GUIDANCE MANUAL

MANAGEMENT OF IMPACTS OF IRRIGATION DEVELOPMENT ON FISHERIES

WorldFish Center
IWMI International Water Management Institute
Imperial College London

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Preface

This manual has been prepared to aid the assessment and management of impacts of irrigation development on fisheries, with a focus on developing countries. Fisheries produce food from the exploitation of natural populations of fish and other aquatic organisms. They are dependent more on the functioning of natural ecosystems than on other food production systems. At the same time, they are important to the food security and livelihoods of many rural people in developing countries – a fact that has only recently been fully recognized. Fisheries therefore link environmental and food security concerns in a unique way.

Irrigation development aims to increase food (or non-food crop production) and to improve rural incomes, employment and food security, but can carry environmental costs. These aspects of irrigation development are assessed in planning, and a variety of guidelines exist to aid the process. Why then are new guidelines for assessing and managing impacts on fisheries needed? Because existing guidelines, which treat fisheries as a fringe aspect of ecological or livelihoods assessment, fail to give an integrated and balanced perspective on the nature of fisheries and the impacts upon them. Treating fisheries simply as an aspect of either biodiversity or livelihood impact assessment can easily result in crucial aspects and tradeoffs being missed or misrepresented.

Managing impacts of irrigation on fisheries is a task that requires the participation of a wide range of stakeholders and an interdisciplinary approach. Hence impact assessment and management should be carried out in a participatory manner by multidisciplinary teams. This manual aims to aid such assessment by providing a knowledge base on key issues likely to be encountered, tools for participatory assessment and a guide to specialist literature. The manual is designed to serve as a stand-alone guide for assessments involving small and medium-sized irrigation developments. Its integrated perspective and guide to specialist literature should make it a useful starting point even for large projects that require more detailed assessment.

It is hoped that the manual will act as a catalyst for improved integration of fisheries concerns in water resource management, for more holistic assessment and management of irrigation development impacts. Hopefully, it will increase involvement of all water users in natural resource management decision making and the ownership of resulting outcomes.

The development of this manual was funded by the Department for International Development of the United Kingdom, under the Knowledge and Research in Engineering Sectors Program.

About this manual

The purpose of this manual is to set out principles and procedures for the assessment and management of the impacts of irrigation development on fisheries for the benefit of rural livelihoods as well as biodiversity conservation.

Basis of the guidance

The guidance presented in this manual is based on an extensive review of the literature by a team of experts in the different relevant disciplines, and on field-testing of concepts and methods in Laos and Sri Lanka. It represents a distillation of current knowledge and practice.

Outline

The manual is organized in five chapters.

Chapter 1 sets the scene. It introduces fisheries and outlines their importance in rural livelihoods, the rationale for irrigation development, impacts of irrigation on fisheries, and the complexity of impact pathways.

Chapter 2 provides a framework and suggested guidelines for assessing and managing the impacts of irrigation development on fisheries.

Chapters 3-5 provide the main knowledge base covering the basic principles and practices that professionals need to know. All principles covered are directly related to impact assessment and management practice. These links are made explicit by providing "tool" boxes with practical applications in most sections. Chapter 3 provides a concise introduction to inland fisheries systems and the key aspects of hydrology, ecology, exploitation and livelihoods. Chapter 4 deals with the impacts of irrigation development on fisheries. Chapter 5 describes ways of mitigating or compensating for negative impacts, and enhancing positive impacts. Many of the approaches can also be used to rehabilitate fisheries already impacted.

How to use the guidance manual

The manual is designed for use by qualified irrigation, fisheries, environmental or social science professionals involved in assessing and managing impacts of irrigation development on fisheries. A key objective of the manual is to foster stakeholder participation and constructive dialogue and collaboration among professionals from different disciplines. We, therefore, recommend that professionals undertaking fisheries impact assessments read the full document once to develop an integrated understanding of the problem, and gain an overview of assessment and management practices.

In practical assessments, professionals may consult Chapter 2 for guidance on procedures, and refer to Chapters 3-5 for specific tools. All procedures and tools are, of course, suggestions and users should feel free to adapt them to their requirements. In most cases, assessments will involve only a selection of approaches and the tools set out here, depending on the key issues identified by stakeholders. It is neither necessary nor indeed desirable to carry out a plethora of assessments on issues that none of the stakeholders find particularly important, as this may result in loss of focus and inaction.

Detailed guidance is restricted to the relevant principles and practices in situations of practical impact assessment and management, where the availability of both data and scientific capacity is limited. However, some references to advanced approaches that require detailed data and/or substantial inputs from research scientists are included. Such approaches may be required in the assessment of large projects or where specific impacts are very significant; they may also be used in cases where the assessment team happens to include appropriate trained specialists. In either case, we again warn against the possibility of concentrating resources on detailed assessments of narrow issues (e.g. the habitat requirements of a particularly charismatic species) while neglecting basic assessments in other areas.

Relation to other guidance documents

This guidance is intended to complement rather than replace the guidance that exists in other documents for environmental and social impact assessment, and for specialist areas such as fish pass design or environmental flow setting. We refer to such documents wherever appropriate.

Chapter 1

Introduction

1.1 What are fisheries?

Fisheries may be defined as the exploitation of living aquatic resources within a common pool institutional setting. There are two important aspects to this definition: the level of management intervention (exploitation only), and the institutional arrangements governing resource use (common pool regime).

These aspects make fisheries different from aquaculture, the farming of aquatic organisms, which implies a management intervention such as feeding, and private ownership of the stock being farmed. This distinction is very important: fisheries rely on the natural ecosystem functioning, and inland fisheries in particular require few resources from those exploiting them. This is what makes them so important in livelihood as well as conservation terms. Aquaculture, on the other hand, may be largely independent of the local ecosystem functioning, but requires far more resources (e.g. land to build a pond, feed, seed fish) of those adopting the technology. Even though it involves fish and water, aquaculture is more akin to agricultural animal production than to fisheries.

These guidelines are concerned with the impacts of irrigation development on fisheries and the living aquatic resources upon which they depend. Aquaculture in irrigation systems is discussed as a possible compensation measure for fisheries impacts, but is not otherwise a focus of the guidelines.

1.2 Why fisheries and aquatic resources matter?

Fisheries play an important role in rural livelihoods in many regions, and the aquatic resources upon which they are based are important reservoirs of biological diversity.

1.2.1 Fisheries' contributions to livelihoods

Small-scale aquatic resources make a contribution to rural livelihoods in many developing countries, and the scale and importance of this have only recently been appreciated (Delgado et al. 2003). Fish provide the bulk of food harvested from freshwater systems, but other animals (mollusks, crustaceans, insects, amphibians) and plants are also important. Again, the focus is on organisms harvested from wild populations rather than farmed.

Participation in fishing may be a form of specialist occupation, part of a diversified livelihood strategy, an occupation of last resort, or a recreational activity. Fisheries-related activities such as gear or boat manufacturing, fish trading and processing can also be significant. Last but not least, fisheries products contribute significantly to the nutrition of many people not involved in fishing, as an affordable source of animal protein, fat and many micronutrients. Table 1.1 gives some examples of the direct contributions of inland fisheries to livelihoods in some regions where this has been studied. Note that fishing is important, at least in some regions in all tropical continents. Moreover, fishing may be as important in seasonally dry areas (Laos, Zimbabwe) as in those where

Table 1.1. Examples of the role of inland fisheries in rural livelihoods in some developing countries.

Region, country	Proportion of households fishing	Characteristics of fishers	Contribution to income in households	Contribution to regional income
Africa				
N.E. Nigeria	40-70%	Rural households, mostly fishing for subsistence	25%	na
Zimbabwe	approx. 50%	Rural households fishing for subsistence	na	na
Asia				
Bangladesh	70%	Most households for subsistence, some commercial	20%	na
India (Karnataka)	na	Specialized fishers, lower castes	>50%	na
Laos	>85%	Mainly subsistence and most rural households and all household members	30%	20%
Sri Lanka (dry zone)	7%	Specialized fishers,	>50% and farmer/fishers	10%
Latin America				
Brazilian Amazon floodplain	80%	Most households for subsistence, some commercial	30% (subsistence) >80% (commercial)	>30%

Source: Neiland and Sarch 1994; Govereh et al. 1989; De Graaf et al. 2001; Lorenzen et al. 2000; Nguyen Khoa et al. 2002; Almeida et al. 2004.

water is always plentiful (Brazilian Amazon). Human settlements are virtually always close to water, and the significance of aquatic resources to livelihoods may be as great where water resources are scarce as where they are plentiful.

1.2.2 Inland aquatic resources as threatened components of biodiversity

Inland aquatic resources are the populations of aquatic organisms that are exploited by fisheries. In general, fish account for the bulk of exploited aquatic resources, but invertebrates such as crustacean (shrimp, crabs), mollusks (mussels, snails), and aquatic insects may also be important.

Inland aquatic resources are highly biodiverse. The fishes, for example, account for about 50 percent of vertebrate species, and roughly one half of these occur in fresh waters. At the same time, fresh water bodies account for only a very small proportion (0.001%) of all the aquatic habitat on Earth, and are subject to extreme pressure from the human demand for water. It is not surprising, then, that aquatic biota is among the most threatened components of biodiversity on Earth. Although accurate data are difficult to collect, in areas where studies have been carried out, about 20 percent of freshwater species are threatened, endangered or extinct – a higher proportion than found in most terrestrial groups. Modeled estimates of future species extinction rates also suggest that the rates for the freshwater vertebrates are five times higher than for terrestrial species (Revenga et al. 2000).

Reviews of freshwater fish extinctions consistently identify habitat alteration as the most serious threat followed by introduced species (table 1.2). Pollution and overfishing occur less frequently among the reasons for fish extinctions. Often, several factors occur together and may act

Table 1.2. Reasons for fish extinctions identified in two major studies.

Factor	*Implicated in % of extinctions*	
	North America[1]	Global[2]
Habitat alteration	73%	71%
Introduced species	68%	54%
Pollution	38%	26%
Overfishing	15%	29%

Source: [1]Miller et al. 1989; [2]Harrison and Stiassny 1999.

synergistically. For example, habitat alteration is known to facilitate establishment and spread of introduced species. Hence habitat alteration is by far the most serious individual threat.

1.2.3 The relationship between aquatic biodiversity and livelihoods

Living aquatic resources are important to livelihoods and harbor significant biological diversity, but is conserving of their biodiversity synonymous with sustaining livelihoods? Although the protection of aquatic resource diversity is often treated as synonymous with safeguarding the livelihoods of the people dependent on the resource, very productive fisheries may exist in highly modified systems of low biological diversity. Fisheries production may be higher in modified systems, and once fishers have adapted themselves to such systems they may well object to attempts at restoring "natural" conditions for the benefit of biodiversity conservation. On the other hand, nutritional studies have shown that diverse fish stocks may supply poor people with a wider range of micronutrients and vitamins than less diverse stocks.

Intensive fishing itself modifies aquatic ecosystems and may threaten components of their biodiversity. Many tropical inland fisheries are so heavily exploited that large, long-lived species have become rare and catches are dominated by very small and short-lived species. Overfishing is deemed to have contributed to a number of freshwater fish extinctions (table 1.2). On the positive side, fisheries interests often play an important role in the protection of aquatic habitats and therefore the conservation of their associated biodiversity. Sustaining both livelihoods and biodiversity are key elements of the sustainable development paradigm. Often there will be commonality between the two objectives, but there may also be conflicts and tradeoffs which should be made explicit.

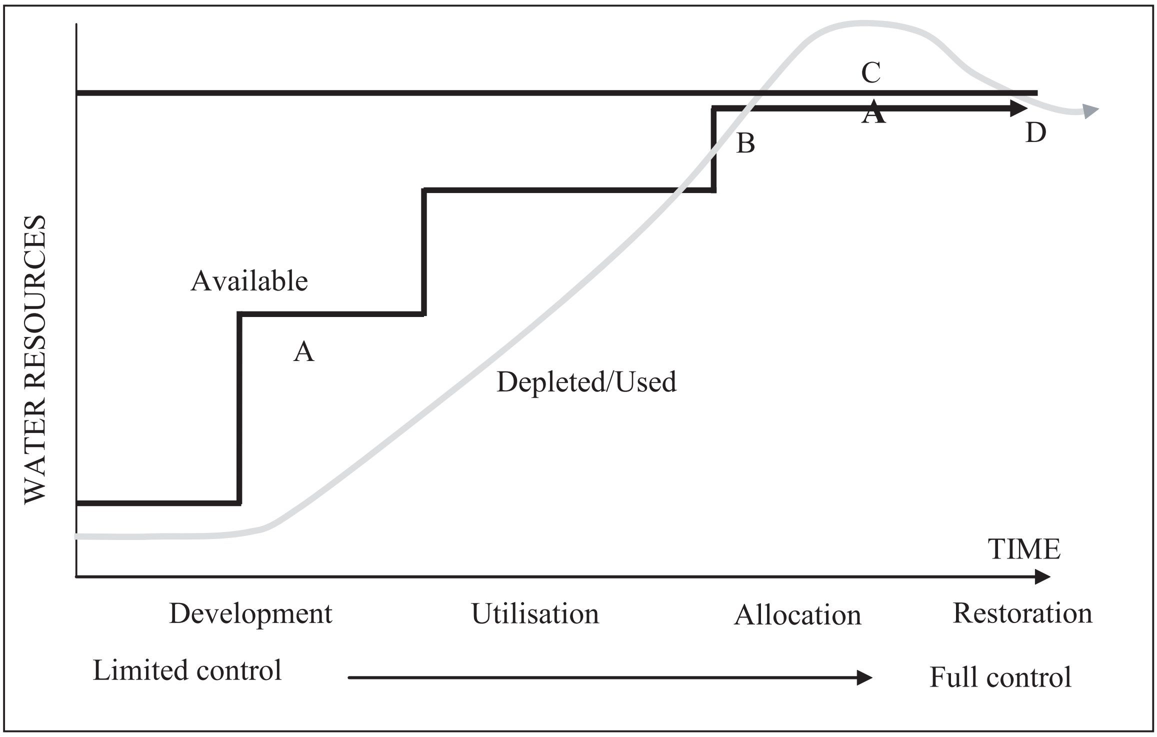
1.3 Irrigation development: rationale and trends

Worldwide, irrigated agriculture is by far the largest consumptive use of fresh water, and consequently impacts on aquatic resources more strongly than most other human activities. Why is irrigated agriculture so pervasive, and how is it linked to the wider process of river basin management?

1.3.1 River basin development

Irrigation development forms part of the wider process of river basin development. River basins worldwide often follow similar patterns of development (figure 1.1 and Appendix 1), with the initial development focusing on utilizing the available water resource for irrigation development and hydroelectric power generation. As the economy and the population grow, attention is focused on developing the water resource for towns, cities and industries. With increasing water scarcity, better management of the available resources becomes essential, and then, the focus changes from seeking to supply water to meet the demand, to managing the demand to fit the supply available. In developed economies, the period of over-exploitation of the water resource is now being followed by concern and action to redress the environmental damage caused, with water supplies to agriculture and other users being restricted in order to "return" water to the natural environment. Under these conditions, fish stocks and fisheries can recover significantly (Cowx and Welcomme 1998).

Figure 1.1. Phases of river basin development.



Source: Adapted from Molden et al. 2001.

1.3.2 Rationale for irrigation development

Globally, the total irrigated area is of the order of 270 million hectares: about 17 percent of cultivated land but producing approximately 40 percent of food and other agricultural commodities. Considering global grain output alone, 57 percent of rice and wheat by value are produced under irrigation (FAO 1996). Irrigated land is thus disproportionately important to agricultural production and to food security for many regions, and particularly for many developing countries.

Water control in agriculture boosts productivity in terms of both output and value by:

a) ensuring adequate water throughout the growing season, contributing to higher yields, reduced yield variance and enhanced quality attributes;

b) securing a crop where rainfall is inadequate (removing the risk of crop failure), or by securing a second or even third crop by making water available in the dry season; and

c) enabling farmers to adapt timing of production to market demand, and periods of shortage and higher prices.

The productivity gains from the use of irrigation can then contribute to economic growth, to poverty reduction and to the creation of sustainable livelihoods through four inter-related mechanisms:

a) improvement in the levels and security of productivity, employment and incomes for irrigating farm households and farm labor;

b) the linkage and multiplier effects of irrigation development (as part of wider agricultural growth) for the wider economy;

c) increased opportunities for rural livelihood diversification; and

d) multiple uses of water supplied by irrigation infrastructure.

1.4 Impacts of irrigation development on aquatic resources and their mitigation

1.4.1 Impacts

The development of irrigated agriculture has the potential to impact very substantially on aquatic resources, more so than most other water resource development activities. While many activities modify aquatic habitats and abstract water, generally, the abstracted water is returned to the river system after use. Despite inefficiencies and often significant return flows, the water abstracted for irrigation is largely consumed by crop evapotranspiration (or at least that is the intention). Hence, irrigation has the potential to remove a large proportion of water from a river basin. In addition, land engineering for irrigated agriculture tends to remove natural wetlands and modify catchment characteristics to an extent rivaled only by urbanization.

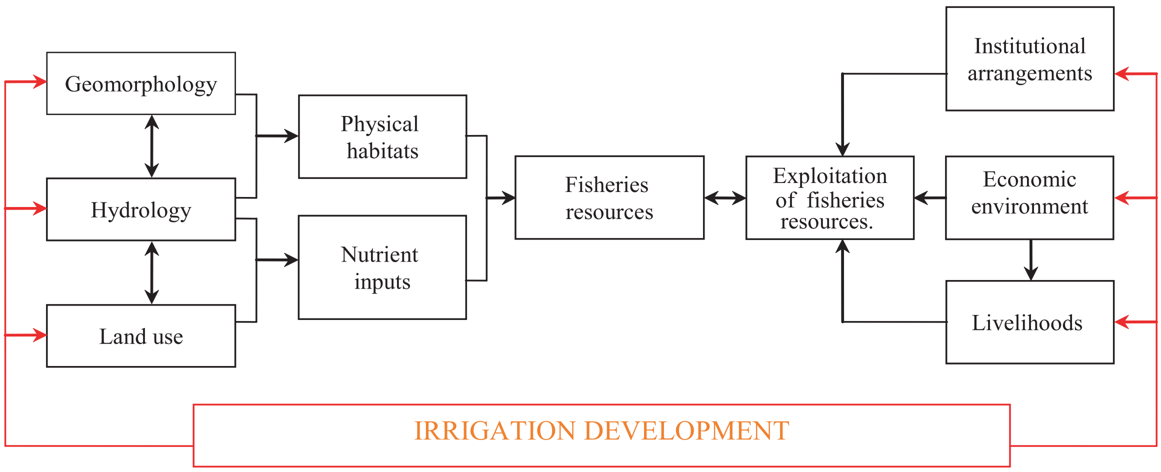
Indeed, large scale irrigation development is associated with some of the most dramatic declines of inland and coastal aquatic resources known. The Aral Sea, formerly the world's largest freshwater lake, has shrunk to less than 40 percent of its former area and its fishery has virtually disappeared as a result of irrigation abstractions from the rivers feeding the lake. The Aswan high dam has diminished not only the fishery of the Nile, but affected fisheries in the whole of the southeastern Mediterranean by reducing nutrient inputs from the Nile. A cross-check survey carried out by the World Commission on Dams on 150 large dams revealed that more than 25 percent of the dams reported marked hindrance of migratory fish as the overriding negative impact (World Commission on Dams 2000). Even small-scale irrigation schemes can impact on local fisheries, for example weir irrigation schemes with command areas of less than 200 ha were associated with a 20 percent loss in fish production (Nguyen Khoa et al. 2005).

However, impacts of irrigation development on fisheries are not always and necessarily negative. Reservoirs frequently support very productive fisheries and, depending on the original and modified hydrological conditions, may result in a local or even regional increase in fisheries production. In the Kirindi Oya irrigation scheme in Sri Lanka, for example, large shallow reservoirs retain more water in the basin for longer than would naturally be the case, and potential and actual fish productions are deemed to have increased as a result. Aquatic biodiversity impacts are a different matter. Large dams in particular are bound to have major impacts on some established species, and are unlikely to have a conservation benefit even if fisheries production is maintained or increased.

1.4.2 Impact pathways

Impacts of irrigation on fisheries arise in multiple and complex ways (figure 1.2). On the one hand, irrigation changes geomorphology, hydrology and land use, modifying physical aquatic habitats and nutrient inputs and thus ultimately, fisheries resources. On the other hand, irrigation expands livelihood opportunities, and often changes the economic environment and institutional arrangements, thus affecting how, by whom and to what extent fisheries resources are exploited. Exploitation interacts directly with the production and biodiversity of fisheries resources, and irrigation impacts on resources arising through this pathway may be just as significant as those arising through bio-physical pathways.

Figure 1.2. Irrigation development and fisheries: outline of impact pathways.



The multiplicity and complexity of impact pathways implies that overall impacts can be quite different from those anticipated on the basis of predictions that consider only one impact pathway. For example, a study on the impacts of irrigation on fisheries in the rice farming landscapes of Laos showed that the greatest impacts arose from changes in fishing practices, while changes in farming practices were highlighted as the greatest potential threat to fisheries production (Nguyen Khoa et al. 2005). In this case, an assessment focusing on river flows and longitudinal connectivity of habitats (as is often conducted by ecologists) would simply miss the most important issues. This shows that impact assessments must be broad-based, capturing and integrating information on multiple impact pathways and mechanisms.

1.4.3 Management of irrigation impact on fisheries

Negative impacts of irrigation on fisheries can be mitigated or compensated to a certain extent, and positive impacts can be enhanced. Maintaining of essential habitats, minimum flows and a degree of flooding, together with the provision of fish passage facilities can maintain yields as well as biodiversity, albeit not necessarily at the original levels. Reservoirs often provide significant opportunities for fisheries, but these will be fully realized only where water management takes account of fisheries considerations, fishers adapt their practices and adopt sustainable fishing techniques, and appropriate institutional arrangements are put into place.

There is a reasonable understanding of measures that are likely to be beneficial to fisheries, but it is not always possible to assess their effectiveness in advance. Hence such measures must often be adopted on an experimental basis, with monitoring and feedback procedures in place to improve their effectiveness on the basis of experience. A major aim of this manual is to provide guidance on both the selecting of mitigation measures and monitoring and experimental management.

1.4.4 Need for consideration and management of fisheries impacts

Impacts of irrigation on fisheries are multiple, complex and varied. They arise from a multitude of factors, ranging from physical habitat modifications to changes in livelihoods opportunities and resultant changes in fisheries exploitation. The complex and intrinsically multi-sectoral nature of these impacts makes their assessment and management difficult (World Commission on Dams 2000).

