*In the water are fish, in the fields is rice*" to describe a desirable situation of abundance and prosperity. In other parts of the world, such as Ivory Coast, rice farming is an equally ancient farming activity, dating back some 3 000 years (ODI, 2000).

Many of the world's lowland rice farmers, particularly those that live at tropical latitudes, are also part-time fishers and vice versa, creating the rice farmer/fisherman lifestyle that characterizes so many of Asia's rural communities. Traditional rain-fed paddy field management creates extremely favourable conditions for aquatic animal reproduction and growth (Heckman, 1979). The ability of aquatic animals to colonize inundated freshwater areas, even seasonal ones, is generally impressive and, in floodplain areas, quite extraordinary. Virtually any waterbody, flowing or otherwise, in a rice farming area, will harbour a wide variety of fish, amphibians, crustaceans and molluscs and insects, almost all of which can be consumed as food by local people. The collection of aquatic animals from rice fields is therefore as ancient an activity as rice farming itself (Figure 2).

Figure 2: At the farm level, there is rarely a clear distinction between fisher, rice and livestock farmer. (Photo credit: Rick Gregory)

In Mali, unstocked rice fields produce modest amounts of fish, implying that some form of rice–fish farming has long been practiced (Peterson and Kalende, 2006). In Senegal, the Jola people have traditionally constructed fishponds in rice fields (Linares, 2002). One of the largest rice–fish systems in the world, Cambodia's Great Lake and floodplain rice growing areas, is an extremely productive ecosystem and has been an important source of aquatic animals for food since the Angkor civilization (early ninth century to early fifteenth century) (Baran, 2005).

The green revolution, which was supported by improved access to water from irrigation, allowed many of the world's rice farmers to bolster rice production and move from being a food deficit nation to self-sufficiency and then to a surplus. The total irrigated rice area in Southeast Asia now covers about 18 million ha, accounting for 18 to 20 percent of all arable land and accounts for 40 percent of the world's and 60 percent of Asia's cereal production (FAO, 2007). Improved irrigation, the use of high-yielding-varieties and increases in fertilizer and pesticide application have resulted in irrigated rice now accounting for 75 percent of Southeast Asia's rice production. This is now an essential food production strategy for the region's more than 500 million people.

In many areas, the successful intensification of rice production through irrigation has coincided with the decline of small-scale capture fisheries and traditional aquaculture practices (Ali, 1990; Gregory and Guttman, 2001a and 2001b; Nguyen-Khoa S. *et al.*, 2005). Indeed, irrigated agriculture is considered to be one of the major causes of degradation of freshwater ecosystems and their fisheries (Petr & Mitrofanov, 1998).

Fishery declines are common areas where rapid irrigation development has created physical barriers that limit floodplain connectivity and impede natural movement and migration of wild stocks. These barriers prevent access to spawning, nursery and growth habitats. Fish end up spawning in the wrong place at the wrong time or not at all. The linkage between fish, rivers, irrigation canals and permanent water bodies in ricefield system is illustrated in Figure 3.

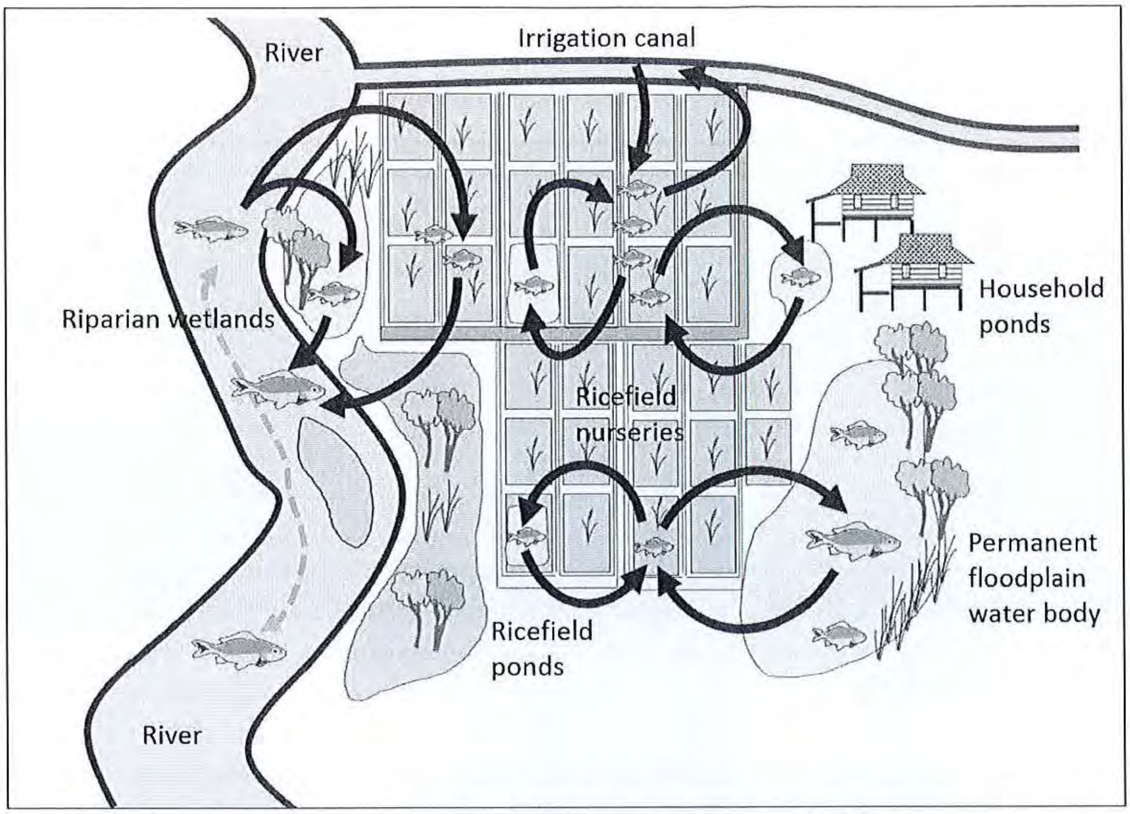


Figure 3: The seasonal movements of fish between rivers, floodplains, waterbodies, ricefields and irrigation systems. Red arrows are lateral migrations during the rainy season. Purple arrows are the lateral migrations that occur at the onset of the dry season. The yellow dotted line indicates the upstream and downstream migration of riverine fish. (Adapted from: Little *et al.*, 2014).

The construction of barriers to saline water intrusion into delta areas also impacts inland fisheries. These structures are either poldered areas (with sluice gates) or barrage structures. These allow freshwater to flow downstream (or out of the polder), but prevent tidal inflow of saline water. In this case, the impact of the structures is to prevent the movement or migration of anadromous (e.g. Hilsa and other species of shad, sturgeon) or catadromous (e.g. eel, mullet) fish and shrimp migrating between brackishwater and freshwater areas.

Overfishing and habitat change and degradation have also contributed to this decline, but the reduction in fish catches around rice field areas has also coincided with, and has been impacted by, the move towards shorter rice cropping varieties, the intensification of fertilizer and pesticide use, and reductions in water levels and periods of inundation.

Over time, these impacts reduce the diversity and productivity of the fishery and the benefits of development projects (such as improved agriculture production and more secure water supplies) are thus negatively offset by lost fisheries. This trend has gone largely unnoticed in many countries in the enthusiasm to increase crop production, achieve national rice security and meet export targets.

Additionally, the intensification of rice production in Asia has coincided with the emergence of aquaculture as a means to produce aquatic foods more intensively than had been possible through the exploitation of traditional capture fisheries. Indeed, in situations where aggressive agriculture practices, pollution or overfishing have damaged traditional capture fisheries, many rural people have either turned to aquaculture or now purchase cultured fish as a way to meet their nutritional requirements, (Edwards *et al.*, 1996).

The shift from exploiting naturally occurring, common property resources to the deliberate and private farming of fish and other aquatic animals, mirrors a similar change that occurred in terrestrial foraging communities, millennia before. However, just as many Asian rural farming communities still depend on the gathering of naturally occurring plants in and around their fields, so wild caught aquatic animals continue to provide millions of Asia's rice farming people with essential high quality animal protein in their diet (Hortle, 2007).

To a large extent, the bulk of floodplain rice field fisheries operate during the wet season but dry season irrigation systems also provide opportunities for fish production. The traditional irrigated rice and fish systems of Cambodia's Tonle Sap, for example, and their operation provide a historical lesson on pragmatic, integrated water use that could be used to inspire modern irrigation design and management. However, the multiple uses of water from irrigation schemes require more complex and flexible management than in the past. Up until now, where fisheries operations have existed in and around irrigation systems they have tended to do so more by accident than design.

1.1.3 IRRIGATION SYSTEMS HAVE TYPICALLY OVERLOOKED OR IGNORED FISHERIES IN THEIR DESIGN AND OPERATION

In most cases, productive fisheries have declined in irrigation systems due to lack of awareness or priority regarding their impacts on fish. These systems were not designed or operated in manner that would allowed sustained, or even improved, fishery productivity. Most environmental assessments of irrigation impacts rarely even recognize the existence of inland fisheries (Dougherty and Hall, 1995). However, water for agriculture is now facing competition from many other potential water users, (tourism, hydro-electric power, fisheries, new crops etc.) and more flexibility is required to meet the diversified needs as well as the shifting cropping patterns being adopted by farmers, (Nguyen-Khoa *et al.*, 2005).

A classic example exists in northwest Bangladesh where rice farmers in one irrigated area have largely replaced the Aus rice crop, (April – July) with the production of fingerling fish in unplanted rice fields. The farmers involved, however, still produce an Aman rice crop, (August – November) followed by a Boro rice crop (December–March). There are three advantages of this type of land use management: 1) fingerlings are produced at the start of the fish culture season, when the demand from pond owners is high; 2) one cycle of fish production breaks the rice production cycle reducing residual pest survival and leading to fewer pest problems in subsequent crops; and 3) The profit from fingerling production is many times that from Aus rice production (Barman, personal communication).

There is now increasing understanding of the need for a balanced and holistic approach to irrigation scheme management, which maintains food production levels, as well as providing other environmental and ecosystem services (Renault and Facon, 2004; Renault, Wahaj and Smits, 2013). These services range from regulating services (i.e. groundwater recharge, flood control), to provisioning (e.g. watering small gardens and livestock, fisheries and aquaculture). The development of fisheries (whether capture fisheries, culture-based fisheries or aquaculture) in irrigation schemes is a particularly attractive option in situations where it can offer additional production at low or no additional water service cost.

Despite efforts in the past (Fernando and Halwart, 2000; Renwick, 2001; Redding and Midlen, 1991), the potential for the closer integration of fish production into irrigation systems has yet to be fully realized and opportunities continue to be missed that could significantly increase local food security, incomes and livelihood diversity. For example, Redding and Midlen (1991) report that in the Sudan, the fish biomass in the minor canals of the Gezira irrigation system ranged between 50 kg/ha and 2 786 kg/ha, with an average of 660 kg/ha in terms of standing stock. This is far greater than the biomass found in many riverine habitats and even some extensive aquaculture ponds in the area. Another area with vast potential is Central Asia, which has more than 300 000 km of irrigation canals, representing huge untapped fisheries potential (FAO, 2001; Petr, 2003).

Although much of the focus of developing rice–fish systems has been on Asia, Halwart and Dam (2006) propose that integrated irrigation–aquaculture (IIA) systems should be promoted in West Africa, emphasizing that IIA should be interpreted more broadly than merely "aquaculture in irrigation schemes". The authors argue that options for the integration of fish production (capture fisheries and aquaculture) with the production of crops exist in a wide range of environments, from river floodplains and lake basins to inland valleys and irrigation systems.

In many areas, integrating fish into irrigation systems can benefit from the local availability of fish seed for aquaculture. Globally, the production and efficient distribution of huge numbers of quality fish seed have driven the development of aquaculture forward. In many regions, fish seed produced from hatcheries is now so inexpensive that it can be used in huge numbers for the stocking of waterbodies such as reservoirs, in what has become known as "culture-based fisheries". For example in Central Asia, irrigation dams are now routinely stocked with fingerlings to enhance fish production and Mexico carries out the systematic stocking of its reservoirs and has established a network of seed production centres for this sole purpose (Sugunan, 1997). In recent years, in recognition of a vast untapped potential, international guidelines for supporting the planning for responsible stocking of reservoirs and other open waterbodies have been developed (FAO, 2015).

Kolding and van Zweiten (2006) point out that freshwater fisheries and aquaculture invariably take place in multiple-use environments, but often are considered secondary activities, particularly in reservoirs meant for irrigation, hydropower, flood-control or water supply. However, reservoirs in China are often built with specific provisions for fisheries and fish culture activities during the planning stage, including preparation of the reservoir bed for efficient harvesting and minimizing the escape of stocked fish.

A key principle to be followed in examining irrigation systems for capture fisheries is to find ways to maximize the degree of system connectivity thereby allowing for the unrestrained movement of aquatic animals through different components of the system. Engineering solutions such as fishways, diversion screens and fish friendly regulators offer substantial opportunities to gain productive outcomes for inland fisheries. Water control structures such as weirs and sluices can be designed to be "fish friendly" and aquatic resource refuges/buffer ponds with high levels of connectivity can form part of an overall irrigation system design (Marmulla, 2001).

Unfortunately, the impacts of irrigation system design on fisheries or the potential for mitigation of the adverse impacts on fisheries or the enhancement of fisheries are more usually considered only after an irrigation system has been completed and has been operational for a while. This tends to prevent irrigation systems from reaching their full fisheries potential and often requires the retrofitting of infrastructure to lessen impacts or support fisheries development activities. A recent example of this is in Lao People's Democratic Republic, where fish passages have been successfully established around low head weirs that had fragmented the river system. Through the installation of a fish passage upstream, wetlands could be linked to downstream floodplains thereby facilitating fish migration into the upstream area significantly increasing fisheries biodiversity and production (Baumgartner *et al.*, 2016).

A second principle is the need to account for water use by fisheries during planning for the multiple use of irrigation water. There are few examples of situations where water services for fisheries have formed part of irrigation scheme water allocation management. In the Gotkhi irrigation system in Sindh, Pakistan, fishponds constituted less than 0.05 percent of the command area serviced by irrigation facilities, but their water demand is still factored into water calculations made by the management of the irrigation scheme (Haylor and Bhutta, 1997).

1.1.4 IRRIGATION MODERNIZATION PRESENTS A UNIQUE OPPORTUNITY TO MITIGATE IMPACTS

It is now more than 30-50 years since most irrigation systems were constructed and there is a drive to rehabilitate and reconstruct obsolete and degraded infrastructure. Most irrigation upgrade schemes tend to avoid rehabilitation of existing infrastructure, because in most instances the structure had either already failed or was not performing effectively. The tendency is therefore to replace or re-engineer obsolete infrastructure.

Irrigation modernisation, where old infrastructure is replaced with new designs, result in structures with extended operational life (upwards of 40-50 years). These replacements provide a once-in-a-generation opportunity to increase fisheries productivity. The next opportunity may not arise for many decades and failure to capitalise on opportunities will lead to ongoing perverse health and livelihood outcomes.

The challenge and response to climate change must also be taken into account in the redesign of irrigation systems that are capable of responding to changes in water availability and flow over the next 50 years. There is currently a window of opportunity to rectify the impact of some of the earlier mistakes in design and operation of irrigation systems to capture greater synergies for improved productivity and nutritional benefits from irrigated agriculture. These opportunities span technical and policy interventions relating to enable more effective integration of fisheries and aquaculture in irrigated areas, covering:

- modification of design and operation of delivery and storage infrastructure to improve water connectivity and flows;
- associated actions relating to construction or improvement of habitat and refuge areas within and around irrigated systems;
- revise policies, modify regulation and management of irrigation systems to enable these modifications.

This review is intended to provide support to the process of irrigation modernization and how the interests and issues of fisheries and aquaculture can be incorporated. It is complementary to the approaches that have been developed for auditing irrigation management performance (e.g. Mapping System and Services for Canal Operation Techniques, "MASSCOTE", Renault, Facon and Wahaj, 2007) and multiple use of water (e.g. Mapping Systems and Services for Multiple Uses, "MASSMUS", Renault, 2010).

The auditing of irrigation management tends to focus on access, water quantity and quality, whereas this review incorporates the additional issues of water connectivity, timing and duration of flows and minimum water levels in water bodies. These are all important, additional considerations when addressing the needs of fish and fisheries within irrigation system design and operation.

1.2 THE IMPACTS OF IRRIGATION ON FISHERIES

The impacts of irrigation on fisheries can be profound in positive or negative ways. Irrigation development changes geomorphology, hydrology and land use, changing physical aquatic habitats and nutrient contents and as a consequence impacts (typically adversely) on fisheries resources. However, irrigation also creates new opportunities for fisheries livelihoods, changing the economic environment and institutional arrangements, thus affecting how, by whom and to what extent fisheries resources can be exploited (Lorenzen *et al.*, 2007).