The complexity of these effects and the lack of quantitative information mean that impacts on fisheries are rarely adequately considered in irrigation planning. However, although complex and subject to uncertainties, the assessment of impacts of irrigation on fisheries should be integrated into irrigation design and appraisal. Therefore, guidelines are provided firstly to understand the mechanisms underlying the complex impacts, and secondly to provide guidance on the selection of mitigation measures and decision-making for irrigation projects.

Chapter 2

Framework for assessing and managing irrigation development impacts on fisheries

This chapter sets out a framework for the assessment and management of impacts of irrigation development on fisheries.

2.1 Guiding principles

Irrigation impacts on fisheries are multi-faceted and complex. Their assessment and management requires the participation of a wide range of stakeholders, from fishers to technical experts, and constructively dealing with complexity and uncertainty. These requirements lead to a set of guiding principles for impacts assessment and management:

- Representation and participation of all major stakeholders.
- Integrated assessment of bio-physical, ecological and socio-economic impacts.
- Effective use of both scientific and local knowledge.
- Flexibility and responsiveness of the overall process, allowing selection of specific approaches and methods in response to priorities, capacity and knowledge.
- Monitoring and adaptive management.

2.2 General framework

The general framework used here is that of Environmental Impact Assessment (EIA). An EIA can provide a structured and sequential process, which can be sufficiently flexible in its implementation to accommodate the range and complexity of concerns identified, whilst ensuring progress towards management oriented outcomes. Viewed as a framework rather than a precisely specified methodology, an EIA can also provide a process and reference points for a range of appropriate assessment tools and approaches in the context specific issues of concern. A further advantage is that the concepts of EIA are widely used and understood, enhancing the prospect for fisheries assessments to be routinely integrated into appraisals and evaluations of irrigation investments.

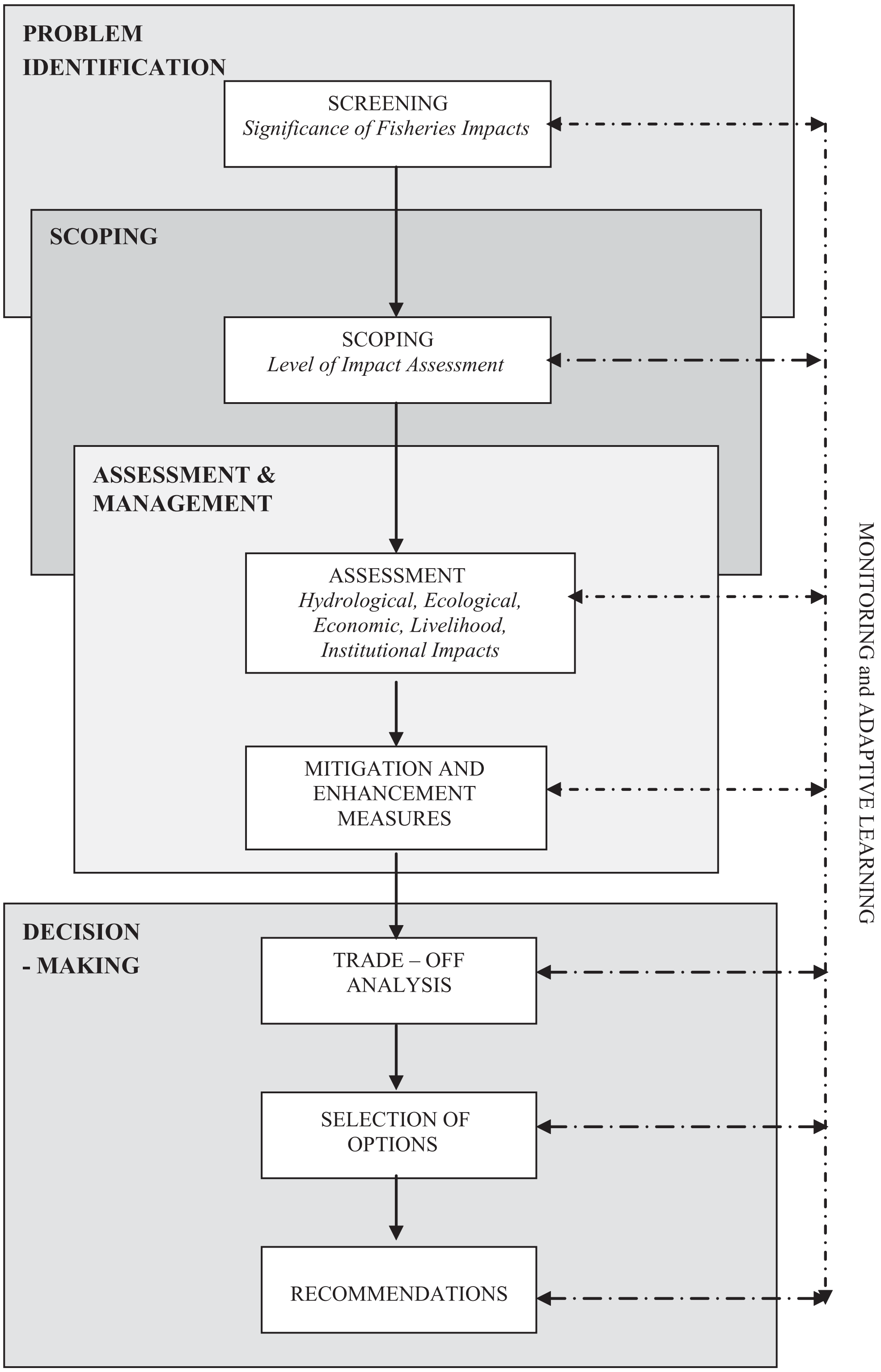
2.2.1 Process

An EIA will typically be carried out in four distinct phases (figure 2.1):

(1) Screening: to assess whether fisheries impacts of an intervention are likely to be significant and warrant assessment.

(2) Scoping: to determine the scope and level of detail required in the assessment.

Figure 2.1. Assessment process for impacts on irrigation on fisheries.



(3) Assessment: of the range of possible impacts and identification of mitigation and enhancement measures.

(4) Decision-making: analysis of trade-offs, selection of options and design and policy recommendation.

Throughout the EIA, the process should aim to establish a holistic perspective on impacts and their management, involve the participation of all relevant stakeholders, and adapt to the specific local circumstances and issues. A holistic approach is called for because the fisheries and irrigation systems involve multiple actors and causal factors. A broad picture of the interdependence between natural processes, fishing, farming and other land uses, and the wider socio-economic environment helps identify key relationships that might otherwise be overlooked or misperceived. It can also assist decision making when there are conflicts over water and land resources. The benefits expected from participation include the capture of local knowledge and an understanding of the values and priorities of different affected groups. These in turn can provide one form of validation for the outcomes of the assessment. A shared understanding of the perceptions and priorities of other groups can also change attitudes and promote consensus in defining of key problems, management objectives and possible solutions. This is particularly important where causal factors are primarily anthropogenic, and given that fisheries are often undervalued because of ill-informed or biased pre-conceptions. Indeed, simply initiating or improving the representation of fishers in negotiations with farmers and other water users can be of value in correcting past sources of bias. Finally, participation should promote acceptance and 'ownership' of recommendations, improving their implementation and sustainability (for example, through greater compliance with regulation or contribution to costs). Adaptation and learning need to be inherent in the application of the approach. The progress and outcomes of the impact assessment should be continually monitored and evaluated, and adaptation will be a necessary response to the inevitable complexity and uncertainty. Thus, feed-back mechanisms should be in place to make sure that information gained is reviewed and used to correct or improve the process and the outputs produced by it. The guidance in this chapter is designed to facilitate this process, while Chapters 3-5 provide throughout for further details and tools.

2.2.2 Core methodologies

The approach proposed here makes use of a set of core methodologies which is used throughout the process, sometimes recursively with increasing complexity and detail as the assessment progresses. These core methodologies are:

1) Stakeholder analysis to identify all relevant stakeholders, their interest in the fisheries and irrigation systems, and their interactions.
2) Mapping and characterization of aquatic habitats and their role in supporting aquatic organisms and fisheries production, both pre and post intervention.
3) Quantitative prediction of impacts on fisheries production, using simple empirical yield standards or more complex models.
4) Livelihoods analysis of primary stakeholders, that is those who derive at least part of their livelihoods from aquatic resource use.
5) Integration of physical-ecological, stakeholder and livelihoods analyses to understand the functioning and responses to change of the resource system.

These methodologies will be used at a crude exploratory level during screening to assess whether a more detailed assessment is warranted. In the main impact assessment, they will be used first to understand the current status of the resource system (Chapter 3), then to project likely impacts (Chapter 4) and finally, to identify mitigation or enhancement measures (Chapter 5). The full information and understanding derived from them will feed into decision making.

2.2.3 Practical implementation

Practical implementation of the impact assessment typically involves a range of activities including initial social mobilization of stakeholders, a series of workshops, participatory and observational field studies etc. It is often useful to structure the activities around a series of workshops. An example of the practical implementation of the approach is shown in figure 2.2.

Further reading: Nguyen Khoa et al. 2005a,b provide assessment case studies and an evaluation of the use of the approach described here.

2.3 Fostering participation

2.3.1 Nature and role of participation

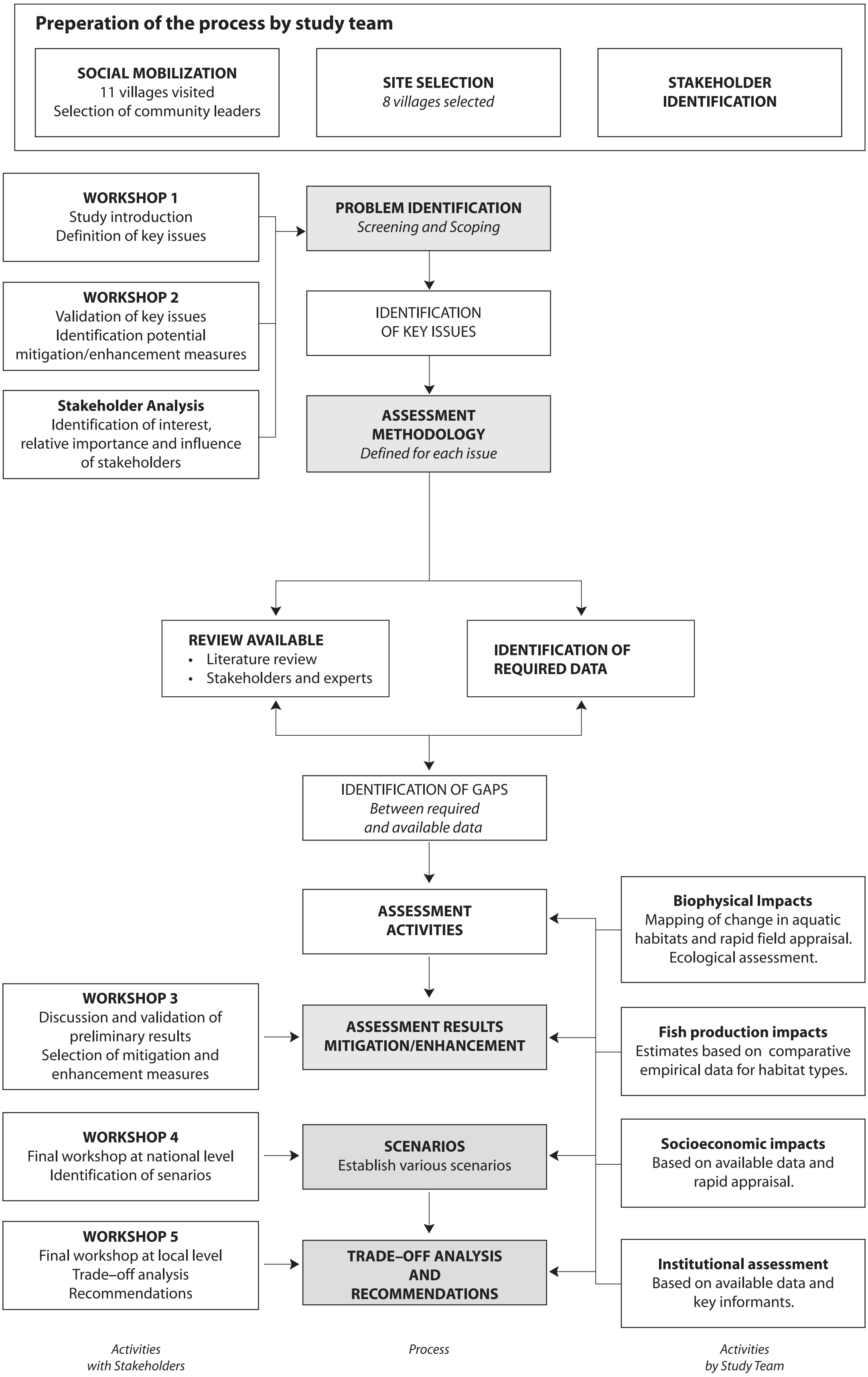
Appropriate participation of stakeholders is recommended throughout the process of assessing and managing impacts of irrigation on fisheries. Undertaking analysis and building decisions with stakeholders exploit local knowledge and promote the ownership of final solutions and their implementation, increasing the probability of sustained success.

Some recommended principles are:

- Clear affirmation of the roles of all stakeholders is needed at each stage of the process, particularly with regard to the selection, weighting and the application of decision criteria. Opportunities should be created for all views to carry weight.
- Inclusiveness is important, and an initial stakeholder analysis (during screening and scoping) plays a key role in identifying and classifying all relevant stakeholders.
- Appropriate mechanisms and methods should be used to facilitate participation.
- Flows of information and feedback to all stakeholders should be maintained throughout the process. Dissemination of information to all groups should be in a common user-friendly format.
- The study team should meet all stakeholders to validate their knowledge and input, and to build trust and confidence.

A recommended approach is to hold a series of stakeholder workshops during the assessment and management process. After each of the major stages (figure 2.1), the assessment team should present their objectives, methodology and findings to a representative group of stakeholders. The workshop participants should be engaged with and contribute to the process of refining objectives and selecting appropriate data collection and analytical techniques. Then, as the process proceeds, they should also contribute to and as far as possible, lead interpretation of findings and decision-making on project implementation and measures for mitigating or enhancing of impacts.

Figure 2.2. Activities during the practical implementation of an impact assessment in Sri Lanka.



Source: Nguyen Khoa et al. (2005b).

Further reading: The World Bank Participation Sourcebook (www.worldbank.org/wbi/sourcebook/sbhome.htm).
The ELDIS Participation resource guide (www.eldis.org/participation/).

2.3.2 Stakeholder analysis

Stakeholders are those persons, groups and organizations with a valid interest in the fishery and in irrigation. Stakeholders can be both those with power to control the use of resources, as well as those with no influence, but whose livelihoods are affected by changing use of the resources. They include those whose livelihoods are connected to it (e.g. fishers, manufacturers and suppliers of fishing equipment, fish traders and processors), the other people affected by the exploitation of fisheries or any measures taken to protect or restore fisheries, and all those influencing the way the fishery or its environment is managed. Clearly, it is important to identify all these stakeholders and their roles early on in any assessment.

Stakeholder analysis (tool 1) is a tool commonly used to initiate participatory processes, and to identify and invite participation by stakeholders. The analysis helps ensure that all potential views are adequately considered in the planning and decision making process. It will ideally be conducted as one of the initial activities in the whole impact assessment process, so that its results inform both screening and scoping stages and the selection and invitation of stakeholders to participate in these stages. However, it may need to be repeated or refined during screening and scoping as more information about the project area and affected groups is collected and interpreted.

Tool 1. Identifying and characterizing stakeholders

1) Identify all stakeholders (persons, groups and organizations with a valid interest in the fishery). This should be based on both the prior knowledge within the assessment team and the participatory assessment by groups or individuals drawn from known stakeholders.
2) Establish the nature and strength of each stakeholder's interests, and the interactions between stakeholders. Visualization techniques such as diagrams mapping stakeholders and their interactions can be very helpful and particularly used in a workshop setting. It is usually helpful to distinguish primary stakeholders (those directly affected) from secondary stakeholders (those involved in managing the fishery or irrigation system but not directly affected, e.g. government departments or NGOs).
3) Assess whether the identified stakeholders should be subdivided further, for example by wealth, gender, or occupational group. This may need to be reviewed during livelihoods analysis.
4) Also, assess whether new stakeholders are likely to emerge as a result of irrigation development (e.g. specialized reservoir fishers).

Stakeholders should be representative of:

- all relevant levels – national, provincial, district and community;
- all relevant organizations – government, non-government and community; and
- all relevant disciplines – irrigation, fisheries, agriculture, water resource management, planning and finance.

Further reading: ODA 1995, Grimble and Chan 1995, and Ravnborg and Westermann 2002 provide practical guidance on how to undertake stakeholder analysis for development projects in the context of natural resource management.

2.3.3 Rapid and participatory appraisal

Rapid and participatory appraisal (RRA and PRA) is a suite of approaches designed to facilitate constructive interaction between development professionals and local people, usually within a project framework. RRA is more extractive, aiming principally to help the development professional to understand the local situation, whilst PRA aims to foster decision making and sustained action by local people. RRA and PRA are flexible and open-ended approaches which seek multiple perspectives and use systematic cross-checking rather than statistical analyses to judge information credibility. A wide range of specific methods including semi-structured interviews (figure 2.3) and visualization techniques such as mapping, scoring and ranking are used to facilitate communication between development practitioners and local people.

Most development practitioners will already be familiar with PRA. For those who are not, we recommend the further reading below. PRA approaches are best learned through practice, therefore, attending a practical course or working alongside an experienced practitioner is highly recommended.

Further reading: There are a number of PRA and RRA manuals for a wide range of applications. Townsley (1996) provides a practical introduction with emphasis on the use of PRA in aquaculture. Chambers (1992) provides an overview of the philosophy and rationale of PRA.

2.4 Screening

Screening is the first stage in impact assessment and may be carried out by the agency or agencies responsible for planning irrigation development and/or responsible for water resource and fisheries management. Ideally, it will involve consultation with stakeholders potentially affected by the proposed developments, although these may not have been fully identified until scoping is also completed.

The purpose of screening is to establish whether an irrigation development project is likely to have any substantial impact on fisheries that would call for an impact assessment. There are three categories of impacts that would warrant such an assessment:

1) Impacts on the actual or potential productivity or biodiversity of fisheries resources.
2) Impacts on livelihoods arising from (1) or from changes in access to resources or livelihoods options.

Clearly, screening must be based on outline descriptions of the planned intervention (4.1- 4.3), aquatic habitats (3.2) and resources (3.3), and stakeholders and their livelihoods (3.6). These outline descriptions can form the basis of more detailed analyses in the full assessment.

2.4.1 Screening for biophysical impacts on fisheries resources

Impacts on fisheries resources (either positive or negative) are likely if the proposed development will significantly affect aquatic habitats or their connectivity (i.e. the ability of aquatic organisms to move between them). Hence if the answer to any of the following questions is YES, then an impact assessment is indicated.

1) Is the development likely to withdraw and deplete a significant share of the current river flow so that a significant change in total flow or in the extent of flooding likely?
2) Is land use likely to change in a way that would affect the availability or quality of aquatic habitats? For example, will wetlands be drained for agriculture, or agricultural land and water use, changed so that rainfed or flood prone ricefields will disappear, or siltation of natural aquatic habitats increase?

An assessment of impacts on fisheries resources is particularly indicated if there is evidence that fisheries are important to the livelihoods of at least some people (see 2.4.2).

In addition, such an assessment is indicated if there is evidence that impacts on the biodiversity of fisheries resources are likely to occur and may be conservation-relevant. This is particularly likely to be the case if:

- The site in or near an area has already been identified as particularly rich in biodiversity, or worthy of conservation because of its natural uniqueness.
- Some species known to occur at the site are officially classified as endangered or threatened.
- The site is known to represent an important migratory route for some aquatic species (even when the site itself is not considered as having conservation significance).
- The site is part of a watershed in relatively pristine condition, (e.g. primary forest, little agriculture, few other modifications to river) though such watersheds are becoming very rare and are of great potential conservation value even if no assessment has yet been carried out.

The aquatic ecosystem is isolated from other aquatic systems so that there are strong natural barriers to colonization by aquatic species. Such aquatic systems are often poor in overall diversity, but may harbor endemic species (species that do not occur anywhere else).

Mapping of aquatic habitats (tool 2), identifying resources (tool 4), and forecasting impacts (tools 21-26) at a preliminary level will be required.

2.4.2 Screening for livelihoods impacts

With regard to impacts on the actual or potential productivity of fisheries, three aspects of potential impacts on livelihoods should be considered (4.5).

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

Changes in patterns of access may arise from irrigation development even if fishery productivity is relatively unaffected. Alternatively, access may be unchanged, but productivity may be affected. If negative, both types of change may act to worsen the absolute position of poor people in terms of the distribution of poverty and vulnerability. Even if poor people are not made worse off in absolute terms, it may also be undesirable if their relative position is made worse off, that is if the project results in a significant widening of differences in wealth and living standards. Such widening can result in social conflict, or in processes that further contribute to growing inequity.

Figure 2.3. Semi-structured interview with farmer/ fishers in Laos.

It is also worth noting that whilst the emphasis here, and in this manual generally, is on impacts on poverty and livelihoods, the aggregate economic value of changes in fishery productivity may also be significant. Thus, the existence of fisheries of significant economic value may also signal the need for an impact assessment, even if the distributional or livelihood impacts for poor groups are not predicted to be severely negative. In such case, the net benefits from irrigation development might be significantly lessened by reducing fishery output, or irrigation may provide opportunities to enhance the management and productivity of the fishery.

It will not be possible to predict all potential changes at the screening stage but if ANY of the answers to the following four questions is "yes" a fisheries impact assessment is warranted.

1) Is the project likely to have an impact on the actual or potential productivity of a fishery that is a livelihood asset for some people, and/or significant in terms of the aggregate economic value of its output?

In answering this question the value of a livelihood asset should be considered not just in terms of income, but also including other aspects such as (tool 13):

- Is fishing the sole source of livelihood for some groups?
- Is fishing valuable as part of a diversified livelihood strategy for other groups, reducing risk or helping "smooth" seasonal labor use and consumption?
- Are the people most dependent on fishing as part of their livelihood strategy among the poorest and most vulnerable?
- Are fish an important source of nutrition for affected people?
- Does fishing for sale provide a means to gain cash for immediate needs?

- Do fish play a role in social relations/social capital as a means for reciprocal exchange or provision of “social security” for dependent groups?
- Are other strong social or cultural values associated with fishing?

2) Is the project likely to have an impact on seasonal or spatial patterns of access to the fishery for some groups (tool 27)?

Again, answering this question requires consideration of the following:

- Is fishing the sole source of livelihood for these groups?
- Is fishing valuable as part of a diversified livelihood strategy for these groups?
- Are these groups among the poorest and most vulnerable?
- Are fish an important source of nutrition for these groups?
- Do these groups fish for sale to provide a means to gain cash for immediate needs?
- Do fish play a role in social relations/social capital for these groups?
- Are other strong social or cultural values associated with fishing for these groups?