1.2.1 EXTENSION OF FISH HABITATS – A POSITIVE EFFECT

An example of positive irrigation impacts on fisheries can be found in the Kirindi Oya irrigation scheme in Sri Lanka. The large shallow reservoirs of the system now retain more water in the basin for longer than would naturally be the case and fish production has increased as a result (Nguyen-Khoa, Smith and Lorenzen, 2005; Lorenzen *et al.*, 2007). Indeed, the irrigation water storage systems of Sri Lanka are increasingly used for stocking of fish (Chandrasoma, Pushpalatha and Fernando, 2015) as part of culture-based fisheries. The creation of man-made water bodies offers a range of fishery opportunities through the emergence of a new fishery based around indigenous species. A good example are the fisheries for the indigenous Thai river sprat (*Clupeichthys aesarnensis*) that have emerged in large reservoirs of Lao PDR and Thailand. In other examples, non-indigenous fish species have been introduced to develop a fishery. The Lake Tanganyika sardine (*Limnothrissa miodon*) is an example of this and a fishery has been established after its introduction to Lake Kariba reservoir.

The stocking of fish, or culture of fish in cages in irrigation reservoirs is another example of a positive effect. However, this must be evaluated in terms of a net positive effect, as it must be balanced against the loss of riverine fisheries caused by damming of watercourses to create the reservoir (Figure 5).

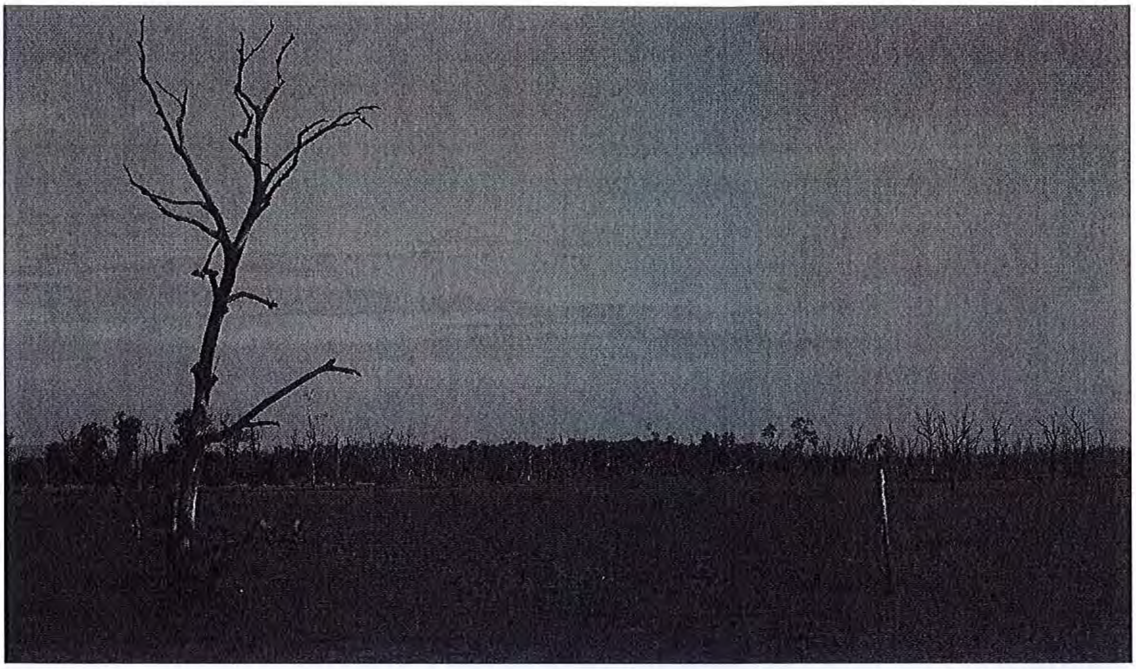


Figure 4: Man-made reservoirs create new habitats for fish and typically result in the creation of new fisheries. They may require initial, or even repeated, stocking to develop the fishery. (Photo credit: Rick Gregory)

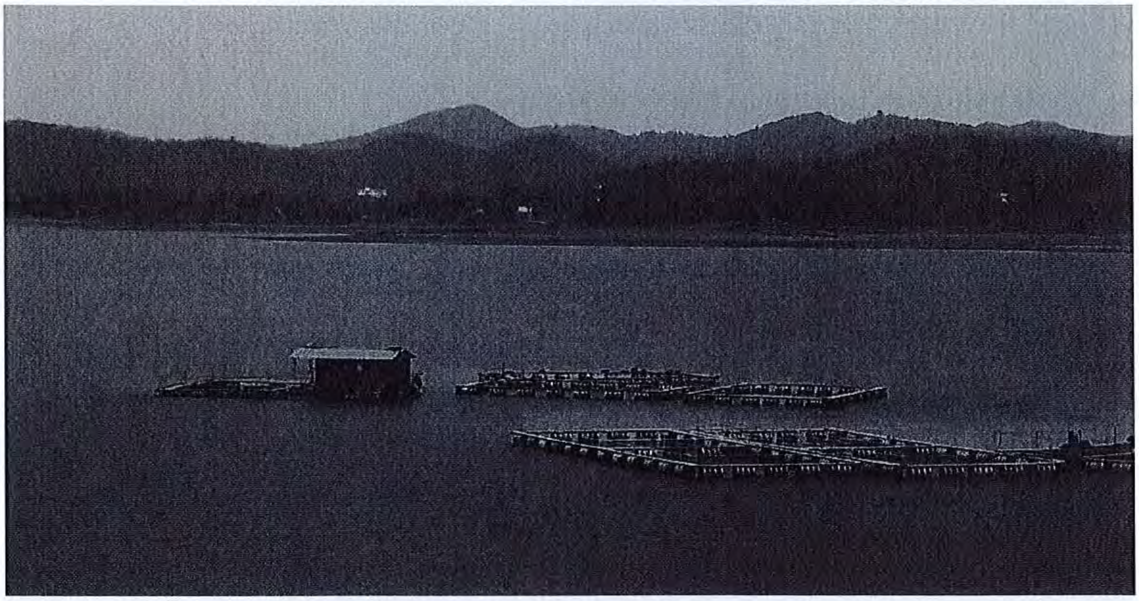


Figure 5: Fish cages on an Indian reservoir (Photo credit: Simon Funge-Smith)

1.2.2 ALTERING ENVIRONMENTAL FLOWS

Water diversions for productive use, and the associated impounding created by water-regulators, can fundamentally change the characteristics of rivers. Irrigation schemes consume water, as not all of the water abstracted or stored is returned to the riverine environment or drainage area. They also store water seasonally, preventing its free flow and may discharge water out of season, as required by dry season crops. Both of these characteristics have impacts on the amount and timing of water available to aquatic ecosystems and the fisheries that they support.

- Impounded areas lack habitat diversity and favour resilient species. Many fish species simply reduce in abundance or become locally extinct on the basis of habitat change alone.
- Flow regimes also become altered downstream of irrigation diversions. Changes in flow impact the amount of available habitat and can reduce or change natural spawning cues. These impacts can significantly alter fisheries productivity, especially for species dependent on flow to complete essential life history stages.

1.2.3 IMPACT ON FISH DURING WATER ABSTRACTION

Existing irrigation pump and diversion systems throughout the Murray-Darling Basin are having unintended environmental impacts (Thoms & Cullen, 1998). For instance, millions of native fish are removed from the Murray-Darling Basin every year when they are extracted by pumps and diverted into channels (Baumgartner, Reynoldson, Cameron, & Stanger, 2009). This presents a problem for environmental water management which is making substantial efforts to provide water flows for fish to breed, but then loses many of the new recruits to fish populations through:

- Extraction in large numbers of fish into irrigation diversions
- Mortality when they interact with the infrastructure that is being used to deliver environmental flows (King & O'Connor, 2007).

Both issues can be completely mitigated, but require a suite of engineering work to achieve this (Brown *et al.*, 2014).

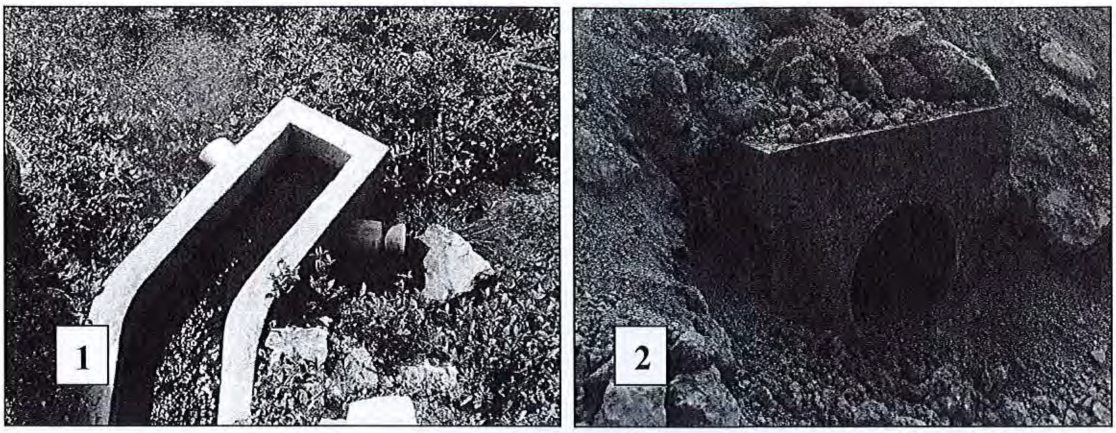
1.2.4 BARRIERS TO MOVEMENT OR MIGRATION

Where irrigation areas are isolated from the surrounding floodplain by embankments, they can have a significant negative effect on the surrounding fishery by limiting the space available for aquatic animals to colonize, reducing the connectivity of floodplains and creating bottlenecks that can increase the effectiveness of fishing effort, resulting in overfishing and stock decline (Le *et al.*, 2007, Baumgartner 2005).

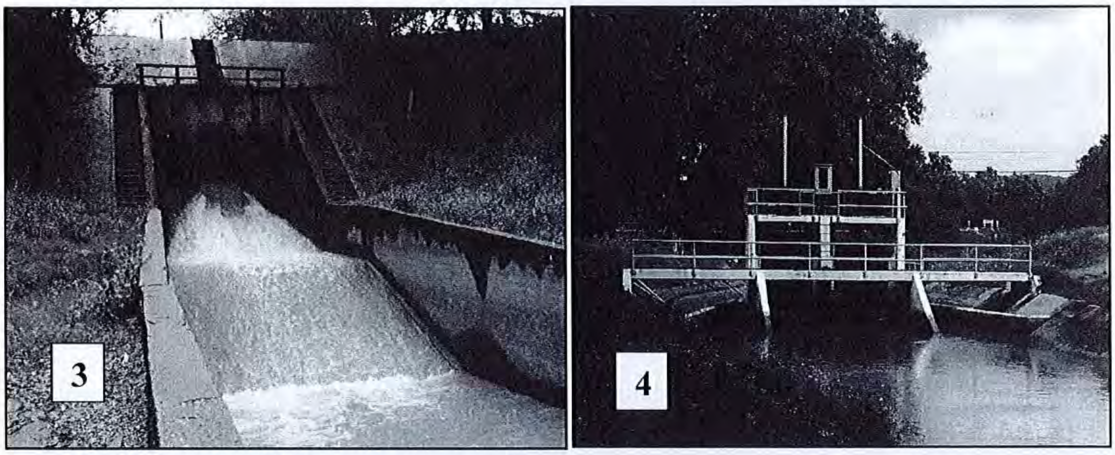
Irrigation infrastructure (weirs, sluice gates, culverts) and saltwater barrages can block fish movement (Daming and Kung, 1997), which is particularly important because most freshwater fish species are considered migratory (Barlow *et al.*, 2008). Some examples are illustrated in Figure 6.

In addition, such barriers create artificial aggregations of pre-spawning fish below the barrier which are then extremely vulnerable to overexploitation by fishers, stress and disease.

Channels and road culverts



Water regulators & sluices



Dams, barrages, weirs

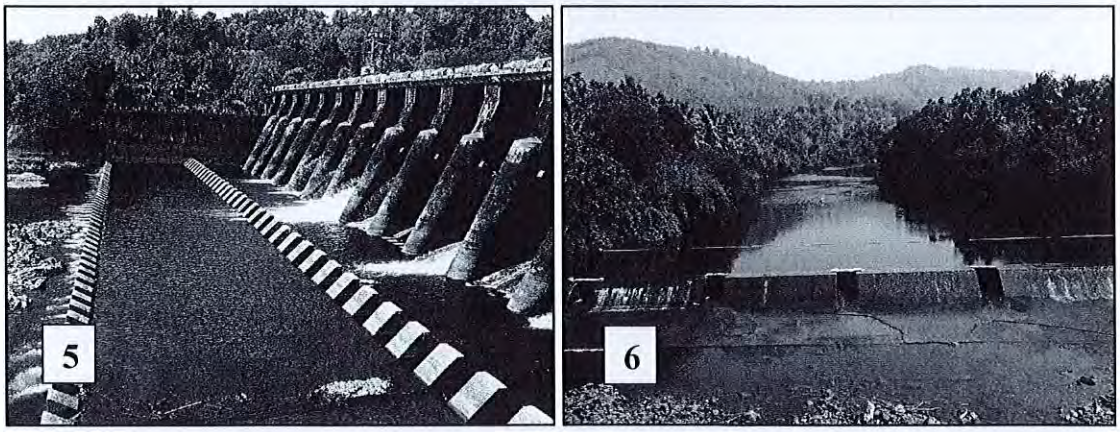


Figure 6: Examples of common irrigation structures and other associated structures, which obstruct fish passage. (Photo credit: 1. Sukanvk2000; 2. Rick Gregory; 3. Lee Baumgartner; 4. Rick Gregory; 5. Vinayaraj V R; 6. Vijayan Rajapuram)

1.2.5 THE COMBINED EFFECTS OF IRRIGATION ON FISHERIES AND AQUACULTURE

The ideal irrigation scheme would utilize only the water required for crop production. However, inefficiencies in water use mean that there are usually significant return flows to the downstream environment, and these can impact fisheries in positive or negative ways. In some cases, fisheries may benefit from existing water use inefficiencies but fish production potential can be reduced if water use in the irrigation system is made more efficient. Table 1 summarizes a range of positive and negative impacts that irrigation systems can have on capture fisheries and aquaculture.

The results in the table do suggest that irrigation systems tend to have more negative effects on capture fisheries and more potential positive benefits to aquaculture. This is primarily because, apart from the creation of new waterbodies, capture fisheries are naturally fluctuating open systems, and the development of irrigation systems invariably means imposing greater controls on water flows and inundated areas. More benefits therefore accrue to aquaculture that are "closed systems" and can benefit from similar water management controls as required for rice or other crop farming.

There are contradictions relating to impacts, with losses in one part of a system and some gains elsewhere. For example, a new irrigation scheme may result in the loss of riverine or wetland habitats, foraging and breeding areas for fish, whereas in another scheme, the extension or expansion of aquatic habitats and niches may be created by the presence of unseasonal water, leakage from the irrigation system, or new flooded areas such as rice fields (Meinzen-Dick, 1997).

The stabilization of water flow is another example where both positive and negative outcomes are possible. This may improve the channel characteristics for some fish species, but may "confuse" other species that rely on a wet season, pulse-flow induced spawning migration.

Only a thorough assessment on a case-by-case basis can reveal whether a particular variable will have net negative or positive influences on different groups of aquatic species.

The large number of negative impacts on fisheries and aquaculture is an indication that much of the emphasis on water planning should aim at minimization, mitigation or compensation of these negative impacts. However, the capture of opportunities presented by potential positive impacts are clearly more easily integrated into existing management systems. In all cases these measures will have cost implications in terms of additional investment, including the adjustment of water management regimes or reduced cropping elsewhere in the system, and the recouping of water charges.

Table 1: Impacts of irrigation systems on capture fisheries and aquaculture

Issues	Impact of irrigation on fisheries and aquaculture	Capture Fisheries	Aqua-culture
Water availability	Reduced water storage capacity in wetlands	–	–
	Increased evapotranspiration	–	–
	Reduction in the level of the water table	–	–
	Increased evaporation and increased salt concentration levels	–	–
	Modified river hydrology, aquatic habitats and ecology	–	+
	Control of flood levels	–	+
	The creation of dams and reservoirs	+	+
	Improved groundwater recharge through seepage	+	+
	Unintended creation of refuges and wetlands	+	+
	Increased water availability in the dry season	+	+
Water flows	Erratic changes in water levels	–	–
	Irregular flows causing the drying out of some areas	–	–
	Short periods of high velocity flows	–	–
	Irrigation dam pulse releases leaves fish stranded and damages gears	–	–
	Poorly sited culverts constrain movement of fish stocks, creating bottlenecks exploited by fishers	–	n/a
	Decreased frequency, duration and magnitude of floods	–	+
	Protection from extreme or flash floods	+/–	+
	The stabilization of downstream flows, (esp. dry season)	+	+
Water quality	Increased pesticides and herbicide residues	–	–
	Increased salinization through waterlogging	–	–
	Increased siltation from agricultural intensification	–	–
	Reduced water turbidity	–	+
Biodiversity	Reduced species richness and diversity	–	n/a
	The spread of exotic species e.g. golden apple snail	–	n/a
	Exotic species proliferation in reservoirs	–	n/a
Habitats	Loss of habitats, foraging and breeding areas for fish	–	n/a
	Land reclamation and drainage for agriculture causes reduced wetland habitat area, quality and connectivity	–	n/a
	Lack of habitat variation in canal type environments	–	n/a
	The extension of habitats and niches through waterlogging	+	n/a
Connectivity and fish migrations	Reduced floodplain connectivity	–	–
	Weirs and barrages preventing the movement of fish stocks	–	n/a
	Habitat partitioning through roads and dykes	–	n/a
	Removal of spawning stimuli through water flow regulation and flood control measures	–	n/a
	Improved duration of connectivity	+	+
Fishing pressure	Increased "catchability" of fish in bottlenecked areas	–	n/a
	Increased pressure on local resources owing to increased numbers of people supported by irrigated agriculture	–	n/a
	Increased fisheries livelihood options	+	+
Drainage	Discharges of poor quality water affecting downstream sites	–	–
	Possibility of salinization of drainage water can increase water salinity in estuaries and lagoons	–	–
	Increased dry season runoff of high nutrient and turbid water	+	+

1.3 THE IMPACTS OF FISHERIES ON IRRIGATION AND IRRIGATION FARMING COMMUNITIES

Fisheries activities or the management of fisheries can impact irrigation schemes and the farmers that use them. These range across management activities related to water, as well as the applications to field crops to fertilize or control pests. These impacts are summarized in Table 2.

Table 2: Impacts of fisheries activities or management on irrigation systems and farming communities

Issues	Impact of fisheries and aquaculture on irrigation farming communities	Positive/ negative
Public health	Disease vector (mosquito, snail) control	+
	Improved nutritional diversity in farming communities	+
Livelihoods	Increased livelihoods and income generating opportunities	+
Water flows	Herbivorous fish such as grass carp (*Ctenopharyngodon idella*) can help keep reservoir and irrigation canals free from aquatic weeds, aiding water distribution	+
	Fisher-built structures can interfere with canal water flows and downstream water service to farmers	–
Nutrients	Farming inputs may be reduced where water and solids from intensive aquaculture provide supplemental fertilizer for irrigated crops	+
	Rice field nutrient cycling and circulation aided by presence of some fish species, such as the common carp, (*Cyprinus carpio*).	+
Pesticide & herbicide use*	Pesticide use may be reduced or unnecessary where fish are present in rice fields. This can strengthen integrated pest mangement approaches	+
	Some fish species can be used to suppress weed growth in rice fields, e.g. the common carp, (*Cyprinus carpio*)	+
Invasive species	Aquaculture can result in the introduction of exotic aquatic animals detrimental for agricultural production, such as the golden apple snail (*Pomacea canaliculata*) or the Chinese mitten crab (*Eriocheir sinensis*)	–
Water logging of cropping areas	Desirable for fisher/ aquaculture communities Can be a source of conflict between farmers and fishers	–

*The use of pesticides in the ECA requires special mention. In some systems, such as rice fish culture, the use of pesticides can impact the health of the fish. In some cases, farmers may be willing to tolerate some pest damage if they can recover crop production losses through increased fish production. Elsewhere, farmers may choose to spray their fields and fish will have to be removed before this is done. This can be accomplished by draining fields into ponds connected to the rice field.

1.4 EXTENDING MANAGEMENT BEYOND THE IRRIGATION COMMAND AREA

In order to effectively examine fisheries opportunities within irrigation schemes, a vision beyond that of the conventional irrigation command area (the cropping area serviced by irrigation water) is required. Given the importance of the connectivity of waterbodies for capture fisheries, it makes sense to examine all waterbodies that are already connected, or which could be connected, by an irrigation scheme; or that are supported, or could be supported, by one. This should include waterbodies upstream and downstream of the conventional command area and should take into consideration other water sources that join and mix with the irrigation waters. This broadened approach that envisions a mosaic of inter-connected waterbodies linked to a source of irrigation water, is the **Extended Command Area** (ECA) (Figures 7 & 8).

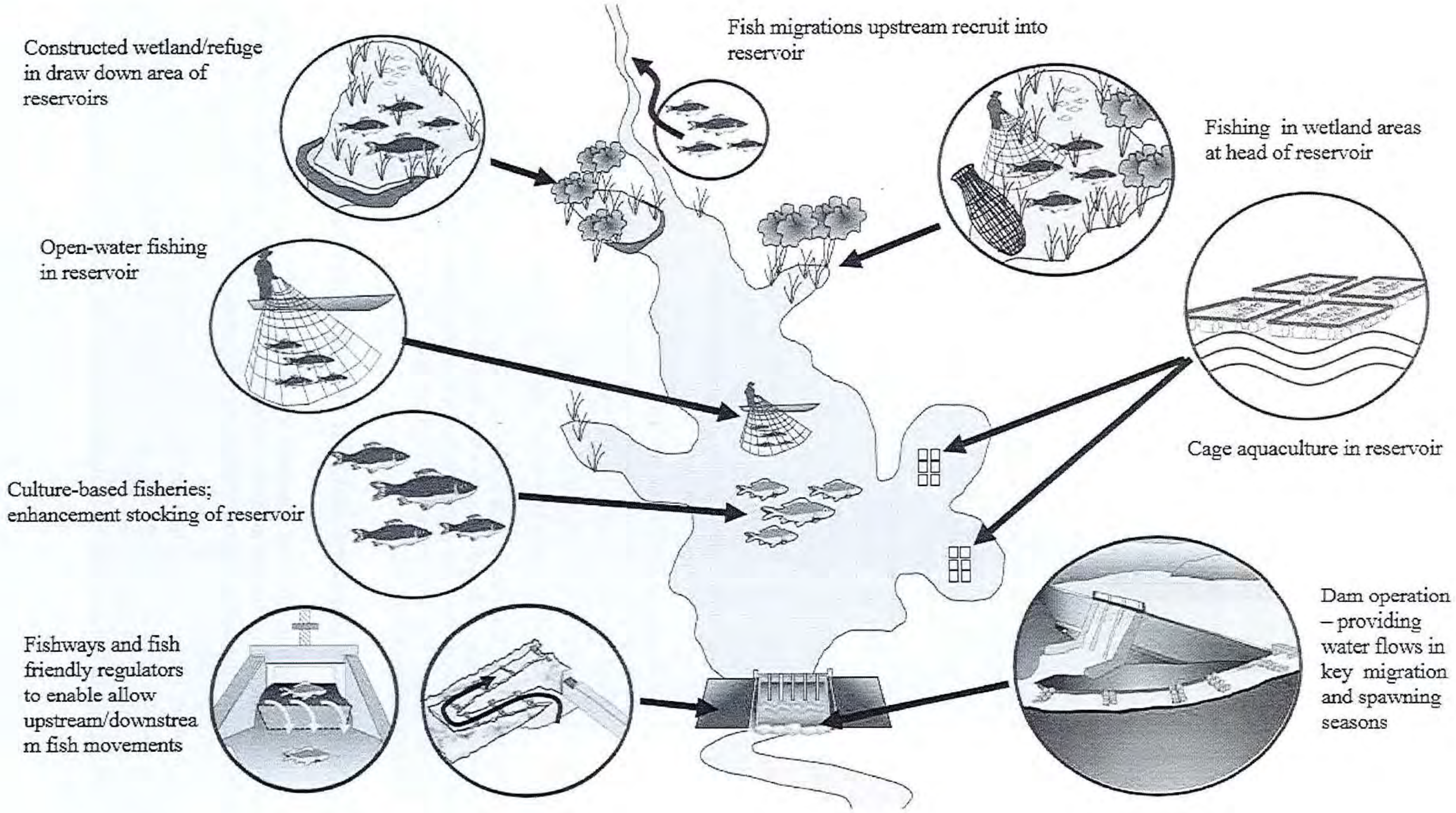


Figure 7: Opportunities for fisheries and aquaculture in the upper part (reservoir and headwaters) of the extended command area. (Graphic: Simon Funge-Smith)

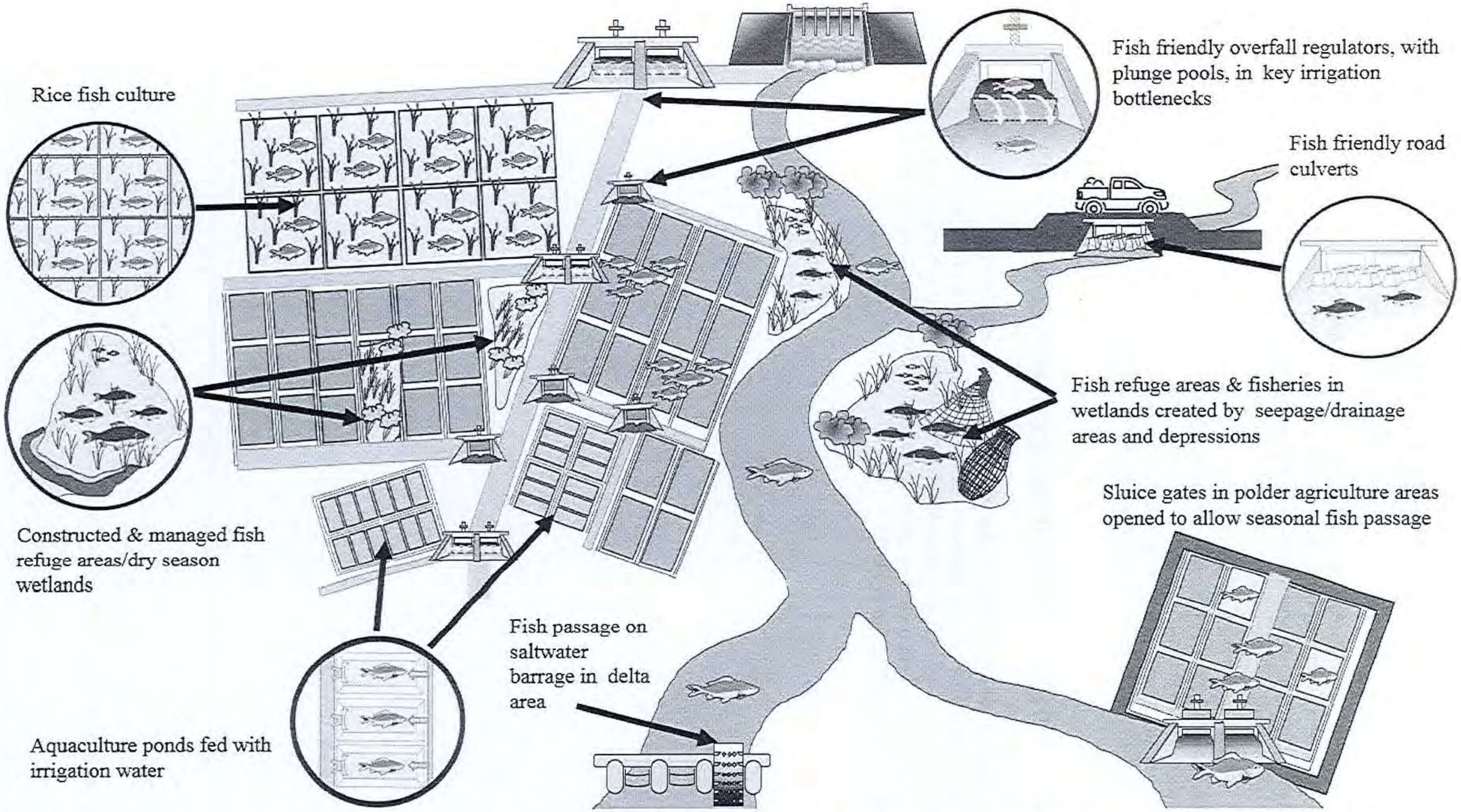


Figure 8: Fisheries and aquaculture integration into the lower part of the extended command area (water conveyancing and distribution system; the command area for irrigated crops; drainage system; associated natural or constructed wetlands and/or waterlogged areas). The water control structures in delta areas are incudes (polder sluice gates and saltwater barrages). (Graphic: Simon Funge-Smith)

Conventional ecological restoration initiatives often focus on recovering the full suite of ecosystem processes and structures damaged by development or degradation. An ECA approach to fisheries in irrigation systems would aim to enhance ecosystem services by maximizing specific ecosystem production processes in response to particular social or economic demands. (Palmer, Hondula and Koch, 2014).

One advantage of such an approach is that opportunities and constraints can be considered from a broad irrigation systems perspective. An ECA lens would allow planners and managers to consider each of the functional areas of the ECA from a fisheries perspective rather than just isolated elements of it. Key constraining elements to fisheries such as the loss of connectivity (choke points) between waterbodies can be pinpointed and remedial actions taken.

In Figure 7, fisheries opportunities for irrigation reservoirs and headwaters are highlighted. Figure 8 illustrates the opportunities for fisheries development within irrigation systems and associated water resources. The ECA vision extends to irrigation canals, trap ponds, field crop areas, drainage canals, wetlands, seepage areas and can also be extended downstream to include delta and coastal areas that may support important capture fisheries or sites for aquaculture, and that are influenced (positively or negatively) by upstream irrigation scheme operation and management.

1.5 THE FUNCTIONAL AREAS OF THE EXTENDED COMMAND AREA (ECA)

In order to understand how fisheries considerations can be integrated most effectively into irrigation systems and the possible benefits that can accrue, it is useful to divide the ECA into five functional areas: water sources; water distribution systems; crop production areas; waterlogged/seepage areas; and drainage areas. Each functional area offers opportunities for improving environments for fisheries development, as summarized in Table 3.

Table 3: Functional areas of the ECA and benefits possible through improved management

Component	Conventional resource management & operation	Improved management & operation for fisheries	Result of improvement	Possible impact on fish production
1. Water sources				
Reservoir	Drawdown without fisheries considerations	Reservoir discharges and drawdown take aquatic biology into account	Critical areas for fish remain inundated at key times in their life cycle	Increase in fish production in reservoir
	Reliance on local fish species colonizing reservoir	Introduction of most suitable fish species for the reservoir environment	Increased biodiversity and efficient use of natural food sources available in the reservoir	Increase in fish production in reservoir
	Reliance on natural stock recruitment	Regular stocking of fingerlings or post fingerlings for culture based fisheries	Fish production increased through better utilization of natural feeds	Large increase in fish production in reservoir
	No designated area management	Breeding and nursery habitat protection and enhancement	Increased breeding success and improved recruitment of fish	Increase in fish production in reservoir
	Low productivity of water and low wild fish production	Promotion of floating cage or pen aquaculture	Increases in fish production and new livelihood opportunities for local people Increased capture fisheries production around cages	New source of fish production
	Degradation of land in reservoir catchment	Maintenance of forests and other ground cover around reservoir	Improved water quality and duration of inflows, plus possible breeding areas for riverine fish species living in reservoir	Some increase in fish production in reservoir
Rivers /streams	Isolation of upper river areas	Installation and management of fish passages around obstructions e.g. weirs	Allows for reconnection of floodplains to river systems and upstream and downstream fish migrations	Substantial increase in fish production in upstream floodplain areas Restoration of migratory species prevented from moving upstream and downstream
Natural wetlands	Isolation of wetland from main river by water regulators	Installation and management of fish passages around obstructions e.g. fish ladder and improved fish friendly regulators	Allows for reconnection of wetland and associated irrigated area to river systems and upstream and downstream fish migrations	Increase in fish production Restoration of migratory species prevented from entering wetland
Groundwater – tubewells	Water pumped directly to crop command areas	Pumped water passes through a fish production unit/area, before reaching crop command areas	Increased fish production and improved nutrient quality of water for crop production	New source of fish production
Rainfall runoff	No fisheries management considerations in run off areas	Management of runoff areas to improve habitats and water quality	Increased fish production and biodiversity	Increase in fish production in waters receiving runoff

Component	Conventional resource management & operation	Improved management & operation for fisheries	Result of improvement	Possible impact on fish production
Domestic wastewater	Domestic wastewater run-off unutilized for fisheries	Use of domestic wastewater (not industrial waste) in pond aquaculture or culture-based fisheries	Increased aquaculture or culture-based fisheries production	New source of fish production
Excavated ponds	Poor excavated pond design and operation	Pond linked to floodplain Pond banks planted with vegetation	Increased fish production and biodiversity	Increase in fish production in excavated pond
	Ponds pumped for irrigation without regard for fisheries	Limitation on maximum amount of water that can be removed during the dry season	Increased survival of fish stocks through dry season	Increase in fish production in ponds plus moderate increase in fish production on surrounding floodplain, through enhanced refuge function
2. Water distribution systems				
Mains canal, secondary, and tertiary canals	Impassable weirs and sluices restrict movement of fish	Installation of fish friendly passes and maintenance of water level and maintenance of canal levels	Allows for freer lateral movement of fish/juveniles and permanent establishment in the canal system	Increase in fish production in irrigation canal system
Buffer ponds	No fisheries considerations	Enhancement of aquatic and surrounding terrestrial habitats and water quality Stocking of juveniles or brood fish into the buffer ponds	Increased fish production and biodiversity Enhanced refuge function	Increase in fish production in the buffer ponds plus 15% increase in production on floodplain through enhanced refuge function
3. Crop production areas				
Rice fields	Fish unable to colonize rice growing areas because of physical obstructions	Open connections between fields maintained during rice growing period	Natural fish and other aquatic animals (OAA) able to become established in rice fields	Increased fish and other aquatic animals (OAA) production from rice fields
		Stocking of fish fingerlings in rice fields with perimeter ditches and dykes	Natural foods in rice fields utilized Weeds reduced	Significant increase in fish production from rice fields
	Irregular water levels in fields	Minimum water level of 5 cm maintained throughout rice growing period	Natural fish and OAA established in rice fields throughout the rice growing period	Increase in fish and OAA from rice fields
	Extensive pesticide and herbicide use	Integrated pest management approach used to reduce use of chemicals in rice production	Reduced toxins in rice field environment Higher biodiversity, improved ecological balance Higher fish survival and growth No reduction in rice production	Increase in fish and OAA production from rice fields
Ponds and ditches in rice growing area	Waterbodies disconnected from each other and rice fields	Connectivity between rice fields and ponds/ditches improved	Allows for freer lateral movement of fish through the rice growing area	Increase in fish and OAA production from ponds & ditches