3) Will changes in fishery productivity or patterns of access worsen the absolute poverty of some groups or individuals (tool 30)?
4) Will changes in fishery productivity or patterns of access significantly widen existing disparities in the distribution of wealth and living standards?

2.4.3 Preliminary assessment for screening

Screening as described above must be based on available data and knowledge. The preliminary assessment needed to carry out screening may involve:

- Identification of potential impacts on fisheries, livelihoods and biodiversity through the preliminary use of assessment tools and checklists as set out in the knowledge base. The results of these activities to be presented and reviewed in a workshop with key stakeholders.
- Initial description and prediction of impacts through an ad hoc committee approach or workshop, in which experts or knowledgeable local stakeholders give descriptive, or possibly numerical rankings, on the importance and magnitude of possible impacts.
- Reconnaissance field visits and community or stakeholder interviews.
- Comparison with similar projects in comparable environments.

Where available data and knowledge remain inadequate it must be assumed that answers to the screening questions could be yes, proceeding to the stage of scoping and at least a rapid assessment of potential impacts.

2.5 Scoping

The purpose of scoping is to:

- define the scope of the required impact assessment study;
- consider resource needs and availability;

- avoid waste of resources in unnecessary data collection and analysis; and
- establish contact with and appropriate levels of consultation with, or participation by, all stakeholder groups likely to be affected by the irrigation development.

The scope of the impact assessment must be appropriate to the project and the characteristics of the fishery. It should cover all issues identified during screening and preliminary assessment, and have sufficient breadth and flexibility to allow for identification of new issues, whilst focusing on the known areas of most significant impact.

Scoping will include:

- Preparation of background information on the proposed development.
- Identification of all stakeholders and assessment of their importance relative to project impacts, and their potential influence in planning, implementation and management decisions (stakeholder analysis – see below).
- Notification and involvement of all interested stakeholder groups and collection of their views on the potential impacts and scope of assessment required.
- Determination of the scope of the study including agreement on:
    - the most critical issues and parameters to assess, including the urgency of potential fishery degradation and degree of irreversibility (a key part of this being eliminating irrelevant issues);
    - the spatial boundaries for the areas potentially affected;
    - the primary technical, ecological and socio-economic processes to be considered, their interactions and their respective time horizons;
    - the level or degree of detail of impact assessment required to assess livelihood and/or biodiversity impacts, taking account of available expertise and resources; and
    - the level or degree of detail of impact assessment required to assess the hydrological, biological, socio-economic and institutional processes that determine the livelihood and biodiversity impacts, taking account of available expertise and resources.
- Initial identification of possible mitigation or enhancement measures, or other development alternatives.

From the scoping exercise it should be possible to prepare guidelines for the impact assessment study that will act as a workplan for agencies concerned, or form the basis for drafting of terms of reference for consultants to be commissioned to complete the work. These guidelines should cover:

- the possible impacts to be assessed and the depth of study required for each;
- the allocation of responsibilities to stakeholder groups or agencies for further consultations, and for data collection and analysis;
- the timescale and workplan for all activities; and
- available resources and responsibilities for their provision.

Scoping will primarily rely on the results of the preliminary assessment for information, but should continue throughout the impact assessment as the study scope may need to be adjusted to take account of new information or changing circumstances. It should be seen as part of a process of screening, scoping and impact assessment in which these phases are overlapping and often iterative in practice.

2.6 Impact assessment for individual projects

Impact assessment for individual projects may be carried out as an ex-ante assessment of proposed new irrigation developments, as well as an ex-post assessment of existing schemes with the aim of identifying options for mitigation or restoration.

There are four steps involved in impact assessment:

(1) Description of the project

(2) Description of the pre-project situation

(3) Prediction of project impacts

(4) Identification of mitigation or enhancement measures

2.6.1 Description of the project

Information on the proposed project is required in sufficient detail to allow impact assessment. This information can be drawn from project documents and through consultation with the agency or agencies responsible for planning and implementation. Refer to Section 4.2 for a summary of the key features of irrigation schemes (also tool 21).

Key features of the project to be considered will include:

- the command area;
- changes to the river flow pattern due to diverted irrigation water supply (how much water is abstracted, when and where it goes);
- location and form of engineering structures, reservoirs and other potential habitats;
- crop area and crop types;
- irrigation method(s);
- drainage flows;
- direct impacts on natural drainage and stream flows; and
- direct impacts on floodplain area.

Ideally the project description should not be limited to a single design, but should outline alternative design options that differ in their fisheries impacts. Where only single design is provided initially, possible modifications beneficial for fisheries may be identified during the assessment and presented back to the planning authority.

2.6.2 Description of the pre-project situation

To be able to understand possible interactions and predict potential impacts it is necessary to have sufficient information describing the pre-project situation (for example, as illustrated by the situational variables in figure 3.1). As detailed in Chapter 3, the main areas of concern include:

1) Physical habitats and hydrology (3.2) (figure 2.4);
2) Ecology of fisheries production (3.3);
3) The exploitation of fisheries (3.4);

4) Biodiversity and ecological integrity (3.5);
5) The role of fisheries in livelihoods (3.6); and
6) Institutional arrangements and the management of fisheries (3.7).

Analysis at this stage is mainly descriptive and summative. The aim is to document and understand the pre-project situation as a basis for predicting project impacts (3.8). With regard to livelihoods the aim is to have a baseline or benchmark scenario from which to predict likely trajectories of livelihood change with the introduction of irrigation, the particular focus being groups heavily or partly dependent on fishing.

Figure 2.4. Mapping of aquatic habitats, irrigation infrastructure and land use.

2.6.3 Prediction of project impacts

The aim is to determine the potential impacts of the proposed irrigation development on fisheries and livelihoods, and their causes. As detailed in Chapter 4, the main areas of focus will be:

1) Impacts on physical habitats (4.3);
2) Impacts on fisheries ecology and yields (4.4);
3) Livelihood impacts (4.5);
4) Impacts of institutional change (4.6); and
5) Interactions and synergistic impacts (4.7).

The work to be undertaken will initially follow the plan developed during the scoping stage, although sufficient flexibility will be required to allow any new significant issues identified during impact assessment to be investigated.

The appraisal team will need to select data collection methods that are appropriate after considering the main issues identified, the available information, and the time and resource constraints. The tools suggested in Chapters 3 to 5 provide guides to approaches. Again the potential value of a participatory approach is also emphasized. Stakeholder analysis and consultation during screening and scoping should lead into workshops or other fora in which stakeholder interests can inform and direct the assessment process, and in which the preliminary results of the assessment can be interpreted and debated.

With regard to data analysis and interpretation, the main questions to be answered are what will be the impact over time on biodiversity and on livelihoods of changes in the productivity of fisheries or in patterns of access to fisheries?

Using the answers to these questions, the main focus of analysis should be to predict trajectories of change for the livelihood strategies of impacted people and for the ecology of aquatic habitats. For example:

- Does fishing become more or less important in livelihoods?
- How do incentives for fishing change compared to alternative sources of livelihood?
- How are sources of vulnerability affected?
- To what extent will negative impacts on the pre-existing habitats be compensated by new or modified habitats created by the irrigation infrastructure?

Use of the livelihoods approach (3.6.2) in focusing on the five forms of asset and on the vulnerability should ensure that this is a holistic assessment, and is not focused solely on income.

The assessment should seek to determine not only just potential impacts but also why they may arise as predicted. This is crucial when seeking to identify mitigation or enhancement measures. For example, given negative ecological outcomes caused by change in water flows, the assessment should seek to determine whether the hydrological changes are associated with the new irrigation infrastructure itself, or with poor infrastructure operation and/or maintenance, or with some other cause. When considering social and economic outcomes the number of possible pathways that could be the root cause is even greater. Prediction of impacts thus requires a thorough understanding of the situational variables in the pre-project case and how these are connected via patterns of interaction to possible outcomes.

The assessment of trajectories of change in livelihoods (4.5.5) must also be disaggregated by important socio-economic groupings. In this respect, both differences between households (e.g. caste or class) and within households (e.g. age or gender) are important.

Key comparisons likely to be made are between:

- full-time fishers v farmers and fishers;
- men v women;
- viable farmers v marginal farmers v landless households;
- landowners v tenants;
- migrants v residents; and
- between groups differentiated by caste, ethnicity or religion.

This disaggregated analysis should reveal who the gainers and losers are. It should question whether the losers are worse off in absolute terms or only in relative terms? If only in relative terms, it should be found whether the widening of disparities in wealth distribution is a significant cause for concern.

In predicting the impacts of irrigation development as above, it is also important to consider what the counter factual situation over time would be, that is, what would be the situation without the introduction of irrigation over the same period. It can not often be assumed that things would have remained unchanged. For example, an open-access fishery subject to growing population pressure may be subject to unilateral appropriation and privatization of fishing rights by powerful landowners or communities. Thus, regardless of irrigation development, vulnerable households may find themselves increasingly excluded from access to the fishery.

Other negative trends may also arise in the without-project future and should be identified as far as possible. Irrigation development may not directly address such problems but may provide the "window of opportunity" to introduce institutional or other changes that can mitigate the problem.

2.6.4 Identification of mitigation or enhancement measures

Mitigating negative and enhancing positive impacts of irrigation on fisheries involve several different issues (Chapter 5):

(1) Minimizing loss and degradation of existing aquatic habitats.

(2) Developing new aquatic habitats.

(3) Maintaining ecological connectivity.

(4) Compensating for losses.

All four issues should be considered in any management effort, but priorities will depend on local circumstances and preferences. Moreover, there are likely to be tradeoffs between issues (1) and (2). From a conservation perspective, issue (1) has clear priority over the others, but from a livelihoods perspective this is not necessarily so. It also will involve trade-offs with the objectives of irrigation development as maintenance of pre-impact habitats and their fisheries involves preserving the physical habitats and their hydrology, and limiting impacts of agricultural activities on aquatic systems.

Mitigation measures to lessen the impact of irrigation development on pre-existing fisheries centre around the principles of maintaining habitats and their connectivity. This involves preserving such habitats from land drainage or in-filling, maintaining their hydrological characteristics, and avoiding or mitigating of negative impacts from land use.

Enhancement and compensation measures focus on newly created habitats including reservoirs and irrigation and drainage canals. Fisheries in new habitats, in particular reservoirs, tend to use different technology (boats and gill nets, seines or large lift nets) and are less seasonal than river fisheries. The relatively non-seasonal nature of reservoir fisheries and the opportunities they provide for economies of scale may lead to the emergence of full-time professional fishers. This process can be facilitated through development projects to improve capture and post-harvest technologies, marketing, and the developing of fishermen's organizations. It may also be possible to enhance fisheries through applying of aquaculture technologies or habitat creation. Aquaculture development may also have a role, but it must be realized that farming of fish can not easily replace the livelihoods role of fishing.

The promotion of alternative livelihoods for aquatic resource users affected by irrigation development may be an important, but highly situation specific compensation measure.

2.6.5 Ex-post assessment of existing irrigation developments

The sections above provide guidelines on *'ex-ante'* impact assessment relevant to the planning stages of a proposed irrigation development. However, many situations may call for an *'ex-post'* or retrospective assessment for an existing irrigation scheme.

Clearly, it will be too late to change the decision to implement the scheme or many of its main design parameters, but if aspects of aquatic resource management including fisheries were neglected in the design stages, or in current scheme operation, it may be possible to identify possible improvements. Thus, the main focus of an ex-post assessment will be on the possible identification of measures to mitigate negative ecological and livelihood impacts, and enhance any positive impacts.

The knowledge base (Chapters 3-5) and impact assessment guidelines above remain broadly relevant and applicable to the retrospective case, and only significant points of difference or change in emphasis are highlighted below.

Screening, preliminary assessment and scoping

Screening remains an important first stage for ex-post assessments, as clearly, it is unlikely to be worth investigating the impact on fisheries of all existing irrigation schemes. The checklists of questions in Section 2.4 remain valid with the focus shifting to whether any impacts on production, livelihoods or biodiversity have occurred.

The preliminary assessment can gather available evidence of these impacts from stakeholders and key informants, field visits, and any studies already carried out. It may also be possible to compare the characteristics of the project and the impacted area to other similar projects for which fisheries impacts have been considered, or to the conditions in a comparable area without irrigation development.

Scoping requires the same activities as listed in 2.4 above. Again it will be possible to use available evidence of actual rather than predicted impacts.

Impact Assessment for Existing Irrigation Schemes

As for the ex-ante or planning assessment, three steps are required.

(1) Description of the project

Use can be made of project planning and design documents, and also any subsequent evaluation studies or rehabilitation proposals.

However, it is important to investigate through field visits, key informants and stakeholder consultation how the scheme is currently being managed and operated. Of particular importance are those aspects that may potentially impact on fisheries, e.g. reservoir management and releases, canal and drainage flows, actual command area achieved, etc. It is common that both scheme management and farmer practices will have diverged over time from original design intentions.

(2) Description of the pre-project situation

Whereas description of the pre-project situation in an ex-ante assessment can be based on, or confirmed by actual observation, in the ex-post assessment it has to be based on secondary sources or the recall of stakeholders and informants. Secondary sources may include baseline studies prepared at the time of project design and implementation and other relevant studies or government statistics for the area. Fieldwork must seek to assess what would have been the hydrological, ecological and livelihood characteristics of the area prior to scheme development. Apart from physical changes that can be directly observed in the field, the main source of information may need to be the recall of individual or group interview respondents.

(3) Evaluation of project impacts

Using the knowledge base (Chapters 3-5) and impact assessment guidelines, this will involve seeking evidence for possible impacts and a sufficient understanding of the processes involved, to enable identifying of possible mitigation or enhancement measures.

In the analysis and interpretation of data collected, it is particularly important to take account of the likely counter-factual or "without project" situation. This is so that causality can be established as far as possible, and observed impacts attributed to irrigation development rather than other non-related factors. In practice, this will be difficult. If possible, comparisons should be made to a non-impacted or "control" area that had similar pre-project conditions and has not been subjected to irrigation development. Alternatively, available data should be gathered with regard to pre-project trends for key variables and an assessment made of the extent to which these may have continued in the "without project" scenario.

Overall, a comprehensive evaluation of project impacts will require a thorough understanding of the situational variables for the pre-project situation - physical/biological/technical, socio-economic, institutional - and how these have evolved over time. For large schemes and potentially impacted areas, an in-depth case study approach might be adopted to seek to establish sources of impact, for example, an investigation of reasons for changed patterns of labor allocation in fishing for a selected village or socio-economic group within a village. The analysis must then consider whether the conditions of this group are sufficiently comparable to those of other groups for it to be representative, and for the findings to be generalized in respect of all or at least part of the total impacted population.

2.7 Trade-off analysis and decision-making

2.7.1 Trade-off analysis

As with other aspects of water resource management, management of impacts of irrigation development on fisheries will often be characterized by multiple objectives, multiple criteria, multiple actors and decision makers and multiple stakeholder groups.

The assessment process outlined above will inevitably reveal systems characterized by dynamic relationships and complexity. Furthermore, impacts of irrigation on fisheries often raise conflicting issues and interests, particularly between farmers and fishers. There will also be a mix of direct and indirect impacts (both positive and negative). Some of these can be quantified and estimated in monetary terms (e.g. farming and fishing output) but others, which may be viewed as equally significant in decision making, cannot be fully quantified and valued (e.g. biodiversity, cultural values and livelihood activities of last resort). In such a context, decision makers face challenges when selecting the best design and management options, and this necessitates appropriate analytical and decision making processes.

Trade-off analysis is a process in which stakeholders and a study team engage themselves to assess the merits of different design options or management strategies, and to explicitly determine priorities and make choices. It will use the information generated by the assessment process to answer stakeholders' questions about impacts of different activities on the aquatic resources being studied. Organising that information to make it understandable and useable should be an outcome of the application of the approaches set out in this guidance manual, and is a central feature of trade-off analysis. Trade-off analysis is a tool that can help decision-makers understand resource use conflicts and stakeholders' preferences for management.

Figure 2.5. Workshop involving all major stakeholders.

Where these processes are wholly stakeholder driven, and include active involvement of government agencies or other organizations responsible or accountable for decisions and their implementation, they can function as the actual decision making process. Decisions, depending on their scale and significance may nevertheless be subject to final political approval at ministerial or parliamentary level. However, if consultation and decision making processes are endorsed by the government and political levels from the start, the reversal of any decisions emerging from a stakeholder driven analysis of choices and trade-offs would be an exception rather than the norm.

The major stages in a trade-off analysis are as follows:

1. Begin by drawing on the stakeholder analysis completed during screening and scoping of the impact assessment. What is required is clear identification of stakeholders, their interests and possible resource use conflicts. Participation by stakeholders should then be integrated in the process that follows as appropriate to the issues and the level of technicality involved.
2. Generate an inventory of design options and operational alternatives for the proposed or existing irrigation scheme that will improve the management of impacts on fisheries (Chapter 4).

3. Identify and agree the nature of likely impacts and criteria against which to assess these.
4. Complete an appropriate form and level of multi-criteria analysis and generate a ranking of design and/or operational alternatives from the least preferred to the most preferred outcome.
5. Subject the results to sensitivity analysis and/or scenario planning to assess the effects of risk and uncertainty.
6. Seek final decisions on preferred alternatives through review and iteration of the analysis with stakeholders, making use of information dissemination, trust building and consensus building techniques. Where conflict exists, stakeholders should be facilitated to review their prioritization in the ranking of alternatives in the light of the priorities of others. The aim is to reveal areas of consensus on alternatives that can bring benefits to all, and alternatives that are least damaging, or where trade-offs provide acceptable compensation and conflict resolution. Outcomes will be a combination of scientific results, stakeholders' preferences and national policy priorities.

The terms trade-off analysis (TOA) and multi-criteria analysis (MCA) may often be treated as synonymous, but here TOA is regarded as the whole process (steps 1-6 above) and MCA as the analytical comparison and ranking of alternatives prior to final decision making (steps 2-5). A more detailed guide to MCA is provided in Appendix 2.

Box 2.1. Suggested steps for a trade-off analysis·

- The TOA follows on the completion of the screening, scoping and impact phases of the assessment protocol by the multi-disciplinary study team. These will have included a stakeholder analysis and forms of stakeholder participation as appropriate to the situation.
- The study team completes and draws on the stakeholder analysis as necessary to identify key stakeholders and conflicts of interests.
- A database/information centre is established.
- Representative stakeholder groups are contacted and the wider public in the affected area are informed through print and other media.
- A decision-making forum made up of stakeholder group representatives and supported by the study team is formed.
- The forum assembles an inventory of alternatives for design or operational choices, and considers whether this is comprehensive and adequate. If necessary, further steps are taken to refine or expand the alternatives.
- The forum decides on the criteria for ranking the alternatives with input from the study team.
- Alternatives are assessed against the criteria by, or with the support of, the study team, and results presented to the forum for discussion and approval.
- Alternatives are compared by the forum using MCA methods and a ranking prepared with input from the study team (e.g. Box 2.2).
- A final selection of options that will form the basis for detailed planning is made and communicated to the higher level decision making authority and, if approved, to agencies responsible for detailed planning.
- Subsequent detailed plans are widely distributed for comment from all stakeholder groups, and key outcomes made public.

Trade-off analysis as outlined above can be undertaken at a range of levels of participation and available information. The depth of analysis undertaken will depend on the issues to be addressed and on the data and research resources available. There is no unique approach for TOA as a process, or for MCA as a means to identify preferred alternatives, and this manual can provide only an introduction to approaches appropriate to the management of impacts of irrigation on fisheries. Principles and methods to assist decision making on complex and often conflicting issues are suggested, and further sources of information and guidance are cited. In practice, study teams must determine the details of their approach, including data needs and methods of analysis, depending on the situation being investigated and on the available expertise, resources and time. Box 2.1 suggests the sequence of stages that may be regarded as a minimum for a multi-disciplinary team undertaking an assessment of impacts of irrigation on fisheries; while Box 2.2 shows an example of a trade-off analysis of options for addressing the fisheries impacts of drainage water inflows to coastal lagoons in Sri Lanka.

Box 2.2. Example of a trade-off analysis

Two groups of workshop participants scored six options on five criteria, from 1 (lowest or worst) to 5 (highest or best). The following management scenarios were scored:

Scenario 1 (S1): Restoration of small tanks to retain drainage water
Scenario 2 (S2): Rehabilitation of irrigation canals to reduce drainage water
Scenario 3 (S3) : Construction of a canal to divert drainage water around lagoon
Scenario 4 (S4): Re-use of drainage water to refill downstream tanks
Scenario 5 (S5): Developing prawn aquaculture to compensate for loss of prawn fisheries
Scenario 6 (S6): Returning drainage water to irrigation system by pumping

Scores:

	Group 1						Group 2					
Scenarios / Criteria	S1	S2	S3	S4	S5	S6	S1	S2	S3	S4	S5	S6
Effectiveness	5	5	3	5	1	0	3	4	4	1	1	4
Cost	3	4	4	5	1	0	0	0	0	2	1	1
Time scale	2	4	2	5	5	0	0	0	0	2	3	2
Level of potential conflicts	5	5	4	4	3	1	2	5	3	4	0	3
Potential for conflict resolution	1	1	1	2	4	4	2	4	4	1	1	4
Total	**16**	**19**	**14**	**21**	**14**	**5**	**7**	**13**	**11**	**10**	**6**	**14**
	Preferred options: S4 and S2						Preferred options: S6 and S2					

In this case, no clear consensus arose from the exercise, but the two groups tended to favour a combination of measures involving the rehabilitation of irrigation canals and the re-use of drainage through rehabilitated tanks or pumping.

2.7.2 Drawing on a stakeholder analysis

The key outputs from a stakeholder analysis relevant for TOA are:

- Identification of stakeholders to participate in decision making.
- Classification of stakeholders and their interests.
- Identification of conflicting interests.

It is important that the stakeholders participating in the process are representative of key groups and appropriate for decision making. For practical purposes a balance must be struck between the number involved and the need to ensure that key views or constituencies are not neglected.

A meeting with the leading or sponsoring agency and representatives of the major constituencies (government, civil society, NGO, communities, etc.) to discuss and finalize the composition of the stakeholder group may be a good approach. This meeting will be based on the results of the stakeholder analysis prepared in advance by the study team.

In this manual, it has been recommended that identified stakeholders at local level be involved from the beginning of the assessment process (i.e. screening and scoping). Regional or national representatives may be more involved in the final decision-making phase, when they should interact with key local representatives from the project area.

It is important that stakeholders are enabled to make meaningful inputs in TOA processes. The study team leading the process may need to assist certain stakeholder groups, and especially those who lack technical skills, to construct and evaluate their own goals and preferences in the light of the options being proposed. This will require allocation of sufficient time to achieve planned objectives and outputs. Provision should also be made for the participants of workshops or other fora to evaluate and express their satisfaction and confidence in the process in which they have participated.

2.7.3 Consensus building and decision making

The final stage of the TOA is to seek consensus on the selection of preferred options and on the recommendations to be made to implementing agencies. A range of methods exist to bring stakeholders together and to seek agreement on controversial and disputed issues. In the management of impacts of irrigation on fisheries it is desirable if efforts can focus on consensus building achieved by the stakeholders themselves with minimum outside intervention. At the other extreme, there is enforced arbitration, either by government adjudication or the judicial system.

The involvement of outside arbitrators will increase financial and time costs, and will reduce the sense of empowerment and "ownership" for local stakeholders. The least intervention processes are also most manageable for the impact assessment teams who are unlikely to have extensive experience in conflict resolution. The involvement and dissemination of information to stakeholders throughout the assessment process, and the building of awareness about the consequences of alternative decisions should also have helped to reduce controversy prior to this stage.

The prior stages of the assessment process should have provided a clear assessment of the issues involved, the nature of each group's priority concerns, the legal and institutional context and the sources and degree of conflict. The study team will have already built considerable trust among stakeholders and will have an understanding of the willingness of stakeholders to participate in the process. Completion of MCA may have been particularly useful in clarifying and making explicit these issues.

Once these stages are complete all groups should eventually be brought together to find areas of agreement in a consensus building meeting or workshop. It is beyond the scope of this manual to cover techniques for consensus building and conflict resolution in detail. Further sources of guidance are suggested below.

Key lessons from experience relevant to natural resource management are as follows:

- Have a clear strategy for involving all interested parties in the discussions, and for addressing known fears seriously, with effective, understandable information.
- Use general principles and models for analysis, but be sensitive and innovative in adapting these in different institutional and environmental contexts.
- It is important to consider the dynamics of the systems under study and to integrate measures of variability in impacts and causation over time and space into the assessment and decision making.
- Success is more likely when using resources that people already have, including local knowledge, existing institutions for resource management, experience and ideas.
- Efforts should concentrate on what is achievable, given available time and financial and human resources. Consideration of unrealistic options will waste time, energy and commitment.
- Success is more likely when efforts focus on areas that have broad support. Taking action on these areas first can lead to increased cooperation among groups and motivate them to reach further agreement. In other words, start with the easiest problems first, gain experience and build momentum for change.
- Accept that there are unlikely to be perfect solutions and don't let the pursuit of the best be an obstacle to achieving something merely good and workable.
- Decisions and recommendations must comply with national institutions and legislation.
- At the end of the process, all key stakeholders must perceive the process to have been fair and transparent, and the outcomes to be fair and legitimate.

2.7.4 Use of TOA/MCA in the assessment process

TOA techniques can be used at different points in the project cycle, from review of options and project identification, through project design, appraisal and selection. They can also be used as part of adaptive management to assess options for the operation of existing irrigation schemes, which may for example, include changes in the operation of reservoirs (water levels and release patterns), or decisions on whether to modify, expand or decommission certain facilities during the life of a project.

Importantly, participation and transparency goals can be facilitated and operationalized through multi-criteria processes. Rather than mechanistic decision-making tools, they should become negotiation grounds to decide which options are to receive prominence. They are also a basis to move towards societal consensus on exploring these options more fully.

The stages of the TOA process are implicit in all decision making, whether made explicit in practice or not. Thus transparency can be derived from making these stages explicit and public. For example, identification of criteria makes explicit what issues influenced a decision, whilst evaluation of alternatives against each criterion makes explicit how options are perceived to contribute towards priority objectives. Finally, the comparison and ranking of alternatives makes explicit the trade-offs that have been made. Once explicit, all stages can be subjected to public debate, and in effect the use of these techniques provides an "audit trail", documenting the process by which decisions have been made.

The TOA process may also contribute to consistency and coherence in decision making. Choice of criteria, evaluation of alternatives against criteria, and selection of weighting all require subjective value judgments. MCA techniques at least impose a discipline on this process, ensuring a degree of consistency and coherence in the internal logic of the choices and value judgments made.

Where conflict arises, it may also often result from a lack of communication and/or mutual understanding between different agencies and stakeholder groups. Conflicts arise from the use of different criteria, the making of different trade-offs between criteria, or simply a lack of trust and understanding. An open and explicit TOA process can help overcome this by clearly revealing the priorities and preferences of opposing groups. Even if this cannot resolve conflicts, it may assist in identifying options that rate best for those criteria over which there is the greatest conflict, minimizing that conflict as an obstacle to consensus and resolution.

Further reading: For TOA and MCA concepts, methods and examples see textbooks by Olson 1996 and Janssen 1994, and practical guides by Brown et al. 2001 and Nichols and Von Hippel 2000.

For consensus building and conflict resolution see Fisher and Ury 1982, Rijsberman 1999 and the website: www.resolv.org.

2.7.5 Evaluation of the decision-making process

The following questions are suggested for evaluating the process:

- Did stakeholders use the information collected throughout the impact assessment process to make decisions?
- Were all stages of the process providing good returns to the inputs of time and resources followed?
- Has a linkage between sectors been created particularly between farming and fishing?
- Has the process provided enough information to allow users to make informed choices?
- Were final recommendations technically feasible and implementable in the institutional and environmental context? Were they well adapted to local conditions?
- Are final recommendations stable? Are agreements legitimate, capable of adaptation, and likely to be sustained?
- Did the TOA approach followed provide workable mechanisms for resolving disputes and for arriving at decisions?
- Were empowerment of local stakeholders, and their “ownership” of recommendations maintained throughout the process?
- Were final outcomes satisfactory with regard to livelihood and biodiversity goals of fisheries management?

2.8 Monitoring and adaptive management

Successful mitigation or enhancement requires the capacity to transform experience into design modifications, and reforms in irrigation and fishery management and in institutions. Thus corrective action, or adaptive management, based on learning from experience, must be built into the project from the start, with the project organized around responsiveness and innovation.

Project management will still bear responsibility for the full development of specific tasks, but seek to develop capacity for each community or stakeholder group to mobilize their resources, exploit new opportunities created and evolve institutions as required. Each group or community should be able to access support to achieve greater self-reliance, and to access external resources or expertise through a process of dialogue and negotiation.

Such a process approach puts emphasis on effective monitoring and evaluation (box 2.3), with feedback mechanisms designed to allow experience to inform action. Identification of problems, or shortfalls in achievement compared to mutually agreed targets, should be viewed as an opportunity for joint diagnosis of causes and prescription of remedial action.

Box 2.3. Monitoring

Monitoring of fisheries outcomes of irrigation development and/or mitigation measures should encompass all the key attributes of the fisheries system:

1) Physical environment: habitat, flow and flooding patterns.
2) Biological resource status: level of exploitation, fisheries production (together with exploitations level, a simple indicator of resource status), species composition of catches as an indicator of biodiversity.
3) Livelihoods: assets and role of fisheries in livelihoods.
4) Institutional arrangements: rules pertaining to fishing and aquatic habitat management.

In general, monitoring a limited number of simple indicators will be sufficient. Where a participatory planning process has been initiated, it is best to determine indicators and sampling strategies within this process.

Because indicators may change for reasons unrelated to irrigation (e.g., general environmental or economic trends), it is important to monitor not only the target site, but a control site not subjected to irrigation development and to do so both before and after the development being assessed.

There should be as much flexibility as possible, so as to be able to adapt when things go wrong and capitalize on opportunities when they occur.

In many cases, the effectiveness of management measures is likely to be subject to considerable uncertainty. In the long term, this uncertainty may be reduced, and the effectiveness of management measures increased, if impacts are monitored and management measures adapted accordingly.

Adaptive management is a process of systematic "learning by doing". It involves three main aspects:

- Uncertainty is made explicit.
- Management measures are considered as experiments, designed to yield information as well as material benefits.
- Management measures and procedures are modified in the light of results from management experiments.

Adaptive management may be implemented within just a single site, but it is often advantageous to work across a number of similar sites in order to increase replication and possibly test a range of management options in parallel, thus achieving results more quickly than through sequential experimentation. An outline of design considerations for management experiments is given in box 2.4.

Box 2.4. Adaptive management

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

Costs of adequate monitoring can be considerable, and therefore experimental management should be considered only where the costs of the intervention or the anticipated benefits warrant this expenditure.

2.9 Strategic assessment

Strategic impact assessments synthesize results from individual project assessments as well as wider relevant knowledge. The knowledge base presented here is an example of a strategic assessment with a global perspective, which is necessarily rather broad and unspecific. Assessments carried out on a national or regional basis will provide more specific guidance on impacts and management measures, and are likely to improve the effectiveness of future project level assessments very substantially. An example of this is the strategic assessment of impacts of small and medium irrigation schemes in Laos by Nguyen Khoa et al. 2005. It is recommended, therefore, that wherever possible relevant organizations undertake such strategic assessments.

Chapter 3

Understanding fisheries systems

3.1 Fisheries systems: characteristics, components and interlinkages

3.1.1 Overview

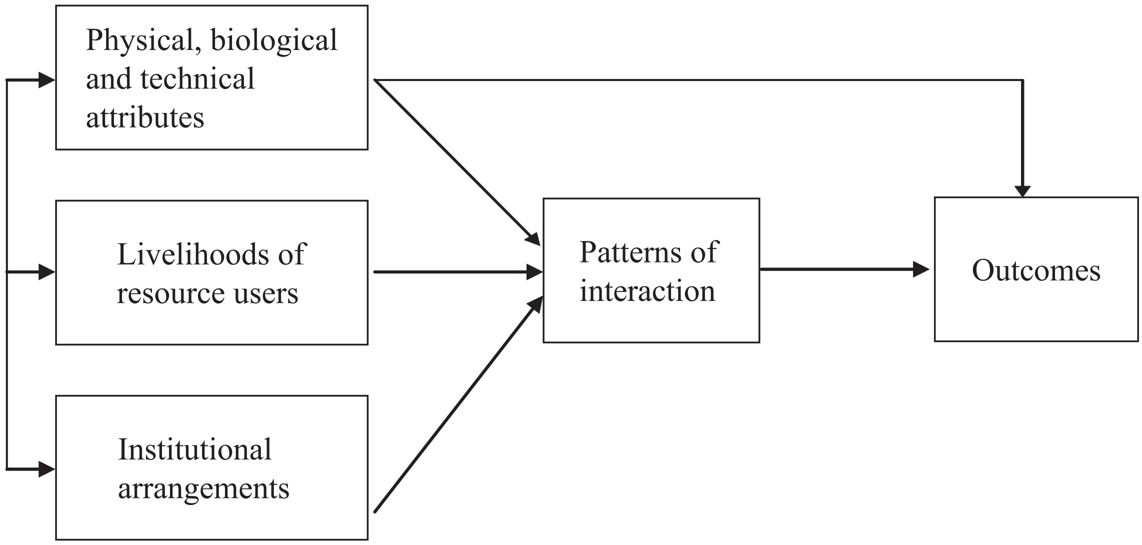
Fisheries are complex resource systems, and the benefits derived from them depend fundamentally on both their innate biological productivity and the level of exploitation. The sustainable use of fisheries, thus depends on the conservation of habitats as well as the regulation of exploitation. Both tasks are more difficult in fisheries than in many other resource systems, because of a number of features such as the difficulty of observing the resource and asserting its status, and the mobility of fish populations that often undertake substantial migrations depending upon a wide range of habitats.

A pervasive feature of fisheries is that in most cases the fish stocks and water, the defining element of their habitat, are common pool resources. Such resources are exploited jointly by many users, who by doing so subtract from the shared resource and therefore the benefits obtainable by others. Because each user obtains the full benefit from his or her resource use, while all share the costs, common pool resources tend to become overexploited and degraded unless appropriate rules for resource use are established and followed. Achieving both is a major challenge in resource management.

In the context of assessing and managing impacts of irrigation development on fisheries, this means that it is not appropriate to conduct an assessment that is too narrowly focused, for example, on the environmental requirements of certain fish species. Rather, it is necessary to understand what the current status of the fishery is in terms of a range of relevant criteria (such as yield, distributional equity, and biodiversity), and how these outcomes are determined. A useful framework for analyzing common pool resource systems such as fisheries is that of Institutional Analysis and Design (IAD), illustrated in figure 3.1. The basic idea of IAD is that most directly, outcomes are determined by physical and biological attributes of the resource as well as the overall level of resource use. The overall level of use in turn is determined by the aggregated actions of individuals, referred to as 'patterns of interaction' in the IAD framework because individuals make independent decisions in the light of 'situational variables' such as physical/biological attributes of the resource, their livelihood opportunities and constraints, and relevant rules and regulations (institutional arrangements).

Arrows in figure 3.1 represent relationships among the attributes. Some biological, physical and technical attributes of the resource affect the outcome of resource use independent of human action (For example, natural productivity or population dynamics). These attributes set the limits that determine what outcomes are achievable in any given system. However, the physical and technical attributes of the resource also affect outcomes indirectly by influencing human action. The nature of the resource, along with the rules in place to determine its use, provides the range of opportunities open to users of the resource. Individuals make decisions on the basis of these, and their resulting actions (patterns of interaction) directly affect outcomes.

Figure 3.1. Institutional analysis framework for analyzing fisheries.



The situational variables influencing the actions of individual resource users can be grouped in various ways. Here we structure them in three groups:

1) Physical, biological and technical attributes of the resource
    - The physical environment, covering catchment land use, aquatic habitats and hydrology, resource trends and natural shocks
    - The production ecology of living aquatic resources, including their responses to harvesting
    - Techniques used for harvesting aquatic resources
2) Livelihoods of resource users
    - Their livelihood assets (human, financial, social, physical and natural capital)
    - Their livelihood objectives and strategies
    - The economic environment at macro, meso and micro level and its trends and shocks
    - The state of market development for labor, for inputs and for fishery outputs, and their accessibility and functioning
3) Institutional attributes
    - The stakeholders involved in managing the resource
    - Transforming structures and processes including:
        - Legislative bodies, executive agencies and civil society organizations;
        - Operational rules for resource use (rules that determine by whom, where, when and how resources may be used);
        - Conditions of collective choice, which are the set of rules which determine how operational rules can be made; and
        - External arrangements pertaining to rules and conditions of collective choice.

Outcomes are physical (e.g. production or consumption) at the most basic level. Stakeholders attach values to physical outcomes according to their own objectives and situations, and thereby translate physical outcomes into benefits and costs.

Interactions between attributes of the resource system are classified into two types. Operational interactions determine outcomes during normal resource use, when physical, technical and biological attributes and decision-making arrangements are fixed. Operational interactions (indicated by arrows in figure 3.1) lead from the situational variables to outcomes, either directly or via patterns of interaction.

Dynamic interactions involve changes to the decision-making arrangements or the biological, physical and technical attributes of the resource, and typically occur over longer time spans. Such dynamic relationships are complex and interactions may originate from any attribute, including the outcomes, and lead to any other attribute. Irrigation development will often be associated with rapid, dynamic change in the fishery system. This is explored further in Chapter 4.

IAD provides a broad and flexible framework for the analysis of common pool resources including fisheries, irrigation systems, and of course fisheries within irrigation systems. It can be used in the relatively simple form shown here, or expanded to enormous complexity depending on the detail required to understand the present situation and the likely impacts of any interventions.

Further reading: The Institutional Analysis and Design (IAD) framework is well described in Oakerson 1992 and Ostrom 1990. For its application to the analysis of fisheries management systems see Pido et al. 1996.

3.2 Physical habitats and hydrology

3.2.1 The hydrological cycle

The starting point for the discussion of the physical and hydrological systems is the hydrological cycle. Water is evaporated from the oceans and falls as rainfall over land where it collects in streams and rivers and flows back to the ocean. An important feature of this process is that the salts leached from land are not evaporated from the sea; only freshwater, free of dissolved salts evaporates and falls again as rain.

The quantity of water falling as rain varies spatially and temporally depending on the seasons and the geographical location. There are marked changes in the quantity of water falling as rain during the year, as represented by rainfall hydrographs, and in its areal distribution, as represented by rainfall isohyets. The pattern of rainfall in a catchment fundamentally influences the local environment, leading to the classification of regions as arid, tropical, humid, etc.

Most rivers have a hydrograph that shows one or more pronounced flood events during a year's cycle. In the temperate zone, floods usually arise from snow melt during the spring and from rainfall during the autumn. In the tropics, floods originate from the monsoon rains during the equinoxes, which may give a two-floods-per-year pattern. More generally, however, one rainy season predominates and a uni-modal flood pattern is common.

Rainfall falling over a catchment gives rise to stream and river flow. The intensity and duration of the rainfall, allied with the land slope, soil and rock type, and vegetation cover have a marked impact on the quantity of rainfall that arises as runoff in the river. Erosion and deposition are a major part of the life cycle of a river basin, which are governed by the pattern of rainfall and river flow. Rainfall that does not contribute to runoff is either stored in the soil horizon or percolates through to contribute to groundwater. This groundwater may return to lower reaches of the river section several months later, forming the base flow for the river during the drier months.

3.2.2 The river-floodplain habitat continuum

A river basin can be characterized in a variety of ways. A useful broad categorization breaks the basin into three longitudinal sections (upper/headwater, middle and lower) and two lateral sections (floodplain, upland). In general terms, higher rainfalls occur at the higher altitudes in the upper catchment, giving rise to silt laden river flows. During flood periods, these waters and their silt load are dispersed laterally within the middle and lower catchment over the floodplain, carrying with them nutrients and organic matter. The annual cycle of flooding, and the silt, nutrients and organic load carried in the floodwaters form the floodplain ecosystems, including those for natural fisheries.

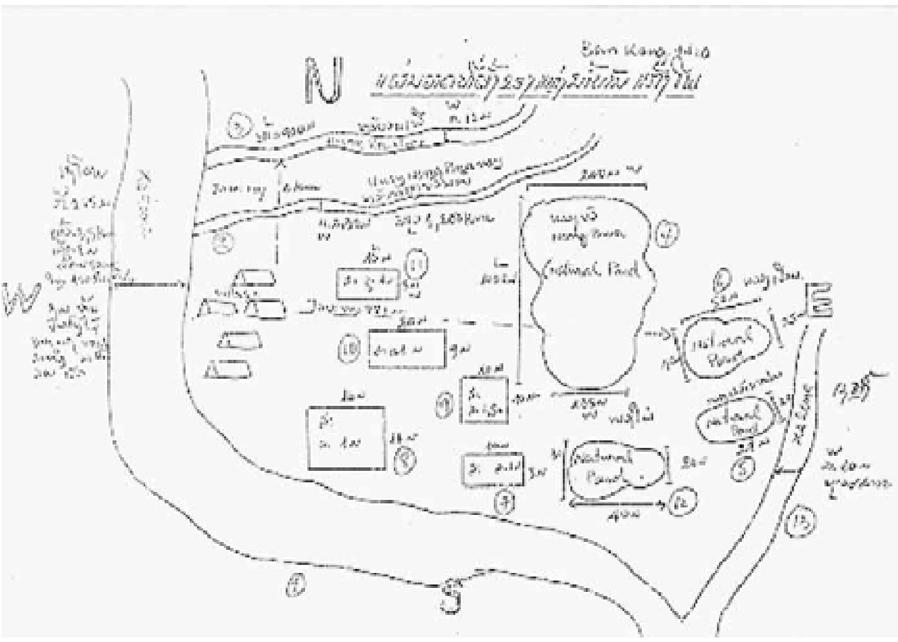
In relation to natural fisheries, a useful description of the relevant components of a river basin is provided by Cowx and Welcomme 1998:

> *"A fluvial hydrosystem comprises the whole river corridor – the river channel, riparian zone, floodplain and alluvial aquifer. It can be considered as a four-dimensional system being influenced not only by longitudinal processes, but also by lateral and vertical fluxes, and strong temporal changes. Fluvial hydrosystems provide corridors through the landscape, and the marginal zones (ecozones) provide buffers between the watercourse and the variety of land uses within the catchment"*

These relationships are represented in figure 3.2, and box 3.1 usefully describes the various physical components in relation to the habitats for fish.

In impact assessments, it is important to gain an overview of the position of the local area within the river basin or catchment (tool 2), as well as to characterize and quantify local aquatic habitats (tool 3).

Figure 3.2. Aquatic habitat map derived from a participatory mapping exercise.



Box 3.1. Habitats of the natural and man-made river and floodplain continuum

Zone	Habitat	
Aquatic		
I	Main channel:	Pools Riffles Point bars Islands Bank features
II	Estuaries and lagoons characterized by marine influence	
III	Continuously flowing side arms and anabranches	
IV	Side arms connected to river at downstream end only	
V	Seasonally flooded floodplain lakes	
VI	Floodplain lakes rarely influenced by floods	
VII	Man-made reservoirs	
VIII	Man-made canals	
IX	Backswamp areas maintained wet through groundwater seepage	
X	Areas of agricultural land/ marsh/ bottomland hardwood subject to seasonal inundation to an extent dependent on flood intensity	
XI	Rain fed wetlands above the flood level but connected to the river system (principally rice paddies)	
XII	Non-floodable land on floodplain or at floodplain margin. Usually plateau, terrace or levee which directly influence floodplain function	

Source: Adapted from Cowx and Welcome, 1998.

Tool 2. Characterizing the local area within the river basin

Using a topographic map:

- Identify the outline of the catchment.
- Determine total catchment area and catchment area above the local area of interest.
- Determine river/stream length above the area of interest.
- Delineate land use zones in the catchment (forested, agricultural, urban, industrial) and determine the approximate areas and the slope of the different zones.
- Note any obvious modifications to the natural river course, such as reservoirs, embankments, weirs, etc.

The above information may be used later as input for simple rainfall-runoff models, or for yield predictive models.

Tool 3. Identifying, characterizing and mapping aquatic habitats

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

1) Groups of aquatic resource users (include all users: men, women and children). Ask them to map aquatic habitats (e.g. figure 2.4), characterize them and possibly rank their importance for different aquatic resource uses (reflecting both habitat quality, and ease of access and capture for users).
2) Visits to selected habitats should be undertaken to cross-check information and carry out measurements.

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

A) Physical characteristics of habitats
   - Lake/wetland/floodplain water area (wet and dry season)
   - Channel width (rivers/streams, wet and dry season)
   - Channel slope
   - Sinuosity ("wrigglyness", measured as channel distance divided by downvalley distance)
   - Water depth (wet and dry season)
   - Flow velocity (wet and dry season)
   - Macrophyte cover

B) Hydrological processes maintaining habitats (cf. tool 4)

C) Connectivity between habitats
   - Natural and man-made constraints to connectivity

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

Key references: Bain and Stevenson 1999; Gordon, McMahon et al. 1994.