Component	Conventional resource management & operation	Improved management & operation for fisheries	Result of improvement	Possible impact on fish production
	Ponds and ditches have low recruitment and fish productivity	Stocking of fingerlings and fertilization. Enhancement of ponds/ditches as fish refuges	Fish and OAA populations in ponds//ditches increased	Increase in fish and OAA production from ponds and ditches
Ditch & dyke vegetables/ orchards	Pesticide and herbicide use in orchards results in high residues in ditches used for irrigation	Runoff from orchard/vegetable areas prevented from entering ditch water supplies. Promotion of the use of pesticides that are least harmful to aquatic life	Reduced toxins in ditch environment. Higher fish survival and growth	Increase in fish and OAA production from orchard/ vegetable ditches
4. Wetlands & seepage areas				
Wetland seepage areas close to rice fields	Low recruitment and fish productivity	Stocking of fingerlings and fertilization. Enhancement of seepage areas as fish refuges	Fish and OAA populations in wetlands increased	Increase in fish and OAA production from wetlands
Borrow pits	High levels of residual chemicals from rice growing areas	Planting of macrophytes in and around wetlands to improve water quality and aquatic habitats	Fish and OAA populations in wetlands increased	Increase in fish and OAA production from wetlands
	Poor water quality	Reduce erosion on embankments through establishment of vegetation and diversion of inflows of poor quality water	Improved water quality leading to higher fish production	Moderate increase in fish and OAA production from borrow pits
	Low recruitment and fish productivity	Stocking of fingerlings and fertilization. Enhancement of borrow pits as fish refuges	Higher utilization of natural feeds in borrow pit	Increase in fish and OAA production from borrow pits
5. Drainage areas				
Wetlands	Water from rice fields and other crop areas discharged into wetlands without consideration of effects on fisheries	Planting of macrophytes, (e.g. phragmites) in and around wetland to improve water quality	Reduced toxins in wetlands leading to higher fish/OAA biodiversity and productivity	Moderate increase in fish and OAA production from wetlands
		Inflows from crop growing areas regulated.	Reduction in sudden changes in water quality leading to higher fish survival	Moderate increase in fish and OAA production from wetlands
	Low levels of wild fish biodiversity and production	Introduction of aquaculture into wetland drainage areas	Increases in fish production and new livelihood opportunities for local people.	New source of fish production
Lagoons (in coastal area, these are typically low salinity brackishwater)	Lost connectivity between lagoons and other water sources	Connectivity improved through physical barrier modifications, (e.g. road culverts)	Increases in fish production and enhanced livelihood opportunities for local people	Moderate increase in fish and OAA production from lagoons
	Degradation of land areas around lagoon	Re-establishment of forest and other land cover	Improved water quality in lagoon leading to higher fish production	Moderate increase in fish and OAA production from lagoons
	Low levels of wild fish biodiversity and production	Introduction of (cage) aquaculture and culture-based fisheries in lagoon areas	Increases in fish production and new livelihood opportunities for local people	New source of fish production

Component	Conventional resource management & operation	Improved management & operation for fisheries	Result of improvement	Possible impact on fish production
	Low connectivity of lagoons to external water sources	Removal or alleviation of physical barriers to fish migration	Fish and OAA populations in lagoons increased	Increase in fish and OAA production from lagoons
Estuaries and deltas	Loss of connectivity to anadromous and catadromous fish in polders	Modification of opening of sluice gates to enable fish passage.	The movement of key anadromous species into poldered areas contributes to the fishery	Increase in fish catches within polders and possible contribution to delta fisheries
	Loss of connectivity to anadromous and catadromous fish through tidal barrages	Installation of fishways	The movement of key anadromous species upstream into freshwater areas contributes to the fishery and catches in the delta and in upstream areas	Increase in fish catch in delta areas and further upstream areas. Improve recruitment of migratory anadromous and catadaromous fish
	Degradation of mangrove and seagrass areas	Replanting and restoration of mangroves and sea grass	Higher fish and OAA biodiversity and productivity	Moderate increase in fish and OAA production from estuarine areas
	Human pressure on estuarine mudflats resulting in low survival of juveniles	Protection through zoning or closed seasons) of mudflats and other estuarine nursery areas	Higher fish and OAA biodiversity and productivity	Increase in fish and OAA production from estuarine areas

1.6 GOVERNANCE CHALLENGES FOR INTEGRATED MANAGEMENT

Before moving onto a proposed process for the ECA approach, it is important to consider how governance frameworks might impact on the proposed integration of disciplines.

National and regional laws and policies can have a large impact on the extent that fisheries can be integrated with irrigation systems. Some countries / regions currently encourage the integration of natural resources governance whereas others retain strict sectoral foci. For example, in Sri Lanka and Cambodia, integrated rice–fish practices are encouraged and in the latter, community fish refuges that support floodplain fisheries have become a national policy thrust (Joffre *et al.*, 2012). Some other countries do not currently allow rice field areas to be used for fisheries purposes nor rice fields to be easily converted for fish culture (Belton, Filipski and Hu, 2017), or specifically ban fisheries-related activities, such as the placing of fish cages in irrigation canals (IWMI, 2007).

Table 4 provides some examples of irrigation policies and their positive or negative impacts on fisheries and aquaculture.

Table 4: Irrigation related policies and their impacts on fisheries and aquaculture

Policy/action subject	Limit, adversely impact, or prevent, capture fisheries and aquaculture	Support capture fisheries and aquaculture
Use of storage reservoir's area	Reserved for water storage only	Habitat created to enhance fisheries
		Stocked for enhanced fisheries
		Stocked for culture-based fisheries
		Designated areas for cage aquaculture
		Managed for recreational fisheries
Water abstraction	Draining of reservoir or dewatering of rivers/waterbodies is only focused on meeting irrigation demands	Minimum water levels in reservoir maintained to sustain fish population and aquatic ecosystem
		Minimum flows sustained in rivers to sustain fish and aquatic ecosystem function
		Creation of refuge areas and wetlands
Irrigation water use	Use permitted for field crops only	Water permitted for use in diversified production systems including aquaculture
		Rice–fish production permitted
Irrigated land conversion	Deviation from primary crop production not permitted	Modification to enable secondary crop (e.g. rice-fish channels) production permitted
		Conversion to fish ponds permitted
Design of water control structures	Lowest cost design and construction , with focus only on water delivery	Designs adapted or required to enable upstream and downstream passage of fish
		Additional measures (such as construction of fishways) required to ensure connectivity
Operation of water control structures	Priority for operation to maximize water delivery for irrigation, irrespective of other ecosystem services	Minimum flows retained in watercourses to sustain aquatic ecology
		Sluices opened during critical fish migration periods
		Sluices operated in a way that is least harmful to migrating fish

In many parts of world there has been a gradual but steady move towards the decentralization of governance (including natural resources governance) to local governments, the closer integration of natural resources management (Thailand, Indonesia, Philippines, Lao People's Democratic Republic and Cambodia), and the deeper involvement of communities in planning and the co-management of their surrounding natural resources.

These trends offer opportunities for the various natural resources departments and sectors to work together more closely. However, even where laws and policies encourage integrated natural resources governance, the institutional structures and relationships between natural resource related government departments may not allow for positive collaboration between them, even if they are located within the same ministry. Such "silo thinking" is not just confined to institutions in the developing world. Constraints to integrated approaches often come down to departmental budgets and the skill sets of personnel who could be involved.

Many irrigation systems are co-managed by water user groups usually made up of farmers and tubewell operators in the command area. These groups are likely to have a strong say in how water from the irrigation system is delivered and used. Fortunately, many rural people already think in multi-disciplinary ways and many will easily understand the logic of an ECA type approach to water resources management, including the integration of irrigation scheme management into a wider resource use context. However, it may still prove challenging to convince a "crop-minded" water users group, of the water needs and requirements for fisheries.

The trend towards irrigation management transfer (IMT) that moves irrigation away from government departments towards water user groups is another reason for promoting the integration of fisheries and irrigation (Garces-Restropo, Muñoz and Vermillion, 2007). Disagreements between different stakeholder groups can be expected because of potential contradictory objectives over the use of water. Participatory approaches to conflict resolution, such as that used by the Ecosystem Approach to Fisheries Management (EAFm) can be fairly easily adapted for irrigation resource users.

In order to be successful then, the integration process proposed requires the close collaboration of irrigation, agriculture and fisheries specialists. Typically, the lead institution in promoting fisheries and the ECA approach will be the Department of Fisheries or its equivalent, yet this department may lack an adequate understanding of water and irrigation management and may not be confident in directing the management of irrigation systems for fisheries. Whichever department takes the lead role, it is important that a multi-disciplinary team is assembled. Fisheries officers involved should have a rudimentary understanding of irrigation and farming so that they can communicate effectively with their counterparts in irrigation, land use or agriculture departments and *vice versa*. This entails challenging staff to work outside of their field of specialization. It is also important that any proposed changes to irrigation system management are communicated to district or subdistrict planning bodies, and frameworks such as provincial development plans, etc. Such planning bodies may have to play an important role in arbitrating between water users and stakeholder groups in the event of disagreements over irrigation water/resources management.

2 LINKING THE PLANNING TOOLS FOR IRRIGATION AND FISHERIES

2.1 ALIGNING PRINCIPLES AND METHODOLOGIES OF THE ECOSYSTEM APPROACH TO FISHERIES WITH IRRIGATION MODERNIZATION PLANNING

Conventional approaches to fisheries management, which focus on fish stocks or aquaculture in isolation, are unlikely to prove successful in promoting the closer integration of fisheries and irrigation schemes. A holistic approach is required, that aims to achieve sustainable fisheries management in an ecologically diverse and multi-stakeholder environment.

The ecosystem approach to fisheries management (EAFm) and its module-based training package, the Essential Ecosystem Approach to Fisheries Management (E-EAFm) offer a practical and effective approach to managing fisheries in such a holistic manner (Staples *et al.*, 2014). EAFm represents a move away from fisheries management that focuses on single target species, towards a systems-based decision-making process that aims to balance environmental, human and social well-being through improved governance frameworks (Staples *et al.*, 2014). To date, EAF has been applied mainly to coastal fisheries management, but its ecosystem-based, stakeholder-led approach also makes it a suitable tool for promoting the integration of fisheries and irrigation systems.

The EAFm process is guided by seven principles: good governance; appropriate scale; increased participation; multiple objectives; coordination and cooperation; adaptive management; and the precautionary approach. The modification of the EAF process for promoting improved fisheries management in irrigation systems could prove useful in improving dialogue between fisheries specialists, irrigation engineers and farmers and creating a strong advocacy base for change.

The use of EAF to develop management that also takes irrigation system concerns into account could also incorporate elements of a second planning tool which is used for auditing and planning irrigation modernization. This is the FAO "Multiple uses of water services in large irrigation systems (MASSMUS)" tool (Renault, Wahaj & Smits, 2013). Although the tool is directed at medium to large irrigation systems, much of the diagnostic thinking, costing and planning could be adopted for use in smaller irrigation systems or subsidiary parts of medium and large irrigation systems.

The MASSMUS tool is a subsidiary tool of the Mapping System and Services for Canal Operation Techniques (MASSCOTE) approach (Renault, Facon and Wahaj, 2007). The MASSCOTE approach is a systematic approach for diagnosing the performance and service levels of irrigation systems. It is an eleven-step process that assesses and prioritizes the irrigation conditions that require improvement, starting with a rapid appraisal procedure (RAP) that allows for a sound diagnosis of the current performance of the irrigation system in question. Improvement in the accuracy and access to water use achievable under the MASSCOTE approach also resonates with fisheries management objectives in irrigation schemes, which, to achieve a balance with crop production, must also calculate irrigation water use. These planning tools can be complex to roll-out and require data input to enable decisions on water allocations and delivery to be made.

The EAFm approach allows further considerations to be identified that can then be used to inform a MASSMUS and/or MASSCOTE planning approach. It also allows the fisheries and aquaculture needs to be more effectively communicated to irrigation managers during the modernization or modification of irrigation systems. The MASSMUS is specifically intended to take other uses of irrigation systems into account, however, there are some key differences between the MASSCOTE approach and EAFm.

The MASSCOTE approach has a canal operation focus and does not apply a system wide view as is proposed for EAFm and the proposed ECA approach. Central to the MASSCOTE objectives are the cost effectiveness of the irrigation scheme and the principle that the user pays and the user decides. Lastly, it aims to build professionalism in irrigation managers, who have skills and the capacity to understand the complexity of the system. These are certainly elements that could be incorporated into the development of EAFm and planning in irrigation systems. From this point onwards we will refer to the proposed ECA approach to fisheries management in irrigation systems as EAFm-i.

2.2 MODIFYING THE EAFM AND THE MASSCOTE APPROACH FOR IMPROVING FISHERIES MANAGEMENT IN IRRIGATION SYSTEMS – THE EAFM-I APPROACH

An EAFm-i would seek to establish a baseline of information on the existing fisheries situation in the irrigation scheme. This baseline would show a comprehensive picture of fisheries activities in the five functional ECA areas and their importance. The baseline would cover the following:

- Aspects of fisheries in the ECA influenced by irrigation system operation and management;
- The water use needs of fisher families;
- Formal and informal rules for fisheries co-management including access to fishing areas;
- The main fisheries techniques used;
- Stakeholder attitudes towards fisheries; organizational arrangements;
- Water delivery services to fisheries;
- Irrigation infrastructure and operation; and
- The capacity of the system to provide the necessary services to fisheries.

Through implementation of an EAFM-i plan, a common understanding and technical language for both irrigation and fisheries managers would emerge. This would also enable fisheries specialists to engage more meaningfully with the MASSCOTE approach or irrigation modernization processes where these are being applied. It will also enable fisheries managers to negotiate with irrigation managers/operators for management amendments that promote fisheries and aquaculture services and benefits. The baseline could then be used to measure the success of improvements to the fisheries.

Details of steps in the EAFM-i process, compared to the EAFm can be found in Annex 1. The rest of this document will focus on irrigation infrastructure, water balances and costings.

A key element in the EAFM-i process is the linkage between irrigation water resources and fisheries and aquaculture. This requires an accurate assessment of irrigation water resources and their management and how they relate to the potential to support or impact fisheries and related activities. An irrigation and water infrastructure system must be evaluated in terms of its capacity to sustain, enhance or introduce fisheries practices. In order to increase fisheries benefits from a system, there are three principle questions that must be answered.

- Is there anything that can be done with the existing system that could reduce negative impacts and therefore improve fisheries activities?
- Is there a possibility for expansion of fisheries activities given existing water availability?
- Can underutilized wetland areas be identified that have potential for fisheries development?

However, fisheries will tend to require different irrigation water management compared to field-crops. In very well managed crop irrigation systems, opportunities for fisheries may be fewer because of the full accountability of water and the lack of surplus discharges or unutilized areas. In order to understand this, the capacity of an irrigation system should also be evaluated in terms of timing. For instance, irrigation canal systems may be regularly (annually) turned off for repair and maintenance or because the field crop is close to harvest, or the irrigation season is over, which may result in reduced or no services to fisheries during these periods. It is also important to consider the possible effects that changes in cropping patterns and irrigation agriculture practices might have on existing or projected water services for fisheries. Table 5 highlights some key water management issues in each of the five functional areas. An EAFM-i plan for an ECA should score highly across all the categories.

Table 5: Water assessment examples for the five functional areas

Functional area	Component	Examples of key questions
Water sources	Reservoir	Will a minimum level of water be retained in the reservoir to support capture fisheries and/or cage aquaculture?
	River/wetlands	Can fish move freely into the irrigation system from the source?
Water distribution system	Canals and channels	Will flows be maintained in these systems during key fish migration times?
		Is current sluice/regulator design friendly to fish passage or result in obstruction or damage to fish?
		Will sluices be operated in a way that does not have a negative effect on fisheries?
Crop production area	Rice field	Can water levels, adequate for fish, be maintained in the rice field for the duration of the rice production cycle?
		Will water be available outside of the cropping season?
Waterlogged and seepage areas	Wetland adjacent to rice field	Will water quality be affected by pesticide residues or other chemicals, or high turbidity?
		Will these areas be pumped for dry season irrigation?
Drainage areas	Estuary	Will water discharged from the irrigation system affect salinities in coastal areas?
		Will freshwater barrages, or sluice gates on polders impact the movement of anadromous and catadromous fish?