3.2.3 Hydrological processes maintaining habitats

Hydrological processes maintain water levels and flows in aquatic habitats, and also play a key role in creating and maintaining the geomorphological characteristics of habitats. Understanding local hydrology is therefore crucial to predicting the effects of interventions such as irrigation development on aquatic habitats.

Water levels and flows

River flows are largely determined by surface flow and groundwater outflow. Empirically based equations such as the rational equation can be used to predict annual flow from catchment area, slope and land characteristics, and annual rainfall.

The hydrology of standing water bodies may be more difficult to ascertain because a wider range of processes can be quantitatively important. The balance of the following processes determines the water volume in a standing body of water:

Water balance = precipitation + surface inflow + groundwater inflow - evapotranspiration – surface outflow – groundwater outflow

Surface inflow from the catchment basin is the dominant water source in river-floodplain environments. Floodplain lakes are often replenished by flooding, and their water levels may fall substantially when no flooding occurs over a prolonged time.

Detailed evaluations of water balance are complex and time consuming. Where water resources development is likely to lead to significant hydrological change, specialist hydrological surveys and modeling should be carried out to establish the water balance of aquatic habitats and predict likely impacts of development. Where no such studies are available, it is important to establish at least a crude understanding of the water balance of major aquatic habitats in order to understand their vulnerability to changes in surface flow and groundwater level (tool 4).

Tool 4. Simple ways to assess the importance of different water sources for wetlands

1) Establish surface inflows via streams/rivers. Where surface inflows are visible or known to occur regularly (e.g. seasonal streams, flooding from river), this is likely to contribute significantly to the water balance. In case of seasonal inflows, soil erosion from flowing water, watermarks on woody vegetation, and debris and sediment deposition are good indicators when surveying such habitats during the dry season.
2) Establish the catchment area of the wetland. Wetlands with a significant catchment area are likely to receive significant surface inflow. Conversely, in the absence of a significant area draining into the wetland, direct precipitation or groundwater must be dominant. Empirical equations such as the rational equation can be used to predict surface inflow from catchment area, slope and land characteristics, and rainfall data.
3) Establish the groundwater table. Usually this will be known or can be measured in wells. Alternatively, it may be necessary to dig a hole, at some distance from local wetlands, and wait for groundwater to seep in. If the groundwater table is substantially lower than the water level in wetlands, then groundwater does not contribute positively to the water balance.

Hydrology and geomorphology

Hydrological processes play an important role in shaping the geomorphology of aquatic habitats through erosion and deposition. For example, erosion of fine sediments in headwaters and their deposition in lower reaches maintain the characteristic substrates of both environments.

The particular characteristics of a given river basin are formed through the interaction of rainfall and subsequent water flow with the rock and soils of the catchment. The formation of the river basin is a function of the hydrological, geological and morphological processes which form and influence the riparian and floodplain vegetation and physical form.

Soil erosion is a natural, major part of the process in the formation of particular characteristics of a river basin. Development activities can significantly affect the natural soil erosion and deposition processes. Dams and reservoirs stop and hold eroded soil, flood embankments prevent the transport and deposition of sediment onto the floodplain. On the other hand deforestation and cultivation within the headwaters of the river basin give rise to high levels of soil erosion and sedimentation in rivers.

Further reading: General overviews of river basins and their management include Petts 1986 and Newson 1991. Gordon et al. 1994 provide a very useful introduction to stream hydrology and many related topics, while Bain and Stevenson 1999 provide a comprehensive manual for fish habitat assessment.

3.3 Ecology of fisheries production

3.3.1 The basis of production

Fisheries exploit living aquatic resources including fish, crustaceans, mollusks, plants and occasionally insects. The resources harvested by fisheries are the result of biological production: the primary production of organic matter by plants and its transformation into animal tissue through secondary production. Typically, aquatic foodwebs have three main trophic levels: primary producers (plants), secondary producers (herbivores and detritivores), and tertiary producers (predators). Although fisheries exploitation is usually focused on the higher levels, the overall level of production and therefore the potential harvest from fisheries are strongly influenced by the amount of primary organic matter available at the base of the foodweb.

Fish production in standing bodies of water such as lakes and ponds is based mostly on primary production by phytoplankton, benthic algae and higher aquatic plants within the lake. Fish production in streams, rivers and their associated floodplains may be based at least in part on organic matter produced in terrestrial systems, but the precise contribution of such external inputs is controversial.

Primary production in lakes is strongly influenced by the concentrations of inorganic nutrients available. This in turn depends on three factors:

1) Inputs of nutrients from terrestrial environments through runoff and seepage.
2) Loss from sedimentation and outflow.
3) Recycling of nutrients within the lake.

Geology and land use of the catchment have a major impact on the inputs of nutrients. Upland areas tend to be naturally poorer in nutrients than lowland areas. Agricultural land use tends to result in large inputs of nutrients from intentional fertilizer use and the erosion of rich soils, while pristine forests tend to release little nutrients to aquatic systems. The relative importance of inputs and outputs compared to recycling within lakes is determined by the residence time of water. Large natural lakes may have residence times of decades or longer so that production is reliant almost entirely on recycling, while small reservoirs often have residence time of less than one year so that production is driven by inputs. Within the lake, nutrient recycling involves physical transport of nutrients from the bottom to the surface because the bulk of organic matter will settle eventually. The efficiency of this transport decreases with increasing depth and consequently so does the degree to which nutrients are recycled. Consequently, biological production tends to be inversely related to depth among lakes with long residence time. These ecological considerations point to three key factors influencing the productivity of lakes:

1) nutrient inputs,
2) residence time of water, and
3) depth.

Inputs of nutrients and organic matter into rivers and river-floodplain systems are determined largely by catchment land use and the extent of flooding. There are two main mechanisms of nutrient and organic matter input: through runoff from the catchment, and through flooding of floodplains. In both cases, there is an ongoing debate over the relative importance of organic inputs from the terrestrial environment versus those produced within the aquatic system. In either case, however, key inputs (be they inorganic nutrients or organic matter) are derived from the terrestrial environment. Hence the main factors influencing the productivity of river-floodplain systems are the catchment area, land use and the extent of flooding. In rivers without significant floodplains, the nutrients and energy required for fisheries production are derived from the drainage basin above the point where production occurs (cf. box 3.2: the river continuum concept), hence drainage basin area or discharge are good predictors of fish production. Conversely, in rivers with substantial floodplains, much of the nutrients and energy required for fisheries production are derived from the floodplain (cf. box 3.2: the flood pulse concept), and flooded area is a good predictor of fish production.

Box 3.2. Basis of fisheries production in river systems

There are three controversial theories about the main sources of biological production in river systems:

- The River Continuum Concept stresses the importance of terrestrial organic matter inputs in the upper reaches of streams for downstream productivity, and assumes that primary production in the river makes only a small contribution.
- The Flood Pulse Concept emphasizes the importance of terrestrial organic matter inputs via floodplains in floodplain rivers.
- The Riverine Productivity Model holds that aquatic primary production forms the main basis of fish production. While terrestrial organic matter inputs far outweigh aquatic production in most systems, such inputs are largely refractory, i.e. are not assimilated by aquatic organisms.

There is ongoing debate on the dominant contribution to riverine fish production and this has implications for the precise nature of aquatic-terrestrial linkages. However, in either case, inputs of organic or inorganic matter from terrestrial environments are crucial to productivity and therefore, management implications are not fundamentally different. The flood pulse is clearly a major factor in the dynamics of most larger tropical rivers.

The close link between terrestrial and aquatic systems presupposes that catchment land use has a strong effect on aquatic resources and in fisheries, land use influences:

- The amount of runoff and groundwater reaching surface water bodies, and therefore their water level and area;
- The concentrations of inorganic and organic matter entering water bodies, and therefore their trophic status;
- The amount of sediment deposited in water bodies, and therefore their benthic habitat and morphology;
- The concentrations of chemical pollutants such as pesticides reaching water bodies; and
- The physical structure, vegetation and fauna of periodically flooded habitats.

These influences are strong and easily measurable in comparative studies between watersheds with different land use characteristics. For example, De Silva et al. 2001 show a strong correlation of small water body fish yields in Sri Lanka with catchment land use.

Agricultural expansion and intensification tends to increase runoff, and nutrient and sediment inputs increase the risk of chemical pollution, and reduce the quality of periodically flooded habitats for fish. The net effect on fisheries production will depend on the balance of these factors and the degree to which fish production is based on the quality of flooded habitats. Often, the overall production effect will be positive. However, the species assemblages are likely to change particularly in watersheds with previously very nutrient poor waters.

3.3.2 Population ecology of aquatic organisms

While overall production is of major interest, where inland fisheries are exploited for food, it is rarely the only consideration. Species differ in their value as food and marketable commodities, and natural resource management tends to be concerned with conserving biological diversity as much as with achieving production targets. It is therefore important to understand the processes that determine the abundance of populations.

Life cycles and habitat requirements

Most exploited aquatic organisms (fish, crustaceans and mollusks) have complex life cycles. Complex life cycles involve several morphologically distinct, free living stages such as eggs, larvae, juveniles and adults. In the course of their lives, many organisms will grow by several orders of magnitude in weight, and their resource and other ecological requirements change drastically. To meet the different requirements of different stages, most aquatic organisms use a variety of habitats in the course of their life cycle. Adults release eggs into a spawning habitat. Larvae will begin feeding either in the same habitat, or in a separate larval habitat to which they are transported passively by water flow. Juvenile and adult feeding/growth habitats again tend to be separate, and migration between them and the spawning habitat is usually active. Hence in order to be able to complete their life cycles, most aquatic organisms require access to a variety of habitats. This requirement has two implications:

1) a variety of habitats must exist, and
2) organisms must be able to migrate between them (actively or passively).

The latter aspect is referred to as the connectivity of aquatic habitats. An overview of the main habitat types of importance to inland aquatic resources is given in box 3.1.

Specific habitat requirements of aquatic organisms may be characterized by a range of measurable factors, including water depth, flow velocity, temperature, substrate, and availability of food organisms. For many temperate fish species, habitat preferences of different life stages have been established experimentally and expressed in the form of preference curves (box 3.3).

Habitat requirements and even life cycles are not necessarily set in stone. Some species display considerable plasticity in their life cycle and can cope well or even benefit from changes in habitat availability, while others show very little plasticity.

Box 3.3. Establishing and describing habitat preferences

The basic approach to establishing habitat preferences is to observe the distribution of the species of interest among habitats of different characteristics. As different life stages tend to have different preferences, this should be done separately for different life stages.

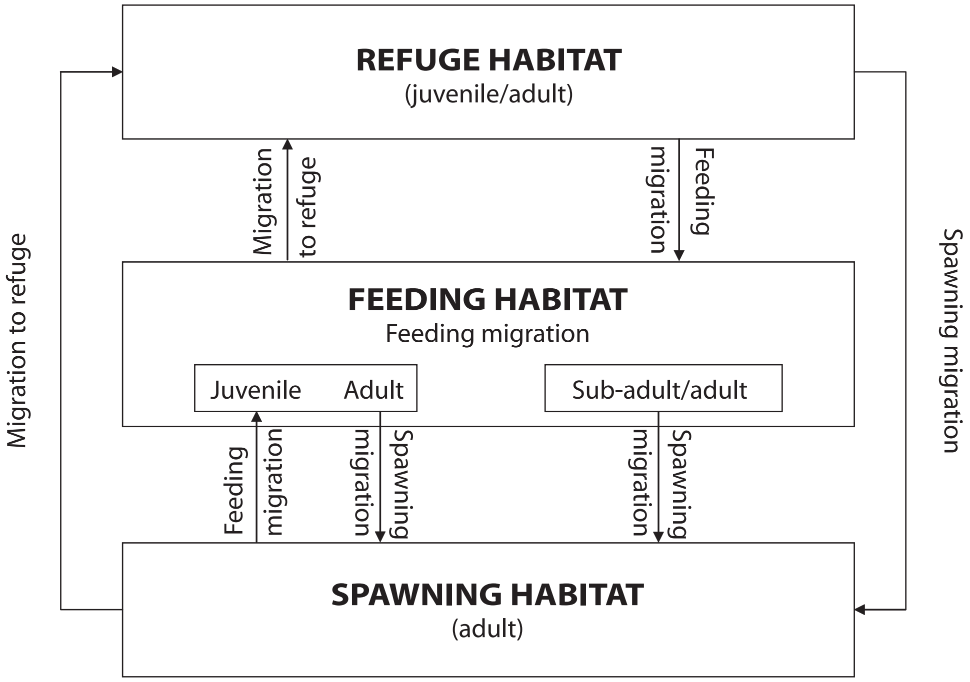
Quantitative habitat suitability indices (HSIs) have been derived for many North American and European freshwater species. No information of comparable detail and quantitative precision exists for tropical species.

If no reliable published data on habitat preferences are available for key species of interest, their preferences should be described in broad terms, such as preference for flowing/standing water, association with aquatic plants etc. Where fishing plays a substantial role in livelihoods, experienced fishers tend to have a quite detailed knowledge of the species and life stages found in particular habitats. Eliciting information on fish distribution through group or individual interviews and correlating this with habitat characteristics is likely to be the quickest way of establishing preferences.

Migrations

A schematic representation of movements between refuge, feeding and spawning habitats is shown in figure 3.3.

Figure 3.3. Fish movements between functional habitat types.



Source: Northcote 1978.

Movements are regarded as migrations if they occur with a regular periodicity and involve distinct habitats. Migrations of organisms that spend at least part of their life cycle in fresh waters are classified as:

- **Potadromous** if the migrations occur entirely in fresh waters, and
- **Diadromous** if migrations occur between fresh water and the sea.

Some migrations occur only once in the lifetime of an organism (e.g. ocean migration of some salmon species), while others occur more frequently, for example, seasonally. Migrations typically occur longitudinally (up and down a river) as well as laterally (from the main channel into the floodplain, swamps etc.). Tropical river-floodplain fish species are often categorized on the basis of their migrations and related biological parameters as:

- **Blackfish:** species resident in floodplain water bodies all year round, and undergoing only short migrations on to the floodplain during flooding tolerant to low oxygen conditions, and reproduction occurring over extended periods of time;
- **Whitefish:** species undergoing long-distance longitudinal migrations in the main river channel, with some also moving into the floodplains at high water. Generally intolerant to low oxygen conditions, reproduction limited to short events usually in the upper watershed; and
- **Greyfish:** species with intermediate migration and life history patterns.

The proportion of potadromous or diadromous species varies between biogeographical areas. In most areas (northern temperate as well as tropical Africa, Latin America and much of Asia), some 20-30 percent of freshwater fish undergo substantial migrations. However, over 90 percent of Australasian (Australia, New Zealand, Papua New Guinea) freshwater fish are migratory. Some migratory species are unable to complete their life cycles if they are prevented from migrating, while others are able to adapt their life cycles. Many migratory species are relatively large as adults, but there are exceptions, that is, large fish that are fairly stationary and small fish that migrate widely.

In river floodplain systems, fish migrations tend to be closely linked to the seasonal flood cycle. Fish migrate upwards before or during the period of rising water to spawn in the headwaters (whitefish), or to spawn and feed on the floodplain (blackfish). This is followed by a period of down-migration as the waters recede. Seasonal migrations are triggered by meteorological and/or hydrological conditions such as rainfall and/or level of discharge. It is not well understood which of these factors act as key triggers as all occur around the same time in natural river-floodplain systems.

Freshwater invertebrates such as crustaceans and mollusks often undergo local movements or may be transported passively over longer distances, but they rarely rely on migration to complete their life cycles. Hence, the issues of habitat connectivity are likely to affect fish populations more than invertebrates.

Regulation of abundance and compensatory effects

The abundance of aquatic animal populations is regulated, that is, its level matched to the carrying capacity of the environment, by a variety of mechanisms including density-dependent mortality, growth and reproduction. The existence of such mechanisms is crucial to the exploitation of aquatic resources and their responses to environmental modifications. The sustainable exploitation of populations is possible precisely because populations compensate for the removal of animals by density-dependent improvements in natural mortality, growth and reproductive rates. Likewise, populations can compensate for loss of animals due to pollution and other environmental catastrophes. In both cases, of course, compensation may not be complete.

The occurrence of compensatory processes also implies that a reduction in the availability of habitat will also reduce population abundance in line with the ecological carrying capacity of the remaining habitat. Again, this has important management implications. For example, where water is removed from aquatic systems for irrigation, efforts to prevent fish from entering outlets or pumps may have little benefit because the water abstraction will reduce available habitat and thus, ecological carrying capacity. On the other hand, where water is abstracted and returned to aquatic systems (e.g. after hydropower or domestic use), preventing fish from entering intakes is important because habitats are only marginally reduced but mortalities could be high.

3.3.3 Ecosystem effects on production

At the species assemblage or ecosystem level, inter-species interactions provide further compensatory mechanisms. If the abundance of one species is depressed by high levels of fishing, or loss of access to a crucial habitat, the abundance of its prey and/or its competitors may increase and maintain or even enhance the combined biomass of aquatic animals.

The result of such interactions is that the overall fisheries yield obtainable from aquatic systems tends to be far more resilient to external pressures than the species makeup of assemblages. The precise nature and extent of compensatory mechanisms is a subject of great controversy and major area of ongoing research. For the purpose of impact assessment and management, it is important to consider the existence of compensatory mechanisms at least qualitatively. As a rule of thumb, compensation means that any changes in aquatic resource abundance and fisheries yield will be smaller than predicted if compensation is not accounted for. However, compensation is unlikely to be complete and it usually involves changes in species and size composition which may be ecologically and economically undesirable.

Further reading: Welcomme 1985; Welcomme 2001; Hoggarth et al. 1999; and Arthington et al. 2004 provide good overviews of tropical fisheries ecology. Bovee 1982 describes widely used approaches for habitat preference assessment, while Lucas and Baras 2001 summarize current knowledge on freshwater fish migrations.

3.4 The exploitation of fisheries

3.4.1 Which resources are exploited?

It is important to gain an overview of the aquatic resources exploited (tool 5). The living aquatic resources exploited differ widely between locations. In some areas, such as the Mekong region, virtually all macroscopic aquatic organisms are exploited; while in others such as inland Sri Lanka, a very limited number of fish species may be the focus of exploitation. Different resources may be exploited by different households, and different people within households; moreover some may be consumed by those who catch them while others may be sold to traders and appear in markets far from the place of capture.

Tool 5. Identifying exploited living aquatic resources

Identification of exploited living aquatic resources should be based on a combination of household interviews, market surveys and direct observation to ensure the full range of aquatic resources used is established. Not all aquatic resource use may be regarded as “fishing”, hence asking about fishers or fishing activities may not uncover the full extent of aquatic resource use. The seasonal dimension is also important and care must be taken to ask about aquatic resource use at different times of the year.

3.4.2 Fishing methods

Fishing may be carried out by a wide variety of methods. Where inland fisheries are traditionally important in rural livelihoods, it is not unusual for a single household to use some 20 or 30 different methods to catch fish, depending on the season, species targeted, and characteristics of the fisher such as gender or age. Fishing gear may be categorized as follows (Hoggarth, Cowan et al. 1999):

- **Set and wait:** set and hauled after a few hours, e.g. gill nets, portable traps, hook and line.
- **Chasing:** active pursuit of fishes, e.g. drag net (trawl), push net, seine nets, spears.
- **Barriers:** more permanent and usually larger gear than set and wait gear, e.g. bamboo barricades, large stationary traps, etc.
- **Hoovering:** used to catch all fish from confined areas of water, e.g. dewatering, poisoning
- **Aggregating:** devices used to aggregate fish for easier capture by a variety of gears.

Commonly used gear types are described briefly in table 3.1, and some are illustrated in figure 3.4.

Figure 3.4. Examples of fishing gear used in inland waters – scoop net used by young boy (Laos), barrier trap in ricefield (Laos).

Table 3.1. Fishing gear.

Name	Description	Category
Barrier	Semi-permanent, often large structures blocking the migration paths of fish. Maybe combined with the use of active gear to catch fish aggregating at the barrier.	Barrier
Brush park	Though not a fishing gear in its own right, branches placed in the water are widely used to aggregate fish, which may be harvested by enclosing the brush park with a seine net and taking the branches out.	Aggregating
Cast net	A net with heavy chains along the edge, thrown and retrieved on foot or from a boat.	Chasing
Drag net	Funnel-shaped net usually pulled by two or more fishers	Chasing
Electrofishing	Use of electrical field to guide fish into nets and/or stun them. Illegal or restricted in many countries for purposes other than research.	Chasing / aggregating
Gill net	A vertical, stationary or drifting net, often used over night. Designed to entangle fish by their gill covers. Nylon and PVC nets are cheap and widely available, and are probably the most widely used inland fishing gear.	Set and wait
Hook	Baited hooks, used either semi-actively with a fishing rod, or passively, often in large numbers.	Set and wait
Light	Though not a fishing gear in its own right, a light may be used to attract and aggregate fish for capture by other gear.	Aggregating
Lift net	Horizontal net lifted from the water at intervals. Common as small hand-held implements, but also very large gear operated mechanically from floats or shore.	Set and wait/ chasing
Poison	Use of poison such as derris powder (rotenone) to kill fish. Illegal or restricted in many countries for purposes other than research.	Hoovering
Pumping out	Building embankments and pumping out the enclosed water.	Hoovering
Push net	Similar to drag net, but held open by wooden bars and pushed, often by a single fisher.	Chasing
Seine net	Usually a tough and heavy net used to encircle fish in midwater (purse seine) or near the shore (beach seine). But gill nets may also be used in this way.	Chasing
Spear	Used on foot or from boats, often at night in conjunction with light.	Chasing
Trap	A very wide range of devices used to trap fish, often on migration pathways.	Set and wait

Many inland fishing methods are closely linked to hydrological conditions. River-floodplain fisheries in particular are exploited by a wide range of gear in a manner closely linked to the flood cycle and to fish migrations (figure 3.8). Often, the highest yields are obtained during periods of rapid water level change at the beginning and the end of the flood season. The flood phase itself is crucial to aquatic resource production, but it also makes fishing comparatively difficult because of water levels and velocities, and the fact that fish are widely dispersed.

Reservoir and lake fisheries may also be exploited by a wide variety of gear, although gill nets often predominate. Reservoir and lake fisheries also tend to be less seasonal than floodplain fisheries. However, they may also exploit fish migrations and spawning aggregations and may therefore be seasonal, but this does not involve the same change in exploitation strategies as in river fisheries.

Tool 6. Identifying fishing gear types and their relation to hydrology

The identification of fishing gear types follows on naturally from the identification of exploited resources and from habitat mapping (both offer the opportunity to follow on with gear type questions). Once an overview has been obtained, it is important to assess as to what extent gear use is dependent on hydrological and other environmental conditions. This information will be used in the impact assessment to identify fishing practices that are particularly sensitive to irrigation development.

3.4.3 Fishing effort and catch

Fishing effort is a quantitative measure of the level of exploitation of an aquatic resource. It is a key determinant of yield, and measuring effort is therefore crucial to understanding yield (tool 7). Effort may be measured in various ways, for example as the number of fishers operating on an area of open water, the number of nets used, or the time spent fishing.

For the purpose of biological assessment, fishing effort must be expressed in a way so that it relates to the effect that fishing has on the stock. For example, consider one fisher setting a gill net for one day, and another, fishing throughout the day with a cast net in the same body of water. If both catch the same amount of fish, the biological fishing effort exerted by the different types of gear is the same because both have removed the same proportion of the available standing stock. In economic terms, however, the effort put into harvesting may be very different: the gill net fisher

Tool 7. Measuring fishing effort

Fishing effort should be measured in a consistent way so that comparisons may be made between the results for different areas in the region of interest, before and after any intervention, or between the result for the project area and data for other regions.

In complex, multi-gear, artisanal fisheries, it may be impractical to measure effort by gear type, and the easiest, and possibly the only practical way, of measuring effort is in terms of time spent fishing. This may be expressed as hours per ha, or fishermen days per square kilometer. There is a great deal of comparative information on fishing effort in terms of the latter (e.g. Bayley 1988; Lorenzen et al. 2006).

Where a fishery is exploited by a range of gear with very different levels of capital investment (e.g. purse seine boats and cast nets used from the shore), time spent in fishing may be an inappropriate measure of effort. In this case, different measures of effort may be used for different gear types, and total effort may be calculated as the sum of standardized effort measures. Effort is standardized by comparing levels of catch per unit of effort for different means of exploiting the same fish stock (i.e. in the same lake).

For example, if a cast net fisherman catches 3 kg of fish per day, and a purse seine boat catches 18 kg of fish per day from the same stock, then one day of purse seine boat effort is equivalent to six days of fishing with a cast net.

If the lake has been fished by 20 boat days and 100 cast net days, then the total effective effort is 220 cast net days (20 boat-days times 6 cast net days per boat day, plus 100 cast net days).

Fishing effort can only be measured by interviewing or observing those who carry out the fishing activity. In general, it is best to quantify the number of people involved in fishing, sample some of these for details of fishing activities, and scale up effort to the total.

has used only the time to set and retrieve the net, while the cast net fisher has fished actively all day. In this section we are concerned only with biological fishing effort.

Catch is the second important variable to characterize the exploitation of fisheries (tool 8).

Tool 8. Measuring catch

Catch, the amount of aquatic organisms harvested, is often easier to estimate than effort. Where professional fishers dominate fishing and much of the catch is marketed locally, market surveys will provide quick and fairly reliable quantitative estimates of catch, which may be corrected for a small amount of consumption by fishing households. However, where much of the catch is consumed within the fishing household, or exchanged outside a formal market, measuring catch is more difficult. Household surveys are then the only reliable source of information. Where fish are not sold, fishers' information on the weight of catches may be very unreliable, and it may be necessary to provide scales to a sample of households (fish are unlikely to be kept until the interviewer returns), or use ways of aiding recall. Examples of the latter include different sized bowls to assess the quantity of small aquatic animals, or sticks of different size to assess the size of major fish caught.

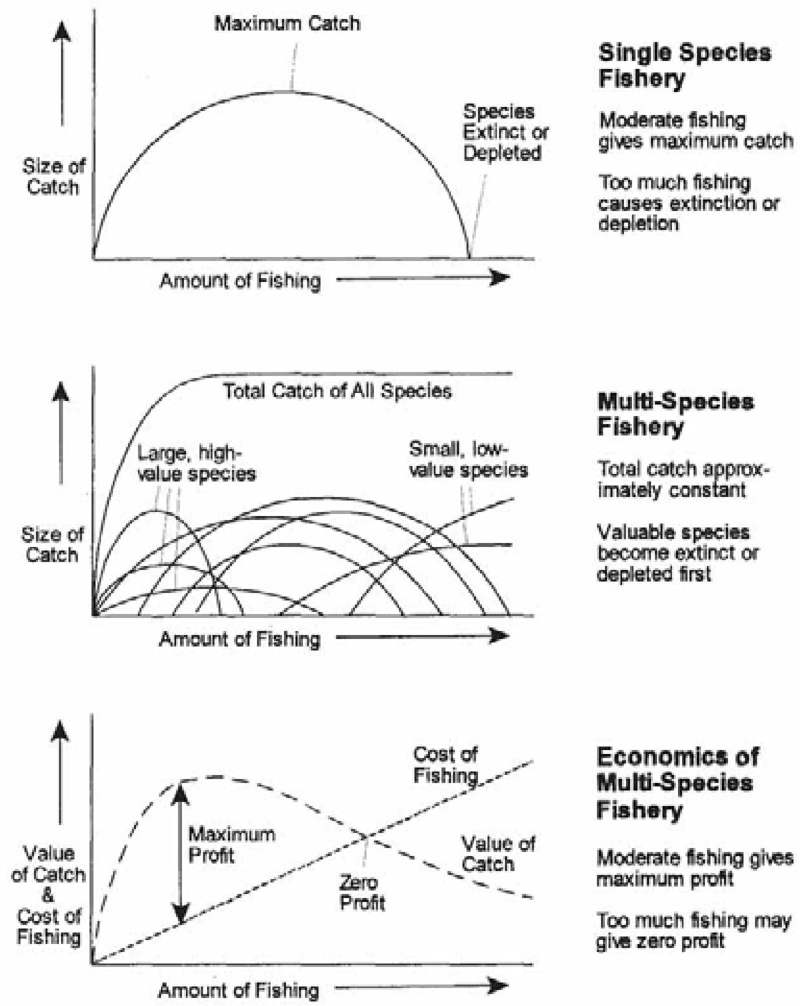
3.4.4 Catch and yield in relation to fishing effort

The catch of fisheries is the amount of fish caught during a particular time from a particular system or by a particular boat or gear. Yield is a derived quantity that may be understood as the long-term average catch given a stock and level of exploitation.

The yield of fisheries is determined by two main factors: the biological production of fish stocks, and the level of exploitation. In a single species fish stock, fish abundance is approximately inversely related to the level of fishing effort the stock is subjected to. As abundance of the stock is decreased from the unexploited state, compensatory processes increase biomass production (as more resources become available for the less abundant stock). Hence total production from the stock increases initially with the level of fishing, but there are limits to the compensatory processes and eventually production will reach a peak and decline if effort is increased further. The result is the relationship between aggregated multi-species yield and effort as depicted in figures 3.5 and 3.6.

Many fisheries, particularly in the tropics, exploit a wide range of species. In such multi-species fisheries, the relationship between total effort and total yield (obtained from a range of different species) tends to be asymptotic, that is, yield increases initially with effort but approaches a constant maximum over a wide range of higher effort levels. This is because, as exploitation increases, large and slow growing species are depleted and replaced by smaller, fast growing species that can produce high yields even at very high levels of exploitation. Even though multi-species yields can be maintained even at very high levels of fishing effort, it is neither economically nor ecologically desirable to operate at very high effort. Economically, the returns to individual fishers tend to diminish with increasing effort (albeit not linearly), and at the level of the overall fishery, unnecessarily high levels of resources are expended to achieve the fish catch. Moreover, the small fast growing species that dominate catches at high effort levels are usually less valuable than the large species they have replaced. Ecologically the overexploitation of larger species is obviously undesirable because it may threaten the very existence of some of these species. Of course, even multi-species yield must decline at very high levels of fishing effort (when even the most productive species are overexploited), but this point does not appear to have been reached in many fisheries.

Figure 3.5. Relationships between fishing effort and catch in single species and multi-species fisheries



Source: Hoggarth et al. 1999.

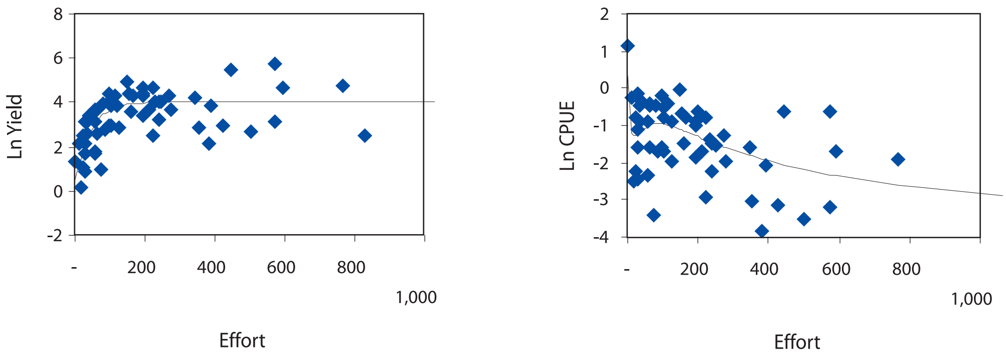
The relationship between fishing effort and catch as well as catch per unit of effort for river-floodplain fisheries in southern Laos is shown in figure 3.6. Catch per unit of effort (CPUE) is an important measure of the return to fishing effort. CPUE is also approximately proportional to stock abundance, and is often used as a proxy for abundance in stock assessments.

The strong dependence of yield on fishing effort has three important consequences for the use and interpretation of fishing yield figures in environmental planning:

1) Catch or yield data must not be interpreted without reference to fishing effort (see tool 9 for approaches to assessing exploitation status of fisheries). If declining catches are reported, the cause might be environmental degradation or overfishing, but it might equally well be a reduction in effort. The environmental management implications of the latter would be very different from those of the former!

2) The impact of habitat modification on the total catch from a fishery is dependent on the exploitation level of that fishery. A village population obtaining one ton of fish from a lightly exploited wetland may be able to maintain this catch even if the wetland area is reduced (albeit at a higher level of effort). If, however, the wetland is already fully exploited a reduction in the area will inevitably cause a reduction in the total village catch.

Figure 3.6. Relationships of yield (a) and catch per unit of effort (b) to fishing effort.



Source: Data from Lorenzen et al. 2006.

3) The potential yield of a water body category (e.g. a swamp) is usually greater than the average of the yields measured in a set of swamps. This is because many water bodies in the set will be less than fully exploited. Where available, the asymptotic yield level gives a better indication of the production potential of an aquatic system.

3.4.5 Linkages between hydrology and fisheries production

The flood cycle in river floodplain systems has a major influence on both fish production ecology and the exploitation of fisheries (figure 3.8). Fish migrate upwards before or during the period of rising water to spawn in the headwaters (whitefish), or to spawn and feed on the floodplain (blackfish). This is followed by a period of down-migration as the waters recede. Meteorological and/or hydrological conditions such as rainfall and/or level of discharge trigger seasonal migration. It is not well understood which of these factors act as key triggers, as all occur around the same time in natural river-floodplain systems. In modified systems, this link may be weakened, for example, dam releases during the dry season may induce floods and the implications of this for migrations are not well understood. Both the gear used in fisheries exploitation and the total fishing effort vary widely with the flood cycle.

Tool 9. Assessing the exploitation status of a fishery

There are several ways of assessing how heavily a fishery is exploited, but only empirical comparative models are likely to be practical in most cases.

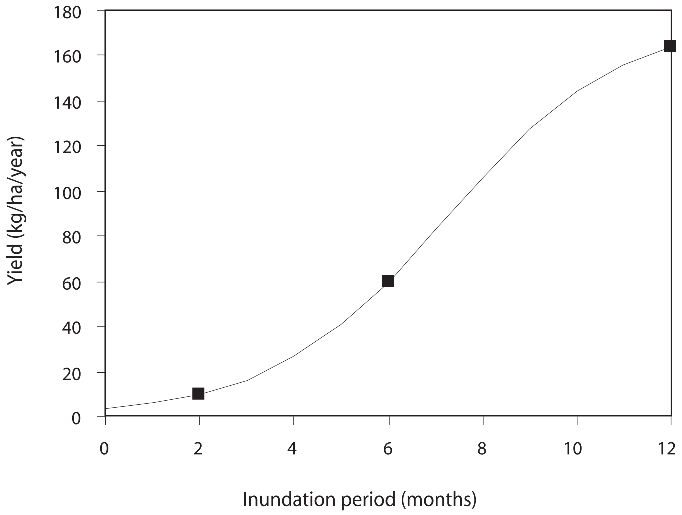
Empirical comparative models: In situations where little data are available, the only way of getting at least a rough estimate of exploitation status is to compare the catch and effort data obtained for the study site, with empirical relationships obtained by studying a wide range of similar systems, such as those shown in figure 3.6. Where possible, relationships derived for similar systems in the same area should be used. However, some fairly robust relationships have been derived for tropical river-floodplains, lakes, reservoirs and lagoons in general and these may be used if more specific models are lacking.

Biomass dynamic models: These are models that describe stock dynamics and catch of particular fisheries, applicable only where a sufficiently long time series of catch and effort data are available.

Dynamic pool models: These are models that account explicitly for population dynamic processes such as growth and mortality. Data requirements are very high.

Further reading: Welcomme 2001.

Figure 3.7. Schematic relationship between the inundation period and fish yield in the floodplains of Bangladesh.



Source: From De Graaf et al. 2001.

Flood duration and fisheries production

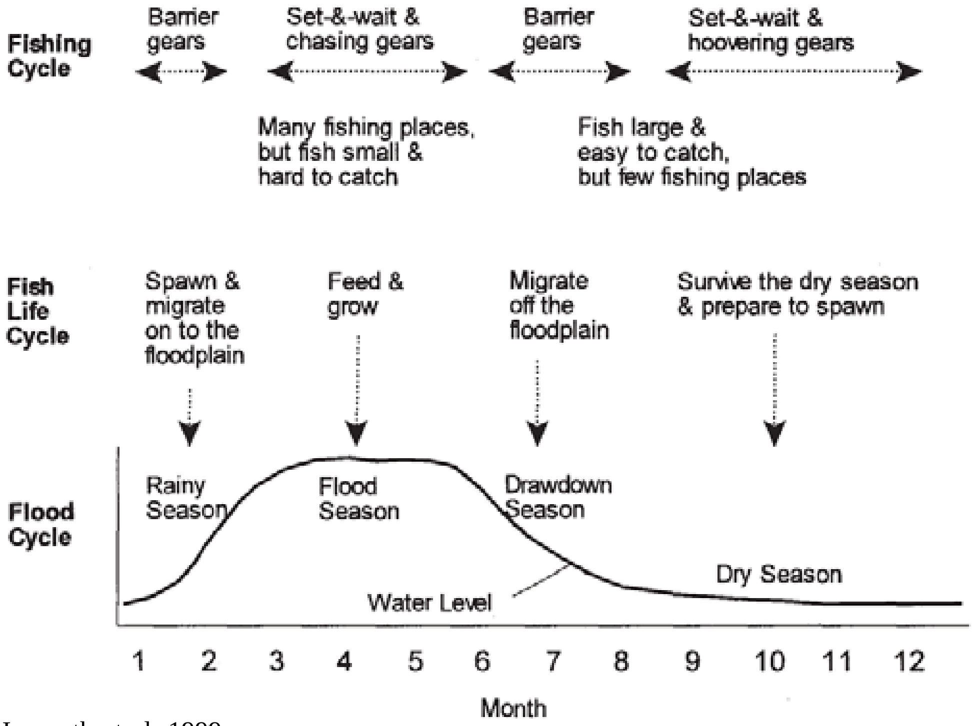
The impact of flood duration on annual fisheries production is non-linear, as illustrated in figure 3.7. Fisheries production remains very low under conditions of short-term flooding (less than about three months duration), but increases rapidly with flood duration thereafter.

Trade-offs between dry and wet season habitat availability

River floodplain habitats are highly dynamic, expanding and contracting dramatically in the course of the flood cycle. Fish production is the net result of the increase in biomass due to growth and reproduction, and the decrease in biomass due to mortality. In river-floodplain systems, fish growth and reproduction are closely linked to the flooded area at high water because this determines overall organic matter inputs, and spawning and nursery habitat for young fish. Mortality on the other hand is closely linked to the water area at low water level because it is here that the stocks are subject to high mortalities due to stranding and extreme crowding in the remaining habitats. The dependence on both high and low water habitats implies that production may be limited by both or by either.

A simple but effective way of considering trade-offs between wet and dry season habitat availability is as follows. Both wet, and dry season habitats have a carrying capacity for aquatic resources, that is, the maximum biomass they can sustain. For resources to reach the carrying capacity of the wet season habitat, their carrying capacity of their dry season habitat must not be less than the carrying capacity of the wet season habitat divided by their maximum rate of production (production/ biomass (P/B) ratio) over the period between the lowest and the highest water level. It is important to consider that this relationship applies to the maximum rate of production, which populations display when their density is much below the environmental carrying capacity. While equilibrium P/B ratios of river fish assemblages are typically in the range of 1-2 per year, exploited tropical floodplain fish may produce at rates of up to 10 per year in low-density situations. When a period between low and high water of 0.5 years is assumed, this leads to a rule of thumb that dry season carrying capacity should not be less than 20 percent of wet season carrying capacity.

Figure 3.8. Relationship between seasonal cycles of flooding, fish biology and fishing in tropical river-floodplain systems.



Source: Hoggarth et al. 1999.

Dynamics of water level, effort and catch

Both the production ecology of resources, and rate at which they are harvested by fishing (fishing mortality rate) tend to be strongly influenced by flooding. The flood effect on fishing mortality arises from three factors of which the first is physically inevitable while the others may or may not occur (figure 3.8):

1) Physical concentration of resources.

2) Change in gear use: use of effective barrier gears in rising/falling waters.

3) Entry of additional fishers due to high returns or limited alternative opportunities at certain times.

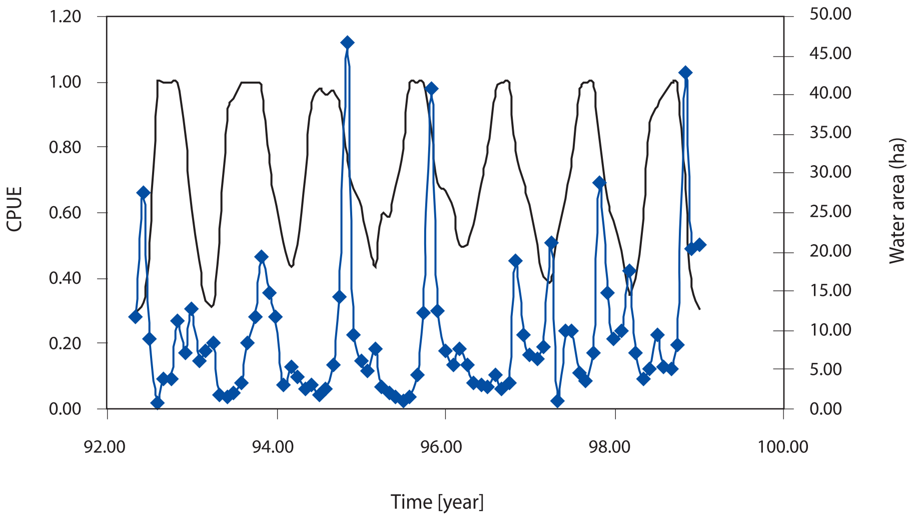
A typical pattern of seasonal dynamics is shown in figure 3.9. The high level of fishing effort at the time of receding water levels coincides with the highest returns (CPUE). This pattern is also advantageous in terms of production ecology, because biomass is removed at a time when the environmental carrying capacity declines dramatically and populations would suffer extreme levels of mortality even in the absence of fishing. Implications of variation and modification of flooding patterns for stock dynamics and effort management are discussed further in Section 4.4.

3.4.6 Fishery characteristics and yields of different habitat types

Fishery characteristics of habitats

Rivers without floodplains: Production is strongly dependent on, and predictable from drainage basin area.

Figure 3.9. Catch per unit of effort (CPUE) in relation to water area in a floodplain water body in Bangladesh.



Source: De Graaf et al. 2001.

River floodplain systems: Production is strongly dependent on, and predictable from the flooded area. Areas subject to seasonal flooding that are entirely cut off from permanent water bodies will not support significant fisheries production.

Estuaries and lagoons: Production dependent on nutrient inputs from the river, depth, and accessibility from the sea. Total production is not strongly influenced by salinity, but production of individual species may be (Joyeux and Ward 1998).

Lakes and lacustrine wetlands: Production is dependent on nutrient inputs, depth, and residence time. Lakes and wetlands in agricultural or densely inhabited catchments receive higher nutrient inputs and tend to be more productive than those in forested catchments. Areas subject to seasonal flooding that are entirely cut off from permanent water bodies will not support significant fisheries production.

Rice fields: Traditional paddy rice systems provide temporal, and in some cases permanent aquatic habitats and support very considerable fisheries production. Paddies are designed to retain water, either from rainfall or from inundation by rivers. Many fish species are able to cross boundary walls (bunds) of rainfed paddies, hence paddies are functionally the extensions of the floodplain habitat. Seasonal paddies do not support resident fish populations, but are newly colonized with every flood. The driving force of this colonization is the natural spawning migration of many species towards headwaters and marginal floodplain habitats. Many species will spawn in rice fields leading to high abundance and biomass production of young fish over the course of the rice growing season. Fish tend to migrate back towards permanent water bodies when water levels fall in the paddies, but many remain stranded or get caught in rice field fisheries.

Fisheries yields from different habitats

The prediction of potential and actual fish yield from basic hydrological, ecological and fishing effort information is of major interest for the assessment of irrigation development impacts. A number of empirical models have been developed for this purpose (tool 10).

> **Tool 10. Assessing and forecasting yields**
>
> Assessing current and forecasting future yields from different habitats is crucial to impact assessment and management. Ideally, current yields would be estimated directly from catch surveys, and future yields predicted using empirical or mechanistic models. Often, however, neither long-term catch data (for a minimum of one full year) nor yield predictive models are available.
>
> In this case, we recommend the use of the indicative yield figures from table 3.2, conducting all assessments using mean values as standard, and considering extreme case scenarios (best and worst) based on the range values. Any seasonal habitats entirely cut off from permanent water bodies should be assumed to produce no fish. Information on fishing effort and environmental factors may be used to assess the relative likelihood of the standard and extreme values, or to generate scenarios based on intermediate values considered to be most likely.
>
> Uncertainty in yield estimates must be made explicit through consideration of a range of plausible scenarios. Under no circumstances should assessments be based on just one set of values deemed to be "most likely".

The following table provides indicative yield data for a wide range of tropical aquatic habitats.

The wide ranges of yield reported in table 3.2 reflect wide ranges of environmental conditions and fishing effort. Accounting for these factors explicitly can improve the accuracy of yield predictions.

Because yields depend strongly on the level of exploitation, asymptotic yields (the relatively constant yields achieved at high levels of exploitation, figure 3.5) provide a better indication of yield potential for particular habitats than averages. Empirical relationships between yield and environmental factors have been derived for many systems and locations. In continental and global comparisons, fishing effort is frequently the most important predictor of the yield.

Table 3.2. Fisheries yield in different inland aquatic systems.