2.3 ASSESSMENT OF WATER BALANCES FOR FISHERIES IN IRRIGATION SYSTEMS

The first step in carrying out an assessment of water balance is to define the spatial and temporal boundaries. Water balances can be conducted for a single rice field, a pond, a farm, a submanagement unit, an entire irrigation service area, or the entire ECA. For the purpose of evaluating management strategies easily, a time frame of a year, six months or a single irrigation or fishing season can be used.

Both the quantity and the quality of water need to be considered. In some cases, water from fisheries areas can be returned to the irrigation system and so become available for other users, in some cases the quality of this water will have been "improved" through the addition of nutrients. Benefits can be described in terms of production supported by the water service – for example crop yield per unit of water used or fish yield per unit of water used. This is considerably more difficult for capture fisheries water balance assessments than it is for aquaculture. Assessing the water balance must also take into account head loss as even if the irrigation water is not consumed, the loss of head through its use for fisheries or aquaculture can render the water unavailable for other purposes.

2.3.1 ANALYSIS OF WATER PERTURBATIONS

Fluctuation and variation in water levels and water flow have obvious and numerous implications for fisheries, some of which are at odds with crop water requirements. Perturbations of water variables (level and discharge) along open-channel irrigation networks are the norm not the exception.

Perturbation in irrigation terms is defined as an unplanned variation of the influencing conditions that may lead to a significant change of the intermediate or ultimate delivered services. Perturbation is a permanent feature of irrigation canals owing to the upstream setting of structures and compounded by intended or unpredicted changes in inflows/outflows at key nodes. Internal or external perturbations are generated along a canal infrastructure despite management efforts to control the water flowing conditions and once they are established, they usually propagate downstream. Amplification of perturbations along canals can lead to large instabilities that penalize downstream users – a common phenomenon in many canal irrigation systems.

In many irrigation systems it will be easier to integrate fisheries with crop areas and downstream components rather than in upstream water distribution channels. The latter are likely to be less stable in terms of water flows and conditions, and farmers are generally less willing to allow fisheries activities to interfere with the crucial issue of water delivery.

The following points need to be considered in perturbation analysis for fisheries:

- frequency and duration of breakdowns or other interruptions in the irrigation system and their effects on fisheries;
- location, frequency and severity of perturbations throughout the irrigation system;
- effects of variable (and non-variable) canal levels and flows on fisheries;
- effects of variable canal levels and water flows on downstream fisheries in the ECA;
- frequency of canal overflows and their effect on fisheries; and
- the irrigation system restart process and its effects on fisheries.

Perturbation analysis should also be undertaken for fluctuations in both quantity and quality in all functional areas of the ECA. For instance, runoff from nearby urban areas or discharge from industries into the canal network might create water quality shocks for some functional areas of the ECA. Management of perturbations must ensure that the functional area is compensated for a deficit of water if the perturbation is negative, or that the surplus is stored, if it is positive. Service agreements between water providers and fisheries practitioners should include compensation measures in the event of the failure to provide water delivery or retention, as required.

2.3.2 MAPPING OF SLUICES, GATES AND THEIR OPERATION

For effective operation of any irrigation system, managers must know the capacity of the structures within their command area. Therefore, system capacity needs to be assessed (or re-assessed) properly for each main structure, considering its functions (storage, transport, diversion, etc.). The way in which a canal system behaves after the structures have been set for a particular water distribution plan and left without attendance is the central focus of sensitivity analysis. It is also important to know how structures react or behave under perturbation in order to be able to plan for adequate actions/responses. For conventional irrigation delivery, sensitivity is a short-term concern (typically, hours or days). For fisheries concerns, the critical periods may be shorter. Within the irrigation infrastructure, the physical characteristics of the irrigation canal system with respect to their various functions: conveyance, water-level control (regulator), diversion (offtake) and division (proportional dividers), and storage must be mapped.

Physical characteristics should be analysed not only from an irrigation delivery services point of view, but also from a fisheries perspective. Since the water services for fisheries may be of a different nature than those for irrigation, the capacity and sensitivity should be analysed in a different manner. This depends upon whether this is:

- a delivery point for aquaculture in ponds (controlled flow);
- a required volume over a period of time, for example aquaculture in ponds;
- the retention of water in functional areas of the ECA; or
- the maintenance of water levels in reservoirs, canals, and waterbodies for capture fisheries purposes.

Behaviour analysis of various irrigation structures is performed through the assessment of their sensitivity: (i) for each main type of structure taken in isolation; (ii) for a combination of associated structures; and (iii) at the reach and subsystems levels. A focal point for fisheries is the regulator gate mechanisms used to control water levels and flows, which usually also dictates fish flows.

Water level and flow rates in a canal distribution network are often controlled by movable sluice and water gates. The operation of these structures is likely to have significant bearing on their "fish friendliness". From an irrigation viewpoint, gates are operated to keep a targeted water level in a canal section (or at a cross regulator) and/or flow rate into a sub-canal. The gates are usually operated when the water level and /or flow rate target changes or there is an unintended fluctuation in water level and/or the flow rate needs to be controlled.

The main purpose of sluice gate operations is to maintain flow rate and water level targets and provide a stable discharge to the lateral or offtake canals. In general, the more frequently the water can be released with the least turbulence, the more fish friendly a sluice or water gate is likely to be. The EAFm-i plan to be developed will also have to include recommendations for water discharge management that favour fisheries, without adversely affecting field crop production. In tidal freshwater areas, sluice gates are commonly used to control the discharge of excess water at low tide and to prevent saline water contamination into poldered crop growing areas at high tide and may represent a significant barrier to fish migration, including anadromous and catadromous species.

Mapping of water control gates and other structures and their frequency of operation provides an indication of the extent to which they will operate as complete or partial barriers to fish movement and the degree to which (in important/critical cases) some form of mitigation may be required (e.g. a fish passage structure, bypass or more fish-transparent structure.

2.3.3 ASSESSING DESIGN OF CANAL WATER REGULATION AND DELIVERY STRUCTURES

Table 6 classifies canal water-regulation structures from a fisheries friendliness perspective. Structures classified as "black" are likely to have severe negative effects, those classified as "grey" have some negative effects, and those as "white" have fewer negative effects. However, a great deal depends on the head of water flowing over the structure and the water velocity passing through it.

Some structures may allow fish passage where the structure is immersed in water, but if there is a significant difference in water level, fish movement upstream or downstream may become impossible until water levels change. Changing the design of a structure can significantly improve the degree to which it is "fish friendly" and reduce mortality of downstream passage, or increase the upstream movement of fish.

Table 6: Examples of canal infrastructure and their effects on fisheries

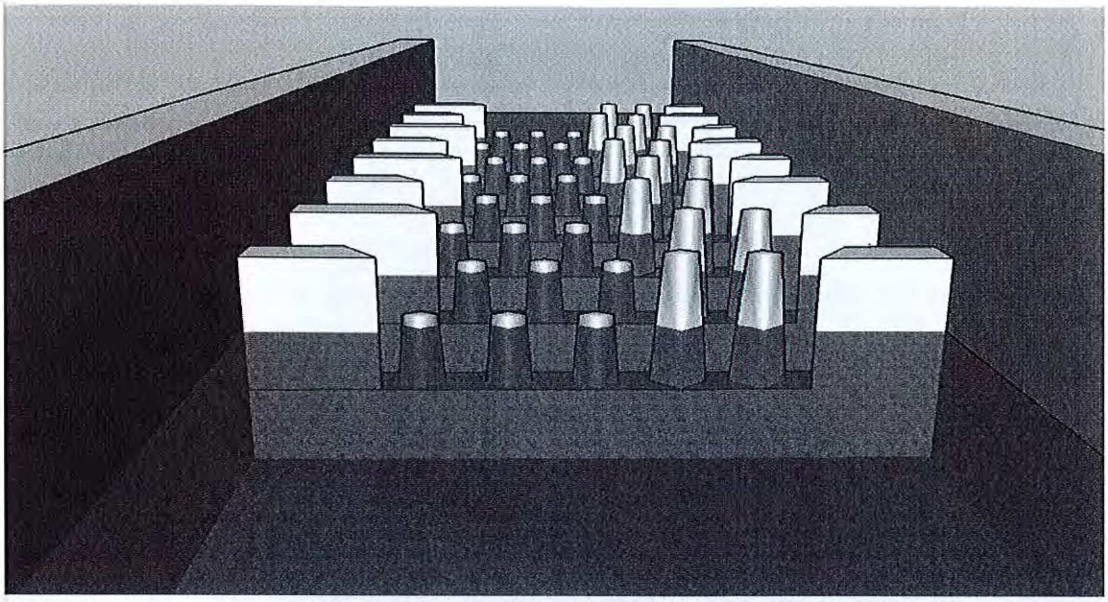
Type of infrastructure	**Classification of level of impact**	**Impact described**
Long crested weirs	BLACK	Physical barrier to fish movement (both upstream and downstream)
Step by step regulator	BLACK (at higher head)	Physical barrier to fish movement (both upstream and downstream) in case of high head over the structure
	GREY	Downstream movement of fish is possible if lower head is exerted over the structure
Undershot gates	BLACK (at higher flow)	Downstream movement of larval and juvenile fish results in impacts from fish strikes, barotrauma (due to rapid fluctuations in pressure) and shear
	GREY (at lower flow)	Upstream movement may be possible
Flap gates	GREY	Fish can easily move from upstream to downstream but cannot move downstream to upstream. May require modification to reduce some impacts (such as plunge pool and improved spillways)
Composite regulators	GREY	These may allow fish movement or require some modification
Overshot flap regulator	WHITE (for downstream movement)	Fish move easily over the flap gate and suffer no barotrauma. However, the gate should be integrated with a plunge pool and spillway design to reduce the risk of fish (especially larval and juvenile stages) striking edges of the structure
Water channels	WHITE	Channels never dry out and a degree of flow is maintained
	BLACK	Channels frequently dry out as water flows vary. Fish stranded and die.

2.3.4 DESIGN MODIFICATION TO REDUCE IMPACTS

An EAFm-i management plan should introduce remedial steps to overcome or bypass major structures that impede fish movements through the ECA. Design modifications can greatly improve the connectivity of water and ensure effective fish passage. This is not merely enabling fish to pass the barrier, but also takes into account potential impacts of changing water pressure (barotrauma), turbulence and impacts on the hard structure (fish strikes). All of these have an effect on the survival of fish passing through a structure.

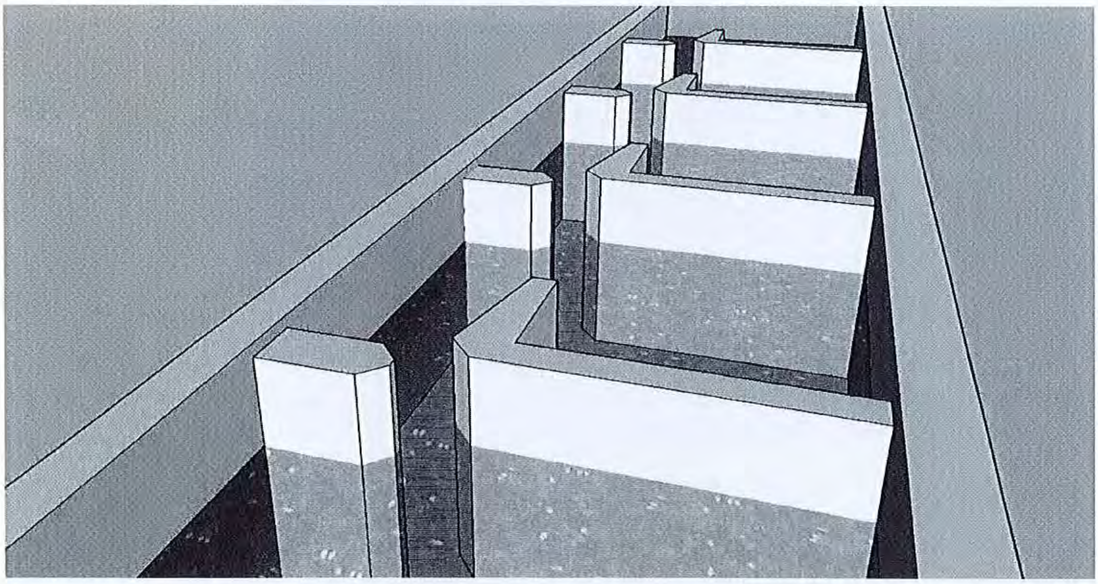
INSTALLATION OF FISHWAYS

Fishways are effectively used to maintain pathways for migratory fish and prevent resource declines (Clay, 1995). Fishways are simply channels around or through an obstruction that permit fish to pass with undue stress. Fish swim through these channels and are able to complete their migrations. Some examples of fishways are provided in Figure 9.



Cone-type

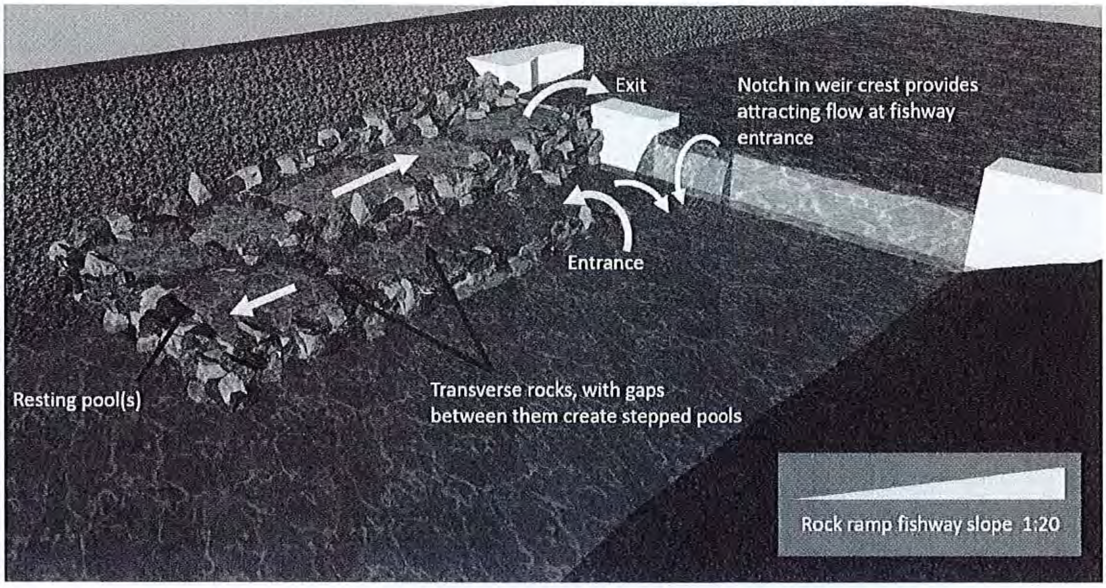
The configuration allows function across a wide range of flows. It is typically used in low height situations. The slope is low (typically 1:20 to 1:30), and resting pools are included. This has shown to enable a wide range of tropical riverine species to pass. It is typically cheaper to construct than a vertical slot fishway. This design could be considered as a more technical elaboration of the concept of a rock ramp. Examples: Fitzroy Barrage and Glenmore fishways in Australia; Pak Peung Fishway, Lao PDR



Vertical slot

The configuration is intended to be passable by a range of species such as Lower Mekong fish species over low head weirs. This would require low slopes (1:15) and small slot widths (150mm) and moderately sized cells (1000 mm X 1500 mm). Flow may not be sufficient to attract species that require fast flowing water. Examples: Several have been constructed in Murray–Darling Basin, Australia; Stung Chinit in Cambodia.