Habitat	Area measure	Productivity (kg/ha/year)	Reference
River without floodplains	Catchment area	0.3 [0.06-0.57]	Welcomme 1985
River floodplain	Maximum flooded area	80 [7-186]	Bayley 1988
Rainfed rice fields (Laos)	Rice field area	60 [4-230]	Lorenzen et al. 2000
Estuaries & lagoons	Average water area	100 [4-2200]	Joyeux & Ward 1998
Reservoirs (Sri Lanka)	Average water area	220 [40-500]	De Silva 1988a
Small reservoirs (Laos)			Garaway 1999
Non-managed		100 [36-176]	
Enhanced & managed	Average water area	250 [50-550]	

Assessing or forecasting yields

Assessing or forecasting yields from different habitat types is central to fisheries impact assessment and management.

Further reading: Welcomme 1985; Welcomme 2001; Hoggarth et al. 1999; and Arthington et al. 2004 provide good overviews of tropical fisheries ecology.

3.5 Biodiversity and ecological integrity

While this manual is concerned primarily with the availability and use of aquatic resources rather than their conservation per se, biodiversity issues should not be neglected in impact assessment. Biodiversity conservation is a key aim of natural resource management, and a legal obligation for signatories of the Convention on Biological Diversity. See Section 1.2.3 for a discussion of the relationship between fisheries and biodiversity.

Three different criteria are commonly used to assess the conservation value of an aquatic ecosystem:

1) **Biodiversity** is the variety of living organisms, most commonly measured as the number of species present in a particular location (species richness).
2) **Endemism** is the degree to which species are confined to the local area and do not occur elsewhere.
3) **Biological integrity** is a more complex concept, encompassing structural features of the aquatic ecosystem such as the relative abundance of different trophic groups (predators, detritivores, etc.).

Clearly, conservation will be most important in systems characterized by high levels of biodiversity and endemicity as well as a high degree of biological integrity. However, the three aspects are not necessarily correlated.

The species richness of local aquatic resources is determined by the regional species pool (which is determined by biogeographical processes), local habitat availability, and the history of local colonization and extinction. As a rule of thumb, large and/or structurally diverse aquatic habitats are more likely to harbor a larger number of species (share of the regional species pool) than small and/or uniform habitats.

The level of endemism, i.e. the degree to which species are confined to the local area and do not occur elsewhere, is strongly related to geographical isolation. In isolated habitats, overall species richness is often low.

Biological integrity is assessed mostly in a comparative perspective, i.e. by comparing structural features of the fish or invertebrate assembly between sites subject to different levels of modification. In areas where a regional index of biological integrity or a similar assessment framework has been derived, integrity should be evaluated within this system. Where no such framework exists, it is best to gauge to what extent the local catchment and aquatic habitats have been modified by human activity.

Tool 11. Checklist for assessing the priority of biodiversity issues

Biodiversity issues should receive particular consideration in the assessment, if any, or several of the following conditions are met:

1) A high proportion of the regional species pool is represented at the location.
2) Some species are endemic to a small area.
3) Some species are classified as rare or endangered, or are afforded special legal protection for other reasons.
4) The catchment and aquatic habitats are relatively pristine.
5) The location provides a crucial link between pristine habitats or an essential migration route for species of special concern.

While the value attached to aquatic biodiversity and ecological integrity may thus vary from situation to situation, any pre-intervention assessment of the fisheries system should include at least a basic assessment of these aspects in order to gauge whether biodiversity issues should be given particular attention.

Local biodiversity and ecological integrity are always strongly influenced by river basin and even larger scale (eco-regional) factors. To gauge the conservation importance of a particular area, it is therefore important to consider the degree to which other developments in the river basin are likely to have impacted on the site, and the extent to which a modification at the site is likely to affect the wider basin and region. An overview of the common developments and their impacts on aquatic biota is given in table 3.3.

Further reading: Welcomme 2001 provides an overview of factors influencing freshwater fish biodiversity. Regional overviews are given by Kottelat and Whitten 1997 for Asia and by Lévêque 1997 for Africa. Karr and Chu 1999 provide an overview of the index of biotic integrity. Abell et al. 2002 provide a guide to eco-regional conservation of freshwater ecosystems.

Table 3.3. River basin developments and their impacts on aquatic biota.

Development	Impact
Flood protection embankments	• Reduce the connectivity between the river channel and the floodplain hydrosystems. • Reduce the degree of flooding and the availability of nutrients and organic material for aquatic resource production.
Dams and reservoirs, weirs	• Reduce flood flow and the extent of flooding downstream. • Reduce or stops the transport/transfer of silt and organic material to the flood plain. • Breaks the longitudinal connectivity of the river channel, hindering or stopping fish migration upstream or downstream. • High fish mortality may occur at downstream passage through turbines.
Irrigation schemes	• Increase evapotranspiration loss of water, therefore reduces availability of water to aquatic habitats. • Increased pressure on local resources owing to increased numbers of people supported by irrigated agriculture. • Possibility of salinization of drainage water. • Associated land engineering and drainage may reduce wetland habitat area, quality and connectivity. • Agricultural intensification may increase siltation and pollution.
Towns and cities	• Reduce the flow of water in the river channel (though to a far lesser degree than in the case of irrigation systems). • Inorganic and organic pollution from the discharge of treated or untreated sewage, and urban runoff. • Localized "plugs" of seriously polluted water are impassable for fish and therefore hinder their upstream or downstream migration.
Industries	• Reduce the flow of water in the river channel to some degree. • Pollution arises from discharge of untreated effluents into the water course. Some industries (e.g. tanneries) produce highly toxic waste.
Gravel extraction	• Disturb spawning grounds for some fish.
Drainage of flood-plains and wetlands	• Reduce availability of wetland habitat.
River training	• Reduces or eradicates pools, eddies and silt bars which provide breeding and living habitats for fish. • Increases the velocity of flow and reduces or removes natural vegetation which provide habitats for fish.

3.6 Fisheries in livelihoods

This section first uses the concepts of livelihoods analysis to assess the diversity of roles which fishing may play in rural livelihoods. Key issues and tools for use in impact assessment are identified. Second, the importance of own labor as the main asset of the poor is considered and tools for assessment of labor markets are presented. Determinants of poverty and gender differences are cross-cutting issues and their importance is highlighted throughout.

All stakeholders who derive any part of their livelihood from the fishery should be considered further in the livelihoods analysis. Stakeholders who influence the fishery but do not derive a livelihood from it are important to be considered in the context of institutional arrangements and management.

3.6.1 The livelihoods concept

Definition of livelihoods

“A livelihood comprises the capabilities, assets (including both material and social resources) and activities required as a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base” (DFID 1999).

Livelihoods are dynamic, evolving in response to economic and social development and the changing constraints and opportunities that this creates. For example, in the long run it is expected that a smaller proportion of the population will gain their livelihoods from the traditional rural activities of farming and fishing, even though enhancing of these activities may be vital for poverty reduction in the short to medium term. In the achievement of positive livelihood outcomes the tradeoffs between productivity, equity and sustainability over time will be critical.

The nature of poverty

A broad conception of the nature and causes of poverty is needed to understand the roles played by fishing in household livelihood strategies. Of main relevance to livelihoods reliant on fishing is the fact that people may be poor for structural reasons, lacking the resources and opportunities to meet basic needs and establish a viable livelihood. Also, that they may be vulnerable to ‘entitlement’ failure, falling into poverty during crises such as illness, crop failure or livestock deaths. Poverty is dynamic; its determinants varying both seasonally and from year to year. In addition, poverty can be considered in terms of lack of access to goods and services including health, education, transport and utilities, or in terms of deprivation of economic, political, social and cultural rights.

Thus, whilst income level is an important determinant of poverty, it is also often not sufficient as a measure of poverty, and indeed many poor people in rural areas of developing countries may depend largely on their own productive activities for subsistence and have very little cash income.

Livelihood analysis

Among rural communities, the capacity to resist poverty and to improve livelihoods often primarily depends on the opportunities offered by natural resource based production systems as conditioned by the wider economic, institutional and political environment. For assessment of poverty, this prompts the consideration of the resources or assets that are used for existence, including those that are owned, those that can be obtained through exchange and those that can be obtained through rights of access, and how these assets can be used in a range of activities (table 3.4). For example, a landless laborer owns his or her labor power, and given a functioning labour market, can exchange this for wages, and that in turn, given a functioning food market, can be exchanged for food. A member of a village may similarly have rights to fish in nearby water bodies, providing a source of food directly, a means for reciprocal exchange for other commodities or labor services, or a commodity to be sold for cash.

To assess the impacts of interventions such as irrigation development, we need an accurate and realistic understanding of such livelihood assets and how people endeavor to use them to achieve positive livelihood outcomes. Core concepts are that the assessment must be people-centered, holistic and dynamic in seeking to understand and build upon processes of change. It must consider linkages between activities at macro and micro levels and the importance of the policy and institutional environment in influencing chosen livelihood strategies and outcomes.

Livelihoods analysis originates in part from analyses of the differential capability of rural households to cope with crises; variation that stems from different patterns of asset holding. This emphasizes the need to understand the policy and institutional environment in which households operate and which may hinder or enable access to both assets and activities; also the 'vulnerability context', i.e. trends and shocks beyond the control of the household, which may disrupt activities or degrade assets and push people deeper into poverty. Analysis must consider both the external risk factors that affect the vulnerable, and their coping mechanisms as determined by assets, food stores, social support networks, etc. (tool 12). Also related, and originating from the literature concerned with the sustainability of ecosystems, are livelihood attributes of 'resilience' and 'sensitivity'. The most vulnerable households will be those with low resilience (the ability to recover from stress or shocks), and high sensitivity (the magnitude of the effect of an external shock) (Allison and Ellis 2001).

Essential in the conceptualization and application of livelihoods analysis is the attention to the economic environment at macro, meso and micro level and its trends and shocks (the 'livelihood attributes' in Section 3.1). In particular, neglect of markets and their influence on livelihoods and poverty can lead to failure to identify livelihood opportunities and constraints arising from market processes and development. These are related to macro and meso level changes in national and local economies, including wider processes of growth, increased competition, technological change, the integration of commodity and factor markets and their accessibility for the poor; institutional development that supports and coordinates markets, and conflicts between the interests of the poor and non-poor. Livelihood analysis that focuses (however usefully) only on immediate micro level opportunities and constraints for households can overlook these issues and how they influence trajectories of change in key variables such as the opportunity cost of labor (see further below) or choice of livelihood strategies (table 3.4).

One example is the need for assessing the state of rural non-farm economy and ascertaining whether it is a residual sector offering only coping activities and absorbing labor displaced from traditional activities of farming and fishing etc., or a dynamic one creating new jobs, exerting upward pressure on wages, and with livelihood diversification as a positive adaptation leading to accumulation by rural households. These issues are discussed further below. Another example is that in the absence of reliable markets to purchase affordable food, households will tend to prioritize labor use in subsistence activities, such as cultivation of food crops, fishing for their own consumption and gathering of wild foods.

It is useful to focus assessment on the five types of asset upon which people draw to build their livelihoods (as in table 3.4 and tools 12 and 13).

Table 3.4. A framework for analysis of rural livelihoods.

Assets	for which access is modified by	in a context of	resulting in livelihood strategies composed of	with outcomes that effect
	Social relations:			
	Gender		Fishing	
	Class	*Trends*:	Cultivation (non-market)	
	Age	Population	Cultivation (market)	*Livelihood*
	Ethnicity	Migration	Livestock	*security*:
		Technological	Other hunting and gathering	Income level
Capitals:	*Institutions*:	change		Income stability
Natural	Customary	Relative prices	Rural manufacture	Seasonality
Physical	Land & water tenure	Macro policy	Rural trade	Vulnerability
Human	Markets	National & world	Services	
Financial		market trends		*Env. sustainability*:
Social	*Organizations*:		Farm labor	Soil & land quality
	Associations	*Shocks*:	Non-farm labor	Water
	NGOs	Climatic	Migration	Fish stocks
	Local admin.	Market		Forests
	State agencies	Disease	Remittances	Biodiversity
		Conflict	Other transfers	

Source: Modified from Allison and Ellis 2001.

Tool 12. Checklist of sources of vulnerability and the policy environment

The assessment should draw on stakeholder knowledge, available secondary information and preliminary field investigations to assess the vulnerability context of fishing households that may be impacted by the project.

Main sources of trends or shocks – primarily climatic and market related :

- What weather variables may influence livelihoods?
- What pest and disease problems may affect crops?
- What animal health problems may affect livestock production?
- What human health problems may affect ability to work?
- What climate or disease factors may affect fisheries?
- What level of variation may take place in market supply and prices of staple commodities or main cash crops?
- The macro-economic environment and its stability?
- Is conflict or civil unrest an issue?
- What is the influence of the agricultural/rural sector policy environment (i.e. the nature and level of government interventions with regard to trade, markets, taxes or subsidies on inputs or outputs, and leading development projects/programmes)?
- What is the level of market access and market development for agricultural outputs and inputs, and for fish, and current relevant commodity demand and supply trends? Hence, what is the pattern of economic incentives facing rural households?
- How do the sources of vulnerability listed above impact on the poorest households?
- How do they impact on women and children in ways that may be different in comparison to men?

Table 3.5 illustrates these concepts by highlighting the aquatic resource related assets that are significant in rural livelihoods in Laos (a full inventory for rural households in Laos would include other assets such as agricultural land, forests and livestock).

Tool 13. Inventory of livelihood assets

An analysis of livelihoods and assessment of potential impacts can start from an initial inventory of livelihood assets for fishing households in the project area. These are:

- natural capital (land, water, biodiversity);
- social capital (social structures in the community including networks and group membership, trust, level of social respect and initiative, access to NGOs, information about how collective decisions are made and ability to influence these, access to wider institutions in society);
- human capital (skills, knowledge, health and ability to work);
- physical capital (infrastructure and goods that support livelihoods such as housing, transport, energy, tools, farm and community buildings, health service facilities, schools, water and sanitation, drainage and flood protection); and
- financial capital (financial resources including savings, remittances, pensions and access to credit).

For examples, see table 3.5.

Specific attention should be paid to assessing the asset endowments of the poorest and most vulnerable households, using a broad conception of poverty as described above. Similarly, the degree to which women have access to and control of assets should be assessed, whilst female headed households are likely to be among the poorest and most vulnerable.

Table 3.5. Aquatic resource related assets in rural livelihoods in Laos.

Assets	
Natural	Fisheries: • Stream and river channels and floodplains. • Small seasonal waterbodies. • Perennial waterbodies.
Physical	• Seasonally flooded rice fields. • Irrigation infrastructure that provides or enhances habitats, or facilitates catches, or aquaculture or fishery management.
Human	• Indigenous technical knowledge of aquatic resource use. • Positive nutritional impact of fish consumption.
Social	• Kinship and social networks important for food security. • Low socio-economic differentiation between households and coincidence of interests for use of communal resources such as fisheries. • Customary and community managed access and ownership rights usually existing for waterbodies.
Financial	• Sale of fish surpluses, a valuable source of cash income for poor households and control of income from fish sales tends to be in the hands of women.

These assets constitute livelihood building blocks. To a limited extent they can be substituted for one another. For example, the poor may draw on social capital such as family or neighbourhood security mechanisms at times when financial capital is in short supply. Alternatively, recognizing the limited or declining productive capacity of their natural capital, they may invest in education and thus human capital to enable family members to access better paid employment. Livelihood outcomes will not be simply monetary, or even tangible in all cases. They may include, for instance, the sense of being empowered to make wider, or clearer, choices. Livelihood indicators include consumption levels, access to levels of the five forms of assets, and processes such as resilience and adaptation.

Livelihood strategies and diversification

Diversification is a common and important feature of rural livelihood strategies. It is defined as the process by which rural families construct a diverse portfolio of activities and social support capabilities in order to survive and to improve their standards of living (Ellis 1998).

Many rural households have complex livelihood strategies that cross the simple boundaries of hunting and gathering, farming, laboring, being an entrepreneur and a consumer. Within the same year they may farm a small plot, consume some of the output and sell the rest; earn wages as a laborer in the locality or as a seasonal or permanent migrant; collect wild resources such as fish, timber or fruits; and purchase food and other commodities from the market. For such households, the changes to farm output, prices, employment, wages and natural resources that may arise from irrigation development may have complex effects.

Farming of crops and/or livestock is the most widespread and important source of livelihood for the majority of people in rural areas of developing countries. However, in regions well endowed with aquatic resources fishing may also be of great importance. In such regions farmers may also be fishers, or there may be households for whom the main source of subsistence and income is fishing but who also cultivate a small plot of land. Although usually fewer in number than households predominantly dependent on farming, there may also be significant populations of 'professional' or full-time fisherfolk. These may be most common where there are riverine or coastal capture fisheries, particularly if fishing in such waters requires specialist skills and investment in costly capital equipment such as boats or other gear. But they may also be found where there are productive inland lake and floodplain capture fisheries (box 3.4).

One dimension of a sustainable livelihood is adequate and stable flows of income and consumption the whole year round. Seasonality in both farming and fishing is known to cause troughs and peaks in labor utilization, and can lead to food insecurity due to the mismatch between uneven farm income

Box 3.4. Examples of farming and fishing livelihoods

In lowland areas of Laos, most rural households have access to land and are semi-subsistence farmers. However, there are extensive riverine and floodplain capture fisheries and the vast majority of rural households also regularly catch fish to provide fish for their daily diet and occasional surpluses are either sold or exchanged.

In very large parts of Bangladesh, there are extensive floodplain capture fisheries and significant populations of full-time fishers. Some of these households may also cultivate small plots of land or gain seasonal employment as farm labourers.

In Sri Lanka, shallow reservoirs or tanks constructed to store water for irrigation provide fisheries for both full-time fishers, and local farmers who may fish when they have spare time.

streams and continuous consumption requirements. These are often called the 'labor smoothing' and 'consumption smoothing' problem, respectively. Livelihood diversification can contribute to the reduction of adverse effects by utilizing labor and generating alternative sources of income during off-peak periods. Diversification also reduces the risk of losing all income sources simultaneously, for example, as a result of climatic or other shocks (Ellis 2000a; Start 2001).

Coping strategies are *ex-post* responses to shocks or unanticipated livelihood failure, demonstrating that diversification may arise from necessity or choice (Ellis 2000a). Diversification can be either a means of survival but doing little for poverty reduction, or a means to sustainable improvements in living standards through exploitation of new opportunities. Thus a common pattern of diversification in relation to household wealth has been observed. Poor households have diversified livelihoods because of a lack of resources such as land or fishing space to allow them to specialize. Richer households may diversify because of the wider range of remunerative activities open to them, and because they have been able to increase their human capital in the form of good health, education and entrepreneurial skills, and accumulate the financial capital needed for investment. Thus it may be households in the middle of the income range (though often still poor in absolute terms) who may be most specialized in farming or fishing (table 3.6).

In a context of economic and population growth, a key question is thus whether diversification is a reflection of worsening impoverishment and desperation as land and/or fishing space become increasingly scarce, or increasing prosperity as labor is attracted into higher paying employment.

This is of central relevance as irrigation development has the potential to expand the non-farm labor market through the stimulus it provides to the rural economy, providing rural households with new opportunities for livelihood diversification. On the one hand, it may create opportunities and incentives that draw labor away from fishing or compensate for reduced productivity of, or access to, a fishery. On the other hand, poor households, without access to the benefits of irrigation and perhaps economically and socially marginalized by its development, may be driven to rely more heavily on fishing as one element of a diversified survival strategy. Identifying and predicting such trajectories of change in livelihoods must be a key element in the planning and assessing of irrigation development (tool 14).

Table 3.6. Livelihood functions of fishing.

Livelihood strategy	Livelihood functions of fishing
'Survival'	• Subsistence (food production and income) • Nutrition – protein, micronutrients, vitamins
'Semi-subsistence' diversification	• Own consumption – food security and nutrition • Complementarities in labor use with farming • Means for barter, or for participation in reciprocal exchange and social networks • Occasional cash source • Diversification for: o labor and consumption 'smoothing' o risk reduction o as a coping strategy/buffering against shocks.
'Specialization' (as fishers)	• Market production and income • Accumulation
'Diversification for accumulation'	• Accumulation • Retention in a diversified accumulation strategy.

Source: Smith, Nguyen Khoa and Lorenzen 2005.

Tool 14. Role of fishing in livelihood strategies

An assessment should be made of the role of fishing in livelihoods in the affected area:

- To what extent is fishing a sole source of livelihood, or a supplement to farming and other activities?
- What is the approximate number and proportion of households that may be affected, categorised by livelihood strategies in terms of the importance of fishing?
- What are the characteristics and importance of the other main livelihood activities, e.g. farming?
- To what extent do the poorest and most vulnerable households rely on fishing as part of their livelihood strategy?
- How much do women and female-headed households rely on fishing, and what particular benefits do they gain from this activity?

Livelihood characteristics of fishing

Artisanal inland fisheries tend to include the poorest members of rural communities. Low costs (table 3.7) and open access to the resource may make fishing one of the few sources of livelihood available as a default activity for the landless. In turn, when population pressure is high this can result in over exploitation of fishery resources. Thus, fishing is commonly regarded in many developing countries (and in much of the literature) as an activity of last resort and a refuge for the economically and socially marginalized. It is commonly perceived that households who specialise in fishing will be a recognizable and distinct social group, and one that is typically among the most deprived and poorest. Fisher households are identified by their trade or by caste, and often expected to be a socially inferior and subordinated class. For inland floodplain capture fisheries this results, at least in part, because fishing is typically a labor intensive activity with relatively low cost requirements for gear or equipment (table 3.7), or for access to the resource.

It is also expected that if full-time fisher households manage to save from their income and accumulate assets, they will tend to seek alternative employment or forms of livelihood diversification such as farming. Thailand provides an example of this as it is reported that economic development is leading to diversification by fishing households, and often out migration from rural settlements to urban areas. The process is being driven by rising economic expectations and the low and highly variable returns to fishing compared to growing alternative sources of employment in towns.

Table 3.7. Economic characteristics of inland fisheries and fishing methods.

'Passive fishing' (set and wait gear)	e.g. gill nets traps hook & line barrier traps	• Fixed costs range from very low to moderate • Low variable costs (labor) • Low energy requirements • Lower skill • Risk of losses through theft or gear damage
'Active fishing' (chasing gear)	e.g. spears cast net scoop net seine net rod & line dewatering	• Fixed costs range from very low to moderate • Labor intensive • Moderate to high energy requirements • Higher skill

However, out migration can be temporary and cyclical, unless households possess the social and human capital that can facilitate entry to permanent and well-paid employment. For poorer households, it may only be children for whom sufficient resources have been scraped together for education who can permanently escape fishing as a way of life (Bath University Centre for Development Studies 1994).