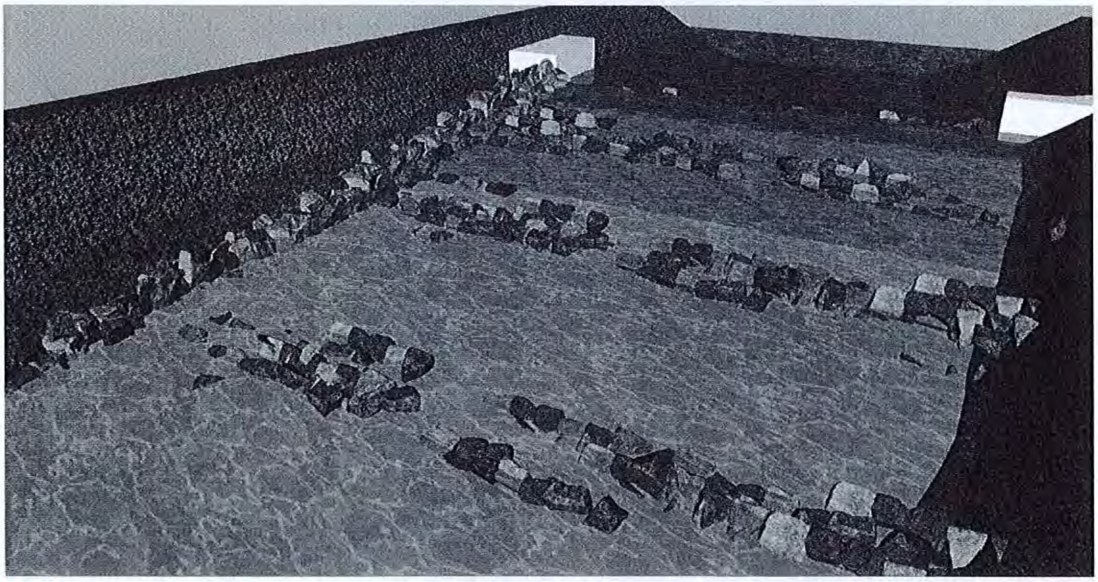
Figure 9: Examples of different designs of fishways in low height irrigation infrastructure (e.g low dams and weirs)



Rock-ramp fishway

Another low-slope solution that uses rocks set in place instead of concrete cones (see cone-type above). Resting pools are includes and the gaps between the rocks are intended to enable fish to find optimal flows to pass up the fishway. The importance of the attracting flow at the entrance to the fishway is highlighted.

Credit: Redrawn from NSW-DPI https://www.dpi.nsw.gov.au/fishing/habitat/rehabilitating/fishways



Whole weir rock-ramp

This uses the same approach as the rock ramp above. The rock ramp extends across the entire weir. This does not require attracting flow as there is no entrance. However, during periods of low flow the rock-ramp may dry out completely. Id this occurs during the critical migration season, then it will be ineffective. Rock-ramps may also be used to mitigate culverts that are placed above water level

Figure 9 (cont.): Examples of different designs of fishways in low height irrigation infrastructure (e.g low dams and weirs)

There is strong evidence to suggest that providing fish passage could have substantial fisheries productivity returns. For example, a fish yield of 67-137 kg/ha/year has been estimated for wetlands in the Lower Mekong Basin, and a first sale value of USD 0.9 – 1.5 /kg (Hortle and Suntornratana 2008, Hortle 2009). Using these data, restoration of a hypothetical wetland of 100-200 ha to full fisheries productivity would return a value greater than the cost of the project within 5-10 years. The estimated economic benefit is based on first sale price only, so it does not include multiplier effects from trade, nor any estimate of the associated livelihood benefits (nutrition/health and employment) from the increased fish supply.

Most fishway designs provide for upstream passage, however the solution will be ineffective if they are not designed effectively and operations are not integrated into irrigation water demand. The most effective fishway designs are those which are designed as a partnership between biologists and engineers from the beginning. It is important that the fishway is considered from project inception and many people contribute to the effective design and implementation. There are many different types of designs available and the best for any particular application can differ from site to site.

In their study in Lao People's Democratic Republic, Baumgartner *et al.* (2016) identified over 7 500 barriers to fish migration across two rivers in that country. The research team was able to design and build a fish ladder to bypass a significant obstacle facing migrating fish species that when completed allowed for the successful passage of 177 Mekong fish species (Figure 10). This work in Lao PDR has shown the effectiveness of appropriately designed fish passages that allow a wide range of fish species to move upstream between rivers and wetland/reservoir habitats.

The combination with improved design for outflows using overshot sluice regulators also offers improved changes of larval fish survival as they return to the river. This can greatly improve the range of species able to enter the system.

Figure 10: Example of the "cone-type" Pak Peung fishway (Lao PDR), in a tropical irrigation system. (Photo credit: Lee Baumgartner)

These fishways are not 100 percent effective, as not all small fish were able to ascend the fishway even when very conservative design parameters were provided. Some species migrated exclusively at night, which has implications for irrigation water distribution schedules.

It is also important to appreciate and seek out local knowledge in the design and operation of fishways (e.g. in the Lao PDR case, a covered fishway was deemed too dangerous by local stakeholders because of safety concerns for children playing or fishing near the structure and becoming trapped. The final design was therefore open-topped).

Despite these limitations, fishways would seem to have great potential as a mitigation tool in irrigation systems and preliminary evidence from these pilots has shown the return of riverine species previously lost from the system for decades.

Specific recommendations on the mitigation of weirs to improve fish passage are as follows:

- where a canal water regulation infrastructure is classified as black, but the head is less than 10 metres, a fishway, or a series of fishways, can be installed to facilitate fish movement upstream and downstream of the obstacle;
- where canal infrastructure is classified as black but the head is less than 5 m, fishways or fishways can be installed to facilitate fish movement around the obstacle; and
- dams or weirs higher than 5m require a series of fishways or another solution.

Key aspects of effective fishway design include:

- considering swimming ability and ecology of local species
- understanding the local hydrology and ensuring fishway operations cater for all annual possibilities
- using a design which accounts for both ecological applications and hydrology
- ensuring internal hydraulics are matched to fish swimming abilities
- ensuring local communities or operators understand how best to achieve fish passage
- those with a long term operations and maintenance plan

IMPROVING THE DESIGN OF SLUICES/REGULATORS

Sluice gates and weirs are critical for irrigation diversion, storage and water distribution. They are usually built on main channels or tributaries and can have significant impacts on fish (Figure 11). There are two ways fish are usually impacted. Firstly, upstream migrations to feeding, spawning and nursery habitat are blocked, restricting the ability of fish to move longitudinally along waterways.

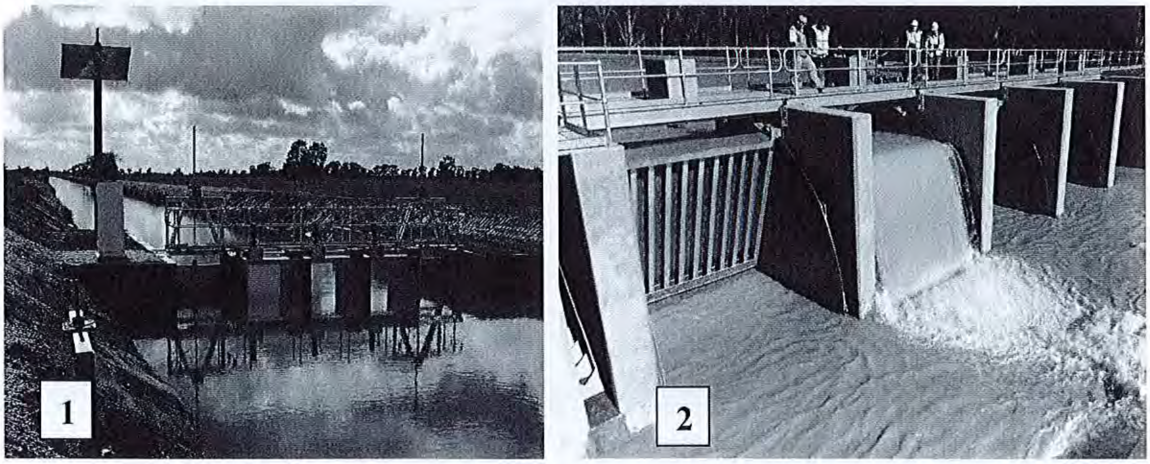


Figure 11: Undershot (left) and overshot (right) regulators. Both impact upstream migration, but undershot regulators have been demonstrated to impact downstream migrating fish, resulting from impacts, barotrauma and shear stresses. (Photo credit: AWMA, Pty. Ltd, Australia.)

Upstream populations are impacted by reduced immigration and downstream fish are vulnerable to exploitation (either by concentration of human fishing effort around the regulator, or through increased vulnerability to predation). This is usually mitigated by constructing upstream fishways, or fish passes, which are designed to suit local species (see previous section).

Sluice gates and weirs also block downstream passage and can facilitate fish injuries and mortality Many fish actively move downstream along river systems, they may also move passively downstream as eggs and larvae. Sluice gates and weirs can either stop these important migrations or expose fish to dangerous shear or pressure changes. Undershot sluice gates can cause eggs and larvae to be significantly damaged.

Overfall weirs can cause injury when adult fish fall onto concrete abutments (Figure 12). This issue is best resolved using overfall regulators in conjunction with a plunge pool to prevent fish-strike mortality (Figure 13).

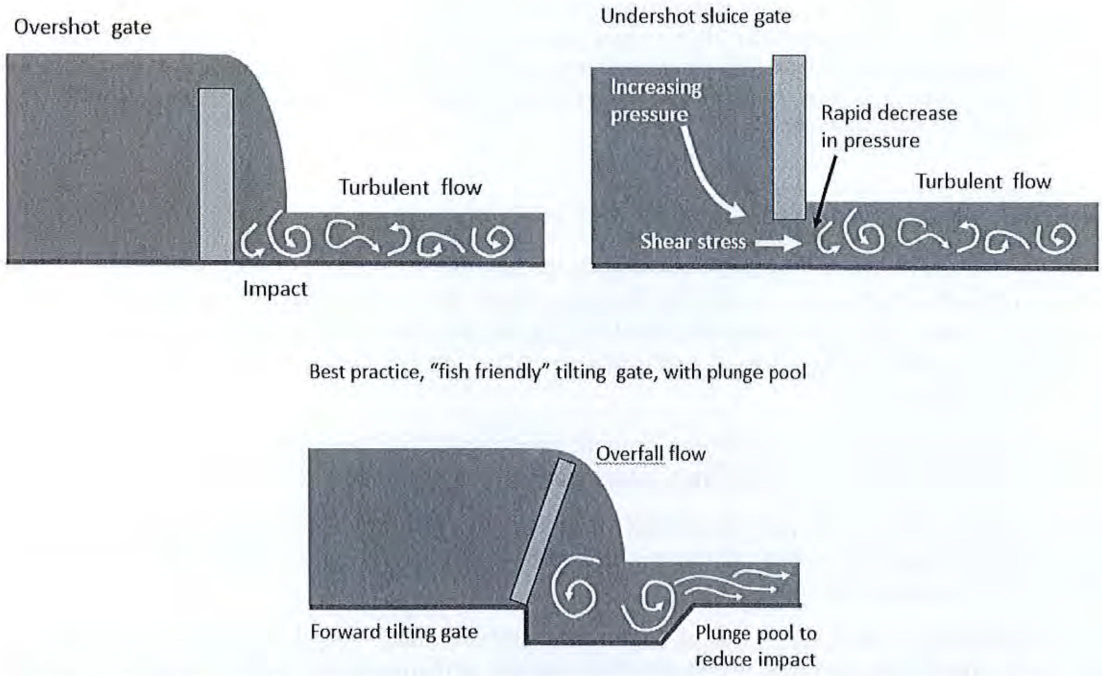


Figure 12: Cross section of different regulator designs highlighting areas of concern for fish. Overshot gates can impact fish when they are discharged into shallow water with high turbulence. Undershot gates can kill fish through physical strike, shear and pressure change. This can all be mitigated by installing forward tilting regulators with deep plunge pools.

Key aspects to weir and sluice gate design require to pass fish successfully include:

- requirement to have an upstream fish pass designed for local species
- avoid sluice-type lifting gates. These have high shear and pressure changes which kill eggs and larvae.
- avoid overfall weirs which have shallow concrete abutments on the downstream side. Fish can fall onto these abutments and become injured.
- to use forward tilting overfall gates instead of lifting sluice gates (Figure 13)
- to ensure there is a deep plunge pool on the downstream side which is at least 2/3 as deep as the structure is high

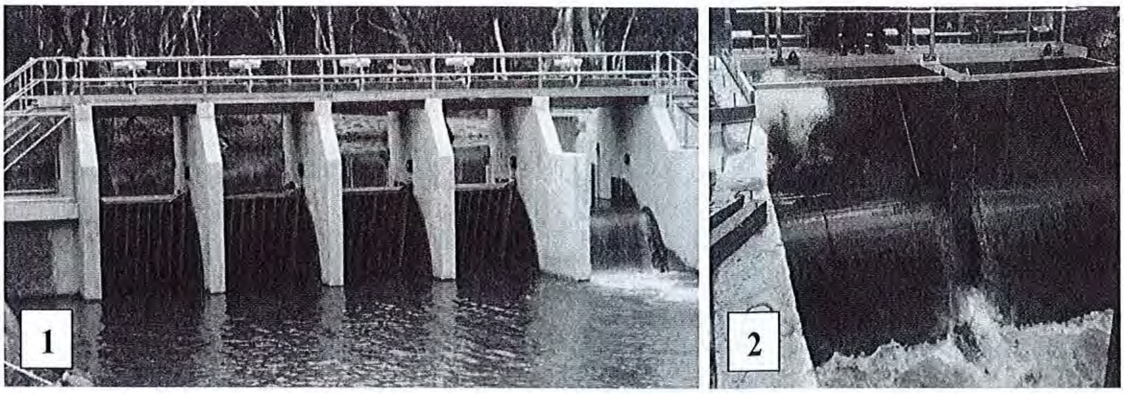


Figure 13: (Left) Best practice regulator from the Yallakool Creek, Australia. An ageing, leaky, undershot regulator was replaced with a tilting overfall design, which contained a deep plunge pool so that fish did not hit the abutment when moving downstream. The regulator now also includes a fish ladder so fish can move upstream. (Right) Best practice regulator from Pak Peung wetland, Lao PDR. This overfall regulator is also constructed together with a plunge pool. It too is associated with a fishway (Figure 10 above). (Photo credit: 1. AWMA Pty. Ltd. Australia; 2. Lee Baumgartner)

ENSURING THAT CULVERTS ALLOW THE PASSAGE OF FISH

The design, operation and maintenance of culverts can also have a marked impact on fisheries. These structures represent bottlenecks in the ECA through which fish may be forced to pass as they move through the system. Their size, siting and level all play an important part in determining their impact on the fishery. Unsurprisingly, they are often focal points for local fishers. Long culverts may deter fish due to low light levels.

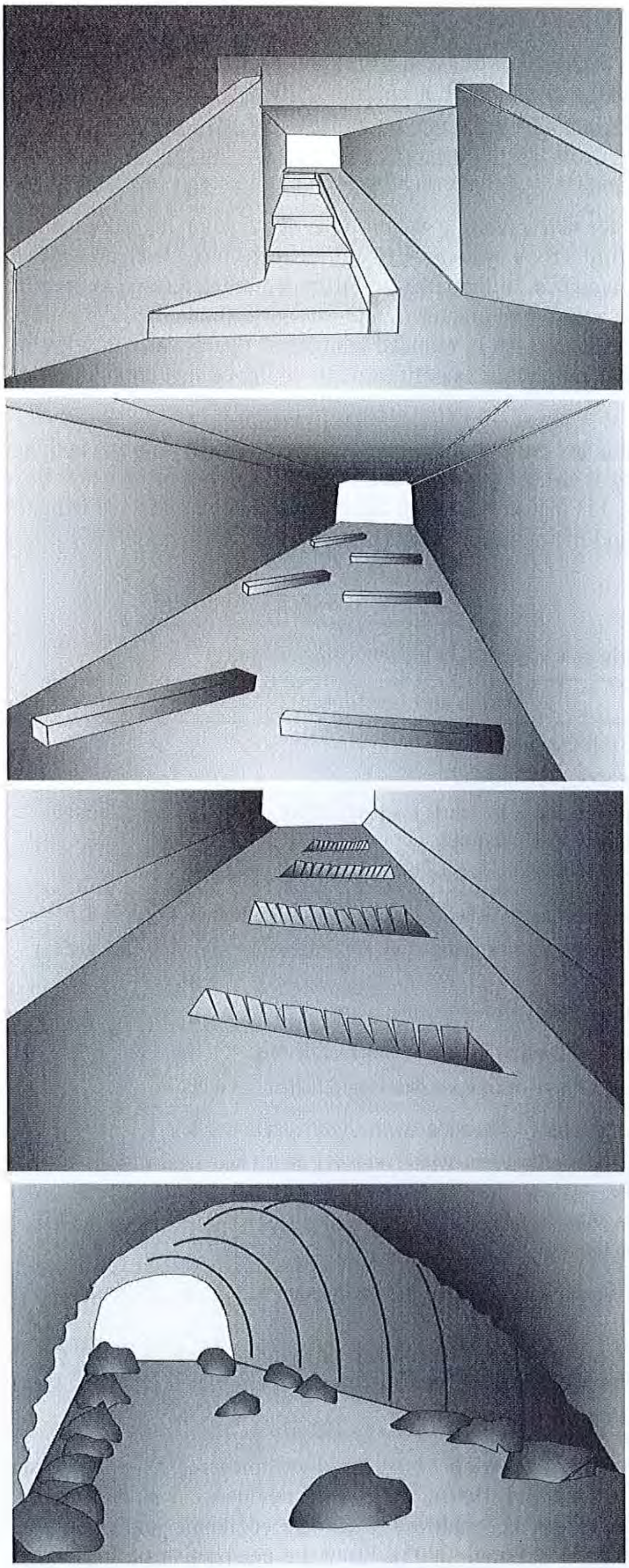
Culverts block fish passage by creating fast, laminar flows, which fish are unable to swim against. There are several different types of culverts but primary examples are box and pipe.

Pipe culverts generally do not provide suitable fish passage as the flow is too laminar and fish usually need to negotiate high flows through the entire length. Pipe culverts can be fitted with fish-friendly modifications to enhance passage success.

Box culverts are far more suited to fish passage when operated under suitable conditions. Box culverts can be fitted with baffles or pools to enhance fish passage. It is important that the swimming abilities of local fish are taken into consideration when baffle passage is designed (Figure 14).

Key parameters for fish friendly culverts include:

- Depth (too shallow will hinder fish, too deep will create excessive velocities)
- Height (needs to capture the entire headwater operating range)
- Slope (influences velocity)
- Darkness (low light can inhibit some fish)
- Baffles (can create resting areas which aid passage of some species)
- Length (the longer the culvert the more challenging it will be for fish to swim through it)



A sloping box culvert designed to replace a stepped culvert where there was a barrier to fish movement.

A series of baffles form a fish ladder. These gradually raise the water and provide resting pools. Ideally slots are also placed to allow fish passage.

A level or minimal slope solution for a box culvert.

Cement baffles break up the laminar water flow in culverts and provide shelter to enable fish to move and rest.

A similar solution to the one above. In this case the baffles are firm plastic. Also used in level or minimal slope solutions.

The baffles can be retrofitted to existing culverts.

Nature-like solution using rocks and gravel in a corrugated aluminium/steel culvert.

The high arch allows light to enter and avoids the deterrent effect of a dark entry.

The culvert bed is at water level so it does not dry out.

Figure 14: Some fish passage solution in culverts

SCREENING IRRIGATION WATER OFF-TAKES

It is widely recognised that when water is extracted or diverted for irrigation, that fish are diverted with it. Depending on the size and operation of the diversion, thousands or millions of fish can be extracted annually from main river systems. Whilst some of these may complete their lives in irrigation areas, they usually have no opportunity to return to the main river. Thus, the benefits of increased food production arising from irrigation development are often offset by depleting fisheries resources.

There is a growing international demand for fish screens at the millions of irrigation, hydropower, and municipal water supply offtakes in the world's river systems. Effective screens provide clean water for irrigators and improved environmental outcomes. In the USA and Europe, targeted research over the past 50 years has given rise to productive screen manufacturing industries worth hundreds of millions of dollars. Adopters (irrigators) save significant cash in reduced maintenance and water savings, and have the added benefits of providing significant public benefit through improved fish populations and water quality.

Best-practice water diversion throughout many parts of the world, such as the USA, Europe and New Zealand, now includes diversion screening as an accepted and valued technology (Baumgartner & Boys, 2012). Screens are now available (Table 11) that protect fish, operate efficiently, and save irrigators money, with little ongoing operational and maintenance costs (Baumgartner & Boys, 2012; Earle & Post, 2001).

Table 7: Some examples of best practice irrigation screening to prevent fish entrainment

Screen type	Design and function
Rotating self-cleaning screen	Water-driven rotating, self-cleaning screen Can operate in shallow water (100 mm). Adopters have reported reductions in debris load and enhanced productivity through reduced irrigation sprinkler head clogging. Fish-friendliness shows substantial promise for large-scale application.
Brushed cylinder screen	Metal screens that are powerfully brushed to reduce debris accumulation. The main advantage of these systems is that they are retrievable, allowing easy access for maintenance. They can also incorporate medium-to-large diversions.
Brushed cone screens	Custom built screens for application in high volume situations. The slot size is less than 2 mm to minimise debris and fish entrainment.
Travelling vertical belt screen	This is suitable for high discharge diversions with significant debris load. The belts move over a series of brushes, which removes debris and maintains the optimal operating range. They are most suited to medium/large canal systems and have a specific target market of large-scale irrigation bodies.
Horizontal screens	Horizontal, flat-plate fish and debris screens are designed to be installed in an off-stream channel. Water, fish, and debris pass quickly over the screen and return to the river, whilst 90 percent of water falls through the screen for the water user. They are low maintenance and cost-effective.

Many screens are still operating 20 years after installation. Overseas, diversion screens are well-tested and have been refined for over a century (Crammond, 1996). There is clear evidence from the USA that large-scale voluntary adoption by irrigators can be achieved when the economic and operational benefits are defined and demonstrated (Moyle & Israel, 2005). From the perspective of an irrigator, screening can deliver substantial economic benefits without compromising water entitlements in any way.

Important aspects of suitable irrigation screens include:

- Mesh size small enough to prevent the smallest fish (including eggs and larvae) from being extracted
- Low approach velocities so that fish are not drawn towards the screen
- Appropriate sweeping velocities to ensure fish are taken away from the screen face
- That the screens to no block or foul
- That they have been designed to suit the ecology of local species
- Integrating screen effectiveness into irrigation system operation

2.3.5 SLUICE GATE/REGULATOR OPERATION

For aquaculture, the operation of water regulation structures that meet the needs of field crops may be appropriate, but for capture fisheries the operation of these gates must be considered differently. Studies on flood prevention and irrigation structures broadly agree that sluice gates need to be operated in such a way that they improve the recruitment and access of migratory fish to irrigated areas and improve the production of resident (non-migratory) fish populations, but minimize any negative impacts to the agriculture sector. A challenge for irrigation and fisheries management is that the peak attracting times for migrating fish may be when the water supply in the ECA is at its lowest, or just starting to rise. This may be too early for farmers looking for wet season irrigation supplementation.

Operation of water regulators for irrigated crops is important for fisheries also and is often overlooked by irrigation managers. 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 1m/s; and
- close the gates towards the end of the wet season to retain as much water in the system as possible for the coming dry season.

Similar conclusions have been drawn in Australia where with respect to the Murray River it has been agreed that regulator gates should be left open and flows in floodplain creeks be allowed to recede with the river, thus allowing fish unrestricted access to the river. Moreover, water allocations are to be delivered during spring and summer months, the known spawning period for native fish (Baumgartner *et al.*, 2014).

In coastal areas (tidal deltas), water regulators are used to maintain freshwater conditions for crop production within polders. As they are usually closed at high tide, to prevent brackish water contamination, their operation can have a profound impact on the movement of fish from marine/brackish water environments.

Irrigation managers should consider these general principles when devising operational procedures for gate operation.

2.3.6 ASSESSING OPERATION AND MAINTENANCE COSTS AND COST RECOVERY PLAN

Water accounting is an important part of irrigation management and so Introducing fisheries into irrigation schemes must also account for water used and not returned to the system. Although fisheries do not consume water directly, losses from fisheries areas will be experienced through additional evaporation and seepage. Accounting must therefore consider all the water that enters and leaves a defined spatial fishery boundary during a particular period of time.

Water services provided by any irrigation or water supply network have inputs and costs related to them. The costs of these services have to be met for sustainable operation and management of the irrigation system. In most cases, the investment costs are covered or subsidized by the state (with the taxpayer paying part of the investment costs).

In many irrigation systems, subsidies have diminished over the years and this has sometimes led to the deterioration of infrastructure and water services. The costs of water services delivered to fisheries operators in the ECA must therefore be offset by revenue collected from them. For example, if a rice–fish culture operation depends on maintaining a higher water level in the rice field than the surrounding fields, then this probably means an increased water demand and the farmer should be charged accordingly.

In order to map the full operational costs for the fishery activity, information regarding water delivered to support fisheries activities, fisheries gross value of production, and the revenue collected from fisheries, must all be analysed. This information can then be compared with the costs of operation and the corresponding revenue collected from crop production. Analysis can then allow irrigation managers to debate appropriate tariffs for water delivery for fisheries.

3 CONCLUSIONS

Re-examining and appreciating the scope for introducing and strengthening fisheries in irrigation systems will enable a greater realization of their potential for food production and a closer integration with existing management arrangements. The concept of the extended command area (ECA) has been used, expanding the conventional definition of an agriculture irrigation command area, as a framework for assessing the current performance and potential of fisheries in an irrigation system.

Two planning tools, namely the ecosystem approach to fisheries management (EAFm) and the FAO MASSMUS/MASSCOTE approach, have been explored in detail as possible practical planning approaches that could engage stakeholders in a more holistic and integrated approach to irrigation and fisheries management. Through combining elements of each of the approaches, an improved planning tool is emerging that utilizes the strong participatory tools used by EAFm with the water service delivery and accounting tools from the MASSCOTE approach. The quantification and costing of irrigation water for fisheries related activities is crucial for the stable, successful and sustainable integration of irrigation and fisheries.

Using the EAFm-i would facilitate the development and implementation of management plans and implementation activities that offer pragmatic frameworks for the systematic exploration, monitoring and evaluation of fisheries options within the ECA of irrigation systems.

At this point in time the ideas presented remain largely theoretical and unproven. The piloting of EAFm-i would no doubt throw up several challenges to the approach, but may also highlight new areas and opportunities not considered here.

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It is important during the stakeholder analysis that these types of user groups are recognized and key individuals representing disparate groups are identified. As a representative from their group they will be the key negotiators in later joint planning exercises. The task force established in start up A should then work with the stakeholder group(s) on introducing the idea of strengthening fisheries in the ECA to local communities in the ECA.

Outcomes: Closer working relationship between task force members and government departments and CSOs/NGOs. Stakeholder group(s) established. Communities sensitized to the concept of ECA and their representatives committed to working with the task force on developing and implementing an EAFm-i plan.

STEP 1: DEFINING THE ECA SCOPE, AGREEING A VISION AND MAPPING PERFORMANCE

Rationale: The scoping of the ECA is important to achieve stakeholder consensus on the functional component(s) of the ECA where integration will be introduced or strengthened and a vision for the EAFm-i plan. The process departs from the EAFm process at this stage as it is necessary to add a detailed ECA performance mapping stage, that quantifies water, infrastructure and land use. This will be essential for later dialogue and negotiation between fishers and farmers, irrigation managers etc.

What needs to be done: The task force and the stakeholder group(s) should work together to develop an agreed vision for the development of the ECA and its multiple water uses and objectives, that can then guide the development of an ECA management plan. The vision statement should appeal to as broad a group of stakeholders in the ECA as possible. Scoping of the ECA should be done through a series of participatory exercises including the determination of the spatial characteristics of the ECA, and the historical and current importance of fisheries to community livelihoods and nutrition.

The EAFm-i plan should focus on more than one of the five functional areas of the ECA but if a single functional area is the agreed focus, then it should still be viewed through an ECA lens to understand the component in a wider context. The mapping of the performance of the irrigation scheme for fisheries is a vital step in the EAFm-i process. It is during this stage that irrigation engineers and fisheries specialists can come together over common matters, namely water use and financial costs. An improved understanding of use interdependencies and associated trade-offs is crucial to the design and implementation of effective management strategies.

The value of water and its alternative uses should be a key ingredient in the decision-making process, and it should play a critical role in the efficiency with which water supplies are managed, how they are allocated among competing uses, and the level and effectiveness of investments to meet competing demands.

Identifying alternative uses in a multiple-use irrigation system and their associated values is a complex task. Integrated water management must recognize all water uses, evaluate their relative economic contributions and social importance, appraise water use characteristics such as whether they are consumptive or non-consumptive, assess water supply needs in terms of quantity and quality, and examine the hydrological interdependencies among uses (Renwick, 2001).

Outcome. Step 1 will culminate in the key stakeholder groups achieving agreement on a vision for the ECA development and having an understanding of the mapping methodologies that will be used to measure current performance levels and future improvements. The functional components of the ECA will have been mapped through community participation, and referenced with GIS and Google Earth images. The knowledge base for the ECA will have been enhanced through the series of participatory exercises carried out.

STEP 2: IDENTIFYING AND PRIORITIZING ISSUES AND GOALS

Rationale: Linking to the agreed vision, Step 2 aims to identify and prioritize the issues, (fisheries/environmental threats and opportunities) and sets achievable goals for the EAFm-i plan. Examples of the prioritization of issues can be found in Table 9.

What needs to be done: It may take several task force and stakeholder group meetings to agree on the issues and the goal of the EAFm-i plan. Consensus may be difficult to achieve as disparate stakeholders may have different viewpoints and struggle to agree on the importance of the specific issues and a common goal.

Outcome: Documentation of the task force and stakeholder group(s) consensus on the issues to be addressed and the goals of the EAFm-i plan.

Table 9: Example of the prioritization of issues in an ECA

Functional Area	Component	Examples of possible priority issues
Water sources	Reservoir	Fish unable to reach reservoir because of dam wall
		Extreme drawdown affecting reservoir fishery
		No technical assistance for cage culture
Water distribution system	Canals and channels	Fish traps in the main irrigation channel limiting fish migrations
		No closed fishing season in operation
		Side canals often dry up because of perturbations
Crop Production area	Rice field	Decline in aquatic ecology in rice fields
		No promotion of rice–fish culture
		Invasive species e.g. golden apple snail
Waterlogged and seepage areas	Wetland adjacent to rice field	Water contaminated by pesticides / high turbidity
		Pumping of wetlands for dry season irrigation
		Waterborne diseases increasing in area
Drainage areas	Estuary	Salinity encroachment during dry season
		Declining estuarine fishery production
		Loss of mangrove cover in coastal areas

REALITY CHECK 1

Experience with the EAFm suggests that at this stage in the process it is useful for the task force and stakeholder group(s) to pause and assess how realistic the issues selected and the goals set are. Re-engagement with the broad stakeholder constituency may be necessary to ground the EAFm-i plan in reality.

STEP 3: DEVELOPING THE EAFM-I PLAN

Rationale/purpose: The aim of this step in to develop a detailed EAFm-i plan that outlines the development steps and highlights the indicators that will be used to measure impact.

What needs to be done: The EAFm-i plan should include a vision for the development of the ECA and set out clear objectives and activities as well as indicators for measuring change. Following completion of the earlier phases, stakeholder consultations should include a presentation of the main findings from the participatory mapping exercises. The EAFm-i plan should aim to maximize the effectiveness of water use for fisheries in all of the functional areas where fisheries activities are possible and explore options for closer integration and multi-user water management. The EAFm-i Plan could include the details on meeting the following objectives: improvement of fisheries activities in the ECA; introduction of new fisheries activities into the ECA; development of operating instructions for improved water delivery service and reuse without significantly increasing the costs of operation; operation of water regulation structures; education and awareness raising on agriculture practices that are harmful to fisheries; providing opportunities for improving fisheries connectivity, water quality and protecting aquatic habitats; and establishing strategies for conflict resolution in cases where potential incompatibilities exist between fisheries and agriculture water uses.

Reiterative steps may be necessary before the plan can be consolidated and finalized with an implementation plan and service agreements with different water users' groups. The plan should include indicators and benchmarks and proposed management actions and compliance. It may also be necessary to draft service agreements with other water user groups that guarantee access to irrigation water for fisheries. Infrastructural modifications may be important components of the EAFm-i plan and require detailed planning and financing to ensure that they meet standards and are completed on time. Modifications to infrastructure to support fisheries activities could incur significant costs and the plan should outline how such costs might be recovered. Other recurrent costs, such as fingerling stocking should also be costed and suppliers contacted. If mitigation measures include regular stocking to compensate for lost/damaged fisheries then resourcing for recurrent costs will have to be found. The identification of sustainable financing sources is also desirable, so that the EAFm-i plan can continue to be implemented/ adapted after the task force disengages from the process.

Outcome: A detailed EAFm-i plan agreed by the broad stakeholder constituency will be the main outcome from this step.

STEP 4: IMPLEMENTING THE EAFM-I PLAN

Rationale: The EAFm-i plan acceptable to the broad stakeholder groups is the main instrument for change and can only be implemented successfully if the stakeholder groups are committed to the goal and objectives and financing for plan implementation has been secured.

What needs to be done: The formalization of the plan, which may include the signing of the document by stakeholder representatives, as well as service agreements and other binding documents, is essential. The development of a detailed work plan, including responsibilities and actions, for implementation is also required at this step. Water operation commitments describing how, for example, the irrigation water or reservoir level is to be managed would form part of the overall EAFm-i plan and should be documented together with other variables that may not relate directly to crops and water delivery, but may be required for fishery services. Changes to local regulations or rules on water use/land use inside the ECA and gaining official permission/ endorsement for the proposed changes may be necessary at this stage in the process, even where the changes are in line with government policy. Once finalized, the communication of the EAFm-i plan to stakeholders and institutions in the ECA is important so that other people can engage meaningfully in the process.

Outcome: Signed service agreements. Funding secured. Infrastructure development/modifications tendered. Communication strategy for EAFm-i implementation developed.

REALITY CHECK 2:

It is recommended at this stage that the task force considers a second reality check, involving a re-assessment of the EAFm plan against the seven core EAFm guiding principles: good governance; appropriate scale; increased participation; multiple objectives; coordination and cooperation; adaptive management; and precautionary approach. Small shifts in EAFm-i emphasis may be required at this stage.

STEP 5: MONITOR, EVALUATE AND ADAPT

Rationale: The monitoring and evaluation phase is designed to assess the impact of the EAFm-i plan on fisheries production in the ECA. It should also provide insight for future changes and further improvement of irrigation scheme management.