The stereotypical picture of fishing as an activity of last resort may, however, not always be true. Whilst the incidence of poverty in absolute terms amongst fisher households may be high, there can still be considerably socio-economic differentiation amongst fishing communities. For example, for some areas in Bangladesh it is argued that fishing communities may possess socio-economic structures which mirror those of their farming neighbors (box 3.5). Gaining information about such differentiation will be an important part of the assessment (tool 15), and will facilitate assessment of conditions for the poorest households and for women.

For example, a study of the area cited in box 3.5 concluded that fishing communities are neither a homogeneous nor subordinate underclass compared to their farming and urban neighbors, but rather a socially separated but parallel society. Survey evidence also showed that fisher incomes in the areas were not significantly lower than those of neighboring farmers. For the majority, fishing was not an occupation of last resort but an inherited profession associated with caste and social differentiation. These factors, for many households, combined with limited access to farm land or other resources, constrained the alternative livelihood options available.

Box 3.5. Fishing society of the Hail Haor floodplain fishery in Bangladesh

Households that catch fish fall into five social groups:

1. Muslim communities specifically associated with full-time fishing.
2. Hindu communities of “untouchable caste”, full-time fisherfolk.
3. Members of a Hindu agricultural caste that migrated from farm land to the north to escape persecution and who have taken up fishing as their main source of livelihood.
4. Households from some Muslim villages, fishing part-time for sale with gill-nets.
5. Households from all communities around the fishery who fish for their own consumption only.

(Bath University Centre for Development Studies 1994)

Wealthier members of fishing communities tend to be more specialized in fishing than the poorest, and may make significant capital investments in gear and fishing methods, or in the purchase or leasing of access rights to a fishery. Resulting differences in fishing capability lead to socio-economic variation by total income, net income from fishing and hourly returns to labor in fishing. The survey evidence in Bangladesh suggested that any surplus assets were invested in fishing rather than non-fishing livelihood diversification. Thus in this case, the poorest fisher households were those too poor to invest in better fishing methods and those having more restricted access to the fishery, to the best fishing areas, or during certain seasons (dry season access to a fishery is likely to be at a particular premium). Like marginal farmers these marginal fishers tended to have more diversified livelihoods, supplementing fishing with the making of fish traps and baskets, or supplying labor to other fishing households (Bath University Centre for Development Studies 1994).

Tool 15. Preparing socio-economic profiles

The aim is to compile information that will reveal sources and the extent of socio-economic differentiation within the potentially affected population. Sources of differentiation may include: caste, class, social status, age, gender, language, religion, ethnicity and mobility.

A preliminary profile of the area can be prepared using secondary information, direct observations and reconnaissance field visits, and discussions with stakeholders and key informants (e.g. local government officials, merchants, school teachers, NGO representatives, etc.).

More refined information may be gained using methods of wealth ranking or other participatory and/or rapid rural appraisal techniques such as focus group interviews, semi-structured interviews of key informants representative of different socio-economic groups and resource use mapping.

Where the above leaves data inadequate with regard to differentiation in livelihood assets, or livelihood options and labour allocation, or for the purposes of a fully detailed assessment, then a well-focused formal household survey may be required.

Outline of a socio-economic profile:

A. Location and physical characteristics
- Description of location
- Sketch map (better if) showing roads, land use, water bodies, rivers, bridges, major settlement areas.

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

C. Economic
- Use and access to marketing services
- Use and access to commercial inputs
- Use and access to livelihood assets – natural, physical, financial, human and social capital (tool 12)
- Employment and allocation of labour (tools 15 and 16)
- Type of livelihood activities and their diversity (tool 13)

In lowland Laos, for the majority of rural households, fishing is also not an activity of last resort. Rather it is one part of a traditional set of diversified subsistence activities that rely heavily on the natural resources available to rural communities (box 3.6). Here economic development and the accumulation of other assets is at an early stage, and clear trajectories of change with regard to the role of fishing in livelihoods have yet to emerge. Fishing will remain an important part-time or supplementary activity to farming for most rural households, though with the development of markets some may specialize more in fishing, while others specialize more in farming or new economic activities. Increasingly however, fishing may become an activity of last resort for those marginalized by the development of farming and the rural economy.

Box 3.6. Fishing in livelihoods in Southern Laos

Southern Laos provides an example of a region where natural fisheries play a particularly significant role in rural livelihoods, which can be characterised by the following:

- Semi-independent villages engaged in semi-subsistence agricultural production, with functioning market access but relatively low levels of market development in terms of market integration and information flows, and often high transport costs.
- Inadequate access to land, inadequate labor to cultivate land and failure to achieve a secure level of rice self-sufficiency are the prime determinants of poverty and vulnerability.
- After meeting rice needs the vast majority of households use surplus labor to fish for subsistence needs and for occasional surpluses for sale or exchange, and fish are the main source of protein in their diet.
- Dependent on the season, people also gather timber and non-timber natural products from forests and grazing land.

Though it is dangerous to generalize, these two examples suggest that the fishing practices of poorer fisher households will tend to have certain characteristics compared to those of wealthier fishers. That is, they tend to be relatively labor intensive, using low cost gear, in pursuit of dispersed small species in shallow water or dispersed fry in the flood season, and offering low returns to effort. Fishing practiced more exclusively by better off households thus tends to be using more expensive gear to catch larger species in deeper water, or concentrated adult fish in the dry season, and offering higher returns. Though again dangerous to generalize, these observations may also tend to apply to the fishing practices of women compared with men, and to part-time compared with full-time fishers (table 3.8).

Table 3.8. Variation in fishing practices by fisher wealth and gender characteristics.

Fishing by:	Tends towards:
Part-time fishers Poor households Women & children	• Low cost gear • Labor intensive • Dispersed small species in shallow water or dispersed fry in the flood season • Low returns to effort • Tends to be open access
Full-time fishers Wealthier households Men	• Higher cost gear • Use of boats • Larger species in deeper water or concentrated adult fish in dry season • Higher returns to effort • tends to have restricted access

Further reading: a guide to livelihoods thinking and a range of relevant methods and tools for data collection and analysis is provided by the DFID Sustainable Livelihoods Guidance Sheets (DFID 1999, available from the Department for International Development in London, or on-line at www.livelihoods.org/info/info_guidancesheets.html). Allison and Ellis 2001 apply the approach to artisanal marine fisheries. Ellis 2000a,b comprehensively assesses the determinants and characteristics of rural livelihood diversification.

3.6.2 Household's own labour allocation

Importance

Labor is both the main source of power in many farming systems and fisheries in developing countries, and also the main asset of the majority of the poorest households. Even where animal or mechanical power is used in farming, it is mainly for seedbed preparation, pumping water and crop processing. Transplanting, weeding and harvesting are almost always carried out by hand. Mechanical applications in fishing are also limited to boat engines or pumping, and most tasks remain relatively labor intensive. In farming and fishing, where sources of power alternative to labor are used, this tends to be by the relatively prosperous rather than the relatively poor. Access to labor is thus a key determinant of output and income for both farming and fishing. For farming, this applies even in areas of high population density and apparent labor surplus because of the seasonality of labor requirements in agriculture and periods of critical peak labor demand. In fishing this may be less marked but seasonality in labor use remains important (tool 16).

Given the importance of own labor to production, the return to labor (value of output per work-day or hour) can be a more important factor in farm decision-making than the return to land (value of output per unit area e.g. hectare). In fishing it is clearly the main factor in decision-making unless major investments of capital have been made. This key point can be further understood with reference to table 3.7, which emphasized that the costs of fishing other than labor costs will often be very low. Returns to the use of labor in fishing will vary with the quality of other inputs used, but given no restrictions on access to the fishery, the marginal fishing unit will just cover its opportunity cost, and for a self-employed fisher this will be primarily the opportunity cost of his own labor. Fishers will continue to enter the fishery if returns per unit effort exceed the opportunity cost of own labor, and the equilibrium number of fishers emerges as returns per unit effort declines as fishing effort increases and catches and revenue decline (figure 3.5). Thus apart from short run variation, or fisheries for which there are effective barriers to entry, fishing incomes will come to depend on the opportunity cost of labor (or opportunity incomes in other enterprises). It is in this situation that fishing may become the occupation of last resort, comparable to livelihoods dependent on other open access natural resources that have insignificant non-labor costs, e.g. the collection of fuelwood from forest areas.

There are a number of reasons why own labor opportunity costs, and thus fisher incomes, may be low in artisanal fisheries such as:

1. the isolation of communities resulting in poor educational facilities, infrastructure links, and few alternative employment opportunities;
2. the existence of surplus labor due to population growth and productivity gains in both farming and fishing;
3. capital asset fixity (fishers tend to be owner-operators of boats and equipment), which helps create asymmetry between entry and exit, i.e. more entering the fishery than those leaving;
4. lifestyle preferences and/or the recreational satisfaction gained from fishing;
5. perverse incentives, i.e. welfare state measures designed to provide an income safety net; and
6. labor immobility resulting from caste restrictions, cultural factors and simple lack of knowledge of alternative occupations (Panayotou 1982 cited in Cunningham 1993).

The lower opportunity costs of part-time, passive and recreational fishing will also tend to drive down returns per unit of effort of fishing in an open access fishery. It is also recognized that even within depressed fisheries some fishers (the "highliners") may earn high incomes from their superior skill and experience, or just due to good fortune (Cunningham 1993). "Highliner illusions", i.e. expectations of good catches and revenue, may then also drive fishing effort beyond the level equating its opportunity cost.

In allocating family labor between activities, poor households may also take into account not only time-cost but also the energy-cost of using labor. Indeed, where nutrition levels are very poor all possible opportunities may be taken to save expenditure of energy. Most fishing activities may require less energy use than many farm tasks, but fishing may also be considered more difficult or dangerous. For example, long hours of immersing in water for long hours is likely to leave people prone to skin diseases or affected by leeches or fevers.

Other factors influencing labor allocation will be time and travel cost to the place of work, the need to and cost of taking meals away from home, and security, particularly for women.

Seasonality

Labor requirements in most farming systems are highly seasonal. Thus labour shortages or 'bottlenecks' may exist for crucial operations such as planting and harvesting when households find it difficult to complete the required task with the necessary timeliness to prevent yield losses. This contrasts with the seasonal unemployment or underemployment they may experience outside the growing season, which can be prevalent even in areas of low population density. This seasonality of labor requirements is particularly pronounced in rainfed agriculture where there are clearly defined wet and dry seasons, and the growing season may typically be only 4-5 months in duration or less.

The seasons when farm households need to work hardest also tend to coincide with those when they are least fit to do so. Nutrition levels are highest in the period after harvest, which, running into the dry season, is also when disease incidence is lowest. During the growing season, food stocks are low or falling, market prices for food are at their highest and people have to work long hours when their general health is poorest. Loss of working time through illness can have a direct effect on crop yields and income for the year, with the impact most severe for the poorest households with little margin over subsistence.

Seasonality also effects fishing, with inland fisheries most productive often during the rise and fall of floods during the beginning and end of the wet season (figure 3.8). Fishing space and access to a fishery also become more scarce during the dry season and, as noted above, this may force some fishing households to seek alternative sources of income during this period.

Gender divisions of labour

In many societies, tradition defines quite strictly which activities are carried out by women and which, by men. Labor division may be both by enterprise and by task. For example, in terms of enterprise women often have responsibility for food crops, kitchen gardens and small stock or compound livestock, while men have responsibility for cash crops and/or non-homestead plots and cattle-herding. By task certain farm work may be regarded as belonging to women (usually planting, transplanting and weeding) and some to men (typically land clearing and preparation and harvesting).

Such divisions generally result in unequal and unfavorable outcomes for women. For example, division by enterprise and task often occurs simultaneously, so that women must provide produce from kitchen gardens at the same time carrying out certain tasks for field crops (both cash and food), while men seldom have a corresponding commitment. As well as sharing farm work, women typically have to spend much time and energy on household tasks including collecting water and firewood, crop processing and cooking and child-care. Men's perception of the contribution of women to farm work may also be distorted; they may regard the time spent on, say weeding cash crops, as fairly insignificant, when in fact it may amount to a high proportion of the total work input for that crop. In fishing households, women often play a key role in processing and marketing.

In fishing, gender divisions may be even more culture and location specific than in farming, but in some locations it is much less apparent. Despite this, division by enterprise as defined by fishing method, location and species caught are common. Division by tasks such as mending nets and boats, or making traps may also exist. Though dangerous to generalize, fishing practiced by women compared with men, tends to correspond to that practiced by poorer fisher households compared with those wealthier (table 3.8).

Tool 16. Profiles of labour availability and use

Information concerning seasonality and gender division of labor availability and use can be collected by preparing annual or seasonal profiles of labour use. This may be best done in a participatory mode with groups of mixed or single sex respondents. Working with the respondents the investigator prepares a timescaled barchart or histogram to represent labor use in different activities over time. Time periods on the horizontal axis may be months or weeks, or even days for critical periods when more detail may be required. The vertical axis can simply record the main tasks undertaken, or an estimate of days of labor use. Large paper sheets or local materials can be used for the diagrammatic representation. Discussion will tend to centre around the farming calendar of tasks, but other activities such as seasonal off-farm employment (and migration), household work, and activities such as fishing and gathering other wild products should not be neglected. Preparing profiles for the situation before and after the introduction of irrigation, or comparing locations with and without irrigated farming will help reveal the impact of irrigation development on patterns of labor use. Preparing profiles separately for men and women will reveal gender divisions in labor allocation and use.

Whilst, given time, very detailed information can be collected, the main objective is to gain an understanding of the main activities undertaken, and the factors determining periods of labor scarcity or surplus. Discussion in a participatory mode will help uncover other important associated issues such as periods of greater incidence of ill health, and male and female preferences with regard to the types of work done.

Communal labor

Many societies have a strong tradition of working together for various purposes. Arrangements for this vary widely, but the following main forms can be identified:

1. Exchange arrangements by which households reciprocate, exchanging labor so as to have sufficient labor for timely completion of an agricultural task; exchanging skills such as in house construction, canal maintenance or boat building; or working to mitigate the tedium of working alone on tasks such as weeding or net mending.

2. Communal arrangements by which households contribute labor to projects, which benefit the community as a whole. For example, construction and maintenance of irrigation works, paths or roads, or communal buildings such as temples, schools or meeting places; or management of common property resources such as forest or a fishpond.

Communal labor often remains a strong tradition in many societies and if so can be utilized in managing the impacts of irrigation on aquatic resource use. When attempting to mobilize communal labor, it is important to understand the way in which the communities concerned have traditionally organized themselves for communal work.

Each of these characteristics of labor use is relevant when considering the potential impacts of irrigation development on aquatic resource use because introduction of irrigation will bring significant changes to patterns of household labor allocation (tool 16, tool 17).

Tool 17. Survey of local labor markets

A survey of local labor markets and alternative employment opportunities for fishers will provide information essential to the prediction of the impacts of irrigation development in terms of future trajectories of change for rural livelihoods. The aim will be to identify groups who may become more or less dependent on fishing as a source of livelihood.

Secondary data sources should be reviewed for information on trends in unemployment and migration for the area. Formal and informal surveys (incorporating PRA methods) can be used to determine the diversity of employment sources for rural households, and to investigate seasonal variation and gender division of labor (for example, through the construction of seasonal and daily labor use profiles for men and women – tool 16).

Using simple budgeting methods, estimates should be made of the average returns to labor in fishing and compared to alternative available employment, particularly in farming. Where fishers are poor, particular reference should be made to other possible occupations of last resort such as collection of fuelwood or unskilled casual laboring in farm or non-farm activities.

Further reading: Ellis 1998 is an excellent text on the economics of rural households and their labour allocation. Upton 1996 provides a further guide, including an introduction to appropriate tools of budgeting and financial analysis.

3.7 Institutional arrangements and the management of fisheries

3.7.1 Institutional arrangements

As mentioned above, a key characteristic of fisheries is that they are exploited as common pool resources. Common pool resources tend to become overexploited, resulting in economic inefficiency and possibly physical degradation of the resource unless the behavior of individual users is effectively regulated. To achieve such regulation is the role of institutional or decision-making arrangements.

The introduction of an irrigation scheme is not just a technical intervention. A set of rules, or institutions, designed to facilitate implementing, operating and maintaining the scheme accompany any irrigation initiative. They may, or as is more often the case, may not, include rules designed to protect the fishery/fishers that are affected by the irrigation intervention.

At the same time these new institutions are introduced into a social order that is already rule bound, thereby affecting and being affected by the existing social and institutional environment. Rules or 'institutions' are intrinsic to irrigation development, and their design and implementation can have a profound impact on both the success of an irrigation scheme and its impact on fisheries and fishers.

The remainder of this section provides some background on the types of institutions used in fisheries and irrigation management in order to give an overview of what institutional areas should be considered in an assessment of the impact of irrigation on fisheries.

In these guidelines the definitions in box 3.7 will be used.

Box 3.7. Definition of terms for institutional assessment

Rules define what actions or outcomes are required, prohibited, or permitted, and the penalties to be applied if the rules are not followed.

Institutions are sets of rules that govern human behaviour. These consist of:

- operational rules for resource use (rules that determine by whom, where, when and how resources may be used);
- conditions of collective choice, which are the set of rules which determine how operational rules can be made; and
- 'constitutional' rules pertaining to conditions of collective choice.

Organisation is a body of people working towards a common purpose, distinct from institutions, but using institutions for organisation and implementation of activities.

It should be remembered that although institutions are designed to be followed, whether individuals decide to follow them or not depends on their own decisions. Frequently, there is a significant difference between what institutions prescribe and what is actually done. Both need to be understood when investigating impacts of irrigation on fisheries.

A complex systems of formal and informal rules regulates many inland fisheries.

There are many different levels at which decisions are made and three levels are commonly recognized as being useful in conceptualizing institutions and how they affect each other. These are the operational, collective choice and constitutional levels.

At the operational level, individuals decide on their day-to-day actions regarding resource use. For example:

- a farmer may decide that he should irrigate his rice field.
- a fisher may decide that he should go fishing in a certain lake.
- or a water guard may decide that he must open the intake gate.

All these decisions will be affected (though not necessarily determined) by any rules that prescribe what must, should, or should not be done with regard to these activities. Such operational rules concern when, where and how fish or water can be withdrawn, who should be monitoring the actions of others, and how, and what rewards or sanctions are given for certain courses of action.

Operational rules are made by groups of decision-makers (which could include local resource users, government officials, and external authorities) at the collective choice level. At this level groups of people (not individuals) decide, for example, how a particular fishery can be protected or improved, or how a particular water control scheme can be operationalized, setting down a set of operational rules to achieve this. In deciding on operational rules people are affected by collective-choice rules: the rules that determine who is eligible or required to make operational decisions, how they must be made (e.g. unanimity, majority, rights of veto), what information must or must not be provided in making them, and what rewards or sanctions will be given for different courses of action.

These collective-choice rules are also made by a group of decision-makers (e.g. regional, national, international policy-makers), this time at a higher level, known as the constitutional level.

Each set of rules is thus nested within another set of rules, the end result of which are the operational rules that affect the day to day decisions of resource users and therefore the outcomes of resource use. Understanding these interactions is important, as often it is the way operational rules are made (not the rules themselves) that leads to unexpected or undesirable outcomes. This is particularly true for irrigation and fisheries, as frequently irrigation decision-making occurs without including individuals with an understanding of the possible impacts of the irrigation scheme on the fishery. In this case the problem lies with the collective-choice rules and should be addressed at that level.

At the same time as there being different levels of rules and rule-making, institutions within a level will also be made by different people in different places, such as government officials in bureaucratic structures, judges in courts, elected representatives in local or national legislatures, or user associations in community halls. For example, the sets of operational rules that determine where and when a fisher can fish, how much he (or she) can catch and with what, may have come from a mixture of government legislation (local, national, regional), local customary law, private associations, or informal user gatherings. Table 3.9 shows the types of activities relating to irrigation and fisheries for which institutions may be crafted at both the operational and collective choice level. The table also contains details of specific institutional instruments where relevant.

Getting a good overview of institutional arrangements is important, because they will have a strong bearing on the outcomes of fisheries exploitation, both before and after any irrigation development. Tools 18 and 19 outline relevant approaches for this.

Tool 18. Studying institutional arrangements in fisheries

Because institutional arrangements may be formal or informal, and involve several different levels of organization, information must be obtained from a range of stakeholders:

- Government at central, regional and local level. What are the legal rules governing (a) the use of aquatic resources directly (e.g. gear or seasonal restrictions imposed at government level), and (b) the rights of resource users to regulate use and make local rules.
- Resource users. Who can fish where, when and how? (Traditional rules may seem so natural to resource users that they are not mentioned, so it is important to ask a range of probing questions).

Table 3.9. Operational and collective choice rules in irrigation and fishing.

Types of rule	Activity being controlled	Details/ possible institutional instruments
Operational Rules	Regulating fish allocation and withdrawal	• Who can fish ◆ Licensing Leasing Membership of specified associations or user communities
		• Amount and type of fishing ◆ Gear restrictions (total restrictions, seasonal restrictions) ◆ Mesh / fish size limits ◆ Reserves ◆ Closed seasons ◆ Catch quotas
	Regulating water distribution	• Who can withdraw water ◆ Membership of specified associations or water-user groups ◆ Permits ◆ Riparian rights • Water distribution method ◆ On demand /semi demand ◆ Canal rotation (free demand) ◆ Rotational system ◆ Continuous flow
	System maintenance (irrigation)	Maintenance of, for example, • Dam and reservoir • Irrigation network • Drainage network • Rural road network • Flood protection dykes
	Monitoring operational rules	Degree of internal versus external regulation
	Enforcement of operational rules	• Presence of fines, social sanctioning. • Extent to which rules are enforceable and legally binding?
Collective choice rules	Who can, cannot or must make the decisions	• Which organizations and personnel? e.g. ◆ user community involvement ◆ cross-sectoral representation ◆ cross-discipline representation ◆ Government/ NGO representation
	What procedures are considered compulsory, advisable or voluntary?	• Consultation ◆ Stakeholder analysis/ participation • information gathering e.g. ◆ Environmental impact assessment ◆ Social impact assessment ◆ Stock assessment (fisheries) ◆ Site survey (what type?)
	What aggregation rules are used to finalise decision-making?	Majority vote, unanimous vote, right of veto
	What information must be made available to decision-makers	See information gathering above
	Monitoring collective choice rules	Who and how
	Enforcement of collective choice rules	• Presence of fines or other forms of sanctioning for breaking rules • Extent to which rules are enforceable and legally binding?

Tool 19. Assessing the level of compliance with rules

There are several ways of assessing compliance:

- Direct questions. General questions such as "Do most people follow rule X?" will often generate reasonably accurate information (more so than asking an individual "do you follow rule X?")
- Enforcement history. Where rules are actively enforced in a formalized way (by user groups or government), it may be possible to trace records of proceedings
- Discrepancies in information on rules. The first condition for compliance is knowledge of rules, and information on rules obtained