What needs to be done: Annual monitoring and evaluation of the EAFm-i plan implementation (by the task force or interdepartmental teams) is important in order to quantify achievements, take corrective actions, and compare conditions before and after plan implementation. Typically the M&E of irrigation and drainage projects is usually meant to provide information on two important flows – water and money, and to evaluate the current level of performance of the water delivery service and its cost-effectiveness (Renaud, Facon and Wahaj, 2007). Seasonal (crop seasons, rainy and dry, summer and winter, etc.) or yearly evaluations of the water delivery service should be discussed among the managers and water users, including fisheries stakeholders, as should any proposed changes in operation, infrastructure and targets for future water delivery. The monitoring of sensitive structures is necessary for enabling proper action to be taken and for operational targets to be achieved. Service targets and service agreements also define what should be monitored. For example, if the service agreement requires delivery of a certain discharge at certain delivery points, then the discharge at these delivery points should be monitored (Renaud, Facon and Wahaj, 2007) to show compliance with service agreements.

Outcome: Quantitative assessments of the progress of the EAFm-i plan and the performance of management actions, plus recommendations for plan modification/adjustments.

ANNEX 2: ASSESSMENT METHODOLOGIES AND TOOLS FOR USE WITH AN EAFM-I

This chapter describes some of the methodologies and tools that can be used during the EAFm-i process.

EAFM-I PRE-ASSESSMENT SHEETS

Pre-assessment sheets can be used in Start-up (A) activity ii (see Table 7). Pre-assessment sheets such as the example in (Table 10) can be used to identify the functional areas where fisheries related activities already exist and to explore untapped potential. These can be used with both technical counterparts and as part of stakeholder discussions.

Table 10: Example of an ECA pre-assessment sheet

ISSUE	ECA functional areas				
	Water sources	**Distribution system**	**Cropping areas**	**Water-logged areas**	**Drainage areas**
Capture fisheries or aquaculture practiced?	✓		✓	✓	
Water availability, flow rate/level reliable?		✓		✓	
Barriers to the movement of fish?		✓			✓
Pesticides or other chemicals used?			✓		
Conflict between stakeholders over water and/or land use?		✓		✓	
High concentrations of contaminants, salts and/or suspended solids?					✓

STAKEHOLDER IDENTIFICATION AND ANALYSIS

This section introduces a matrix that can be used as part of Start-up (A) activity v (see Table 8).

The ECA approach requires broad support from a wide range of stakeholders. Some examples of key stakeholders, their influence and likely motivations are found below.

Irrigation and water managers may have an inflated view of the water delivery service they provide to the users. The attitude of water managers towards fisheries activities and the degree of integration of irrigation services and fisheries are somewhat interlinked. If irrigation managers are aware of, and acknowledge the existence and extent of fisheries and aquaculture activities in the ECA then they are more likely to take note of fisheries' concerns in the management and operation of the irrigation system.

Interviews with water managers allow the determination of their attitude to fisheries. Some might, for example, ignore or deny the importance of fisheries and claim that there is only one use for irrigation water. Alternatively, some water managers might understand the importance of fisheries and take steps to ensure that fisheries concerns are fully acknowledged in management operations and in the maintenance of the system, and that the governance processes include representation of fisheries stakeholders.

Having assessed the water manager's attitude to fisheries, it is important to assess how well the managers prioritize the water services to different practices in the five functional areas of the ECA. Rankings for each of the functional areas should be done with the highest rank denoting a high level of water services in terms of quantity and quality to fisheries and aquaculture in all the functional areas and the lowest rank denoting poor services to all the functional areas and a service that is always deficient in terms of quantity or quality.

Water user groups and associations should be assessed by asking four key questions: (1) is membership open to people practicing fisheries activities in the ECA? (2) Are there safeguards for the rights of water users practicing fisheries in the ECA? (3) Are the concerns of fisheries practitioners taken into account in the management and operation of the infrastructure? (4) Does the user group collect revenue from the water users practicing fisheries and aquaculture? The answers to these questions will give an idea of how well the user group may respond to fisheries management changes in the ECA.

Small-scale fishers will tend to come from poorer families, who may be landless, i.e. have no arable land for cultivation. They will tend to live in different areas of the community, within the ECA, but outside of the central irrigated area. They may be from different villages altogether. They will have few assets outside of what they require from fishing such as nets, a small boat, etc. Education levels will be generally low but practical skill levels will be high. Unless a CSO or NGO has been working in their communities, they will be unlikely to be organized into a formal group. Farmers in the irrigation scheme will tend to look down on these people and their livelihoods. Facilitating interaction between farmers and small-scale fishers can be a challenge.

Aquaculture operators will tend to be richer with more assets, including land and may have some expendable income to invest. Many will have some arable land and may be members of the water user groups in the area. They may cooperate in upstream and downstream value chain networks to ensure their competiveness but are unlikely to be members of formal groups. They will tend to be better educated than fishers. Facilitating interaction between fish farmers and crop farmers should be less of a challenge than with fishers. The matrix in Figure 12 can be used to arrange key stakeholders into interest groups.

VERY IMPORTANT/ LITTLE INFLUENCE Examples of people who **should be represented** in EAFm-i discussions - Water user group members - Fishers in irrigation reservoirs - Fishers in wetlands - Small-scale aquaculture operators - Small-scale rice producers - Other users of resources dependent upon irrigation water but not members of a water user group.	**VERY IMPORTANT/ SIGNIFICANT INFLUENCE** Examples of people who are **essential** to the EAFm-i planning deliberations - Irrigation scheme managers - Water user group leaders - Higher level members of the irrigation department - High investment aquaculture operators - Commercial fishers or concession operators - Commercial rice growers - Local fisheries department - CSOs and local NGOs
LESS IMPORTANT/ LITTLE INFLUENCE Examples of people who need to **be kept informed** of EAFm-i actions but with whom there is less need to engage – Community members with little or no stake in water allocation and its use – Local newspapers and media	**LESS IMPORTANT / SIGNIFICANT INFLUENCE** Examples of people who **need to be convinced** to buy into the EAFm-i or to support the plan. – Community leaders – Local government actors – Local politicians

Figure 12: Framework for stakeholder analysis

The stakeholders in the green cell will be the key stakeholders for the success of EAFm-i; they need to be kept highly motivated and involved. They should not need convincing about the importance of the EAFm-i approach. Several of them will be members of the EAFm-i task force or work closely with it. Those in the blue cell should be represented in discussions on developing and implementing the EAFm-i plan. They will include farmers and fishers and other resource users. Those in the yellow cell require an active strategy for engagement so that they are convinced of the value of the plan and can support its implementation at higher levels. Those in the lower left-hand red cell will be least interested and have little influence. However, they still need to be kept informed of developments.

The more coherent the stakeholder groups, the easier it will be to agree deals over water and land use. Some influential stakeholders may choose to hinder/ block the ECA process (for political or other gains) so their interactions with other stakeholders need to be actively monitored. Most fishers will fall into the Very important/Little influence cell as they usually lack political power or a "voice". They need to be represented and supported externally to have more influence in the EAFm-i process.

PARTICIPATORY MAPPING OF THE ECA

This section introduces the technique of participatory mapping for use in Step 1.2 (Table 7).

Participatory mapping and GIS can be used to create an image of the ECA detailing the main characteristics. This will include identifying important ECA components such as choke points and barriers to fish migration, sites of regular water and land use disputes etc. Through using the images in discussions with the community, farming, water management practices and other practices that are considered harmful to fisheries, or that have untapped potential for fisheries can be identified and located. The challenge here will be to convince upstream communities of the impacts of their actions, on downstream communities and *vice versa*. The participatory maps developed should highlight the features of the irrigation scheme structure and ECA shown in Table 10.

Table 10: Elements for participatory mapping for the integration of fisheries and irrigation schemes

ECA component	ECA detail to include in mapping
Water sources	Reservoirs, buffer reservoirs, water storage areas Rivers and other water sources Tube wells
Water distribution systems	Water conveyance and distribution areas: main canals, secondary canals and tertiary canals Drainage canals Other associated waterbodies
Locations of other structures relating to fisheries connectivity	Identification of choke points/ bottlenecks and barriers to fish migration: roads, culverts, weirs and sluice gates, fish traps
Habitations	Village locations, schools, health centres etc
Crop production areas	Arable land, seasonal crops Waterlogged areas adjacent to wetlands Fishponds Areas of frequent water and land use conflict
Waterbodies and wetlands downstream of drainage areas	Flood prone areas Wetlands, lagoons, estuaries Mangrove areas
Fisheries activities	Seasonal capture fisheries activities Aquaculture sites Main fish trapping and fishing areas Fish species types; fishing gears used and fishing hotspots Fish migration routes and breeding areas
Other information	Seasonal changes in water quality and water use Protected areas Areas of environmental concern e.g. factories, mines

ASSESSING THE IMPORTANCE OF FISHERIES IN THE IRRIGATION SYSTEM

This section introduces assessment trees, also for use in Step 1.2 (Table 7).

Assessment trees can be used with stakeholders living around the ECA to determine whether fishing activities in the irrigation system are an important feature of their livelihoods. In some cases the assessment may be negative and unless stakeholders express a strong desire to develop a new fishery, then no further action is required. An example of a pre-assessment decision tree for functional area 5 is shown in Figure 13.

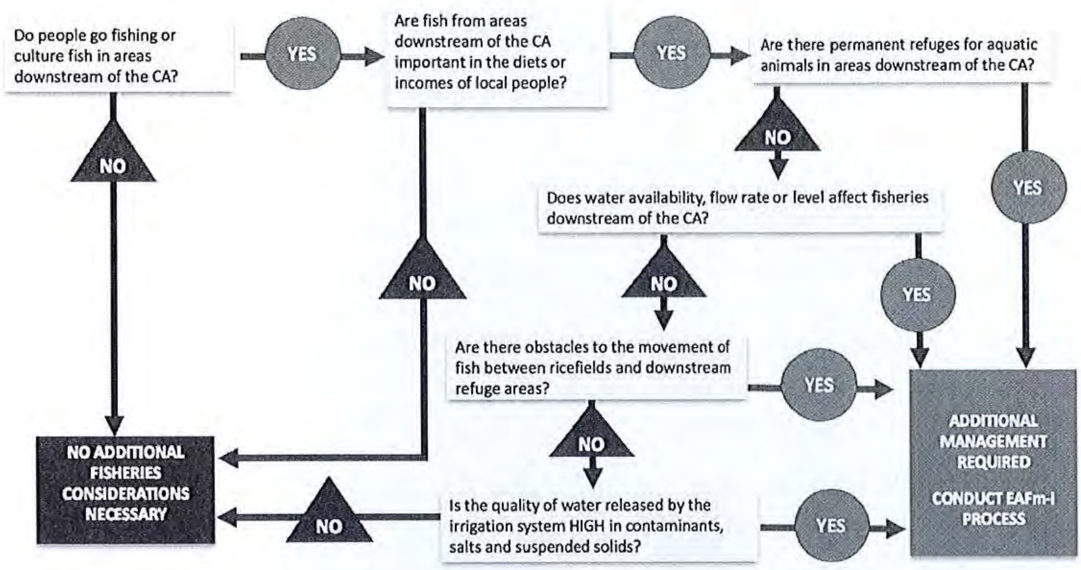

Figure 13: Example of a pre-assessment decision tree

ASSESSING CHANGES IN FISHING AND FARMING PRACTICES

This section introduces Participatory Rural Appraisal for use in Step 1.2 (Table 7).

Participatory Rural Appraisal (PRA) exercises can be carried out with stakeholders to assess changes in fisheries and farming activities production in the irrigation scheme over the recent past. This is important in communities where there is evidence that local fisheries have declined in recent years or since an irrigation scheme began operating. Discussions can also focus on changes to the availability of fish and to fisheries based livelihoods in the area and can include information on:

- the number of people fishing in waterbodies associated with the irrigation system;
- the number of people who fish as their primary and secondary livelihoods;
- access to fishing areas;
- formal and informal fishery access rules;
- income levels and the proportion of overall income derived from fisheries;
- market demand and fish prices;
- changes in water availability and quality;
- trends in fish numbers, diversity and sizes;
- fish disease outbreaks; and
- development of aquaculture in the irrigation scheme.

ANNEX 3: COMPARISON BETWEEN EAFM AND EAFM-I

Comparison between the marine-focused EAFm and EAFm-i for integration of fisheries and irrigation schemes

EAFm		Proposed modification for EAFm-i	
Start-up A		**Start-up A**	
i	Identify the EAFm team and facilitators	i	Identify team and facilitators and form a partnership/task force with commitment to strengthen fisheries in the ECA
ii	Identify the broad area to be managed	ii	Collate background materials on the ECA (includes field visits to main ECA components and communities); Identify ECA components with obvious fisheries development potential
iii	Develop Start-up work plan	iii	Develop Start-up work plan
iv	Introduce EAFm	iv	No corresponding action at this stage (addressed in B (ii) below)
v	Coordinate with agencies and government	v	Determine the legal basis for fisheries and irrigation
vi	Identify stakeholders and organizations	vi	Undertake generic stakeholder analysis of major player influences, motivations and interests
vii	Establish a group of key stakeholders		No corresponding action at this stage (addressed in B (iii) below)
viii	Determine the legal basis for EAFm		Addressed in (v) above
Start-up B		**Start-up B**	
	No corresponding action	i	Task force continues interdepartmental discussions about the ECA involving representatives from government departments, and local CSOs and NGOs
i	Engage stakeholders for participatory planning and co-management	ii	Introduce representatives from local communities to the idea of strengthening fisheries in the ECA
	No corresponding action	iii	Establish a group of key stakeholders with a mutual interest in fisheries and irrigation integrations
	No corresponding action	iv	Continue to build information base on the ECA
Step 1. Define and scope the fishery management unit (FMU)		**Step 1. Define and scope of the ECA**	
	Typically a geographical area		Typically a sub-catchment area with one or more irrigation systems.
1.1	**Agree the FMU vision** Stakeholders agree on the vision of what the plan should try to achieve	1.1	**Agree the vision for fisheries in the ECA** Key stakeholders agree a vision of what the EAFm-i plan should try to achieve within the ECA.
1.2	**Scope the FMU**	1.2	**Scope the ECA**
i	Establish the background on the fishery, gears, people, economics, environmental factors, production	i	Agree the ECA components that will be covered by the EAFm-i plan

EAFm		Proposed modification for EAFm-i	
	No corresponding action	ii	Engage stakeholders in PRA exercises aimed at assessing the status of fisheries; participatory sketching of the ECA; historical perspectives; importance of fisheries to community livelihoods and nutrition etc.
1.3	Assess resources and ecology Assess socio-economic aspects Assess laws and institutions	1.3	**Map ECA performance for existing fisheries activities**
		i	Assess water required by, delivered to, and to be used by existing fisheries related activities
		ii	Analyse costs associated with current operations and services delivered to existing fisheries and strategies for cost recovery/revenue collection from fisheries stakeholders
		iii	Analyse water perturbations
		iv	Map sluices, water gates and other infrastructure and their operation
		v	Assess the need for new/modified infrastructure
Step 2. Identify and prioritize issues and goals		**Step 2. Identify and prioritize issues and goals**	
2.1	Identify threats and issues	2.1	Identify threats and issues to fisheries in the ECA
2.2	Define goals for EAFm plan	2.2	Define goals for EAFm-i plan.
2.3	Prioritize issues	2.3	Prioritize issues to be addressed by the EAFm-i plan, including the promotion of new fisheries related activities
Reality check 1		**Reality check 1**	
i	Identify constraints and opportunities for achieving goals	i	Identify constraints and opportunities for achieving goals
ii	Facilitate focus group discussion	ii	Facilitate focus group discussion
iii	Identify conflict and need for conflict management	iii	Identify conflict and need for conflict management
Step 3. Developing the EAFm plan		**Step 3. Developing the EAFm-i plan**	
3.1.	Develop operational objectives	3.1	Map ECA and irrigation system performance for new fisheries activities in the ECA, including analysis of water and costs associated with operations and services for new fisheries activities
3.2	Develop indicators and benchmarks	3.2	Develop indicators and benchmarks
3.3	Identify management actions and areas of compliance	3.3	Identify management actions and areas of compliance
3.4	Identify sustainable financing	3.5	Develop service agreements with water user groups and plan for the recovery of revenue from fisheries stakeholders for irrigation services
3.5	Finalize the EAFm plan	3.6	Finalize the EAFm-i plan

EAFm		Proposed modification for EAFm-i	
Step 4. Implementation of the plan		**Step 4. Implementation of the plan**	
4.1	Formalize the plan	**4.1**	Formalize the plan
4.2	Develop workplan for implementation	**4.2**	Develop workplan for implementation
4.3	Develop communication strategy	**4.3**	Develop communication strategy
Reality check 2		**Reality check 2**	
i	Check plan against the 7 EAFm principles	i	Check plan against the 7 EAFm principles
Step 5. Monitor, evaluate, adapt		**Step 5. Monitor, evaluate, adapt**	
5.1	Monitor and evaluate (M&E) performance of management actions	**5.1**	Monitor and evaluate (M&E) performance of management actions on fisheries production in the ECA and irrigation system performance
5.2	Review and adapt the plan based on M&E	**5.2**	Review and adapt the plan based on M&E

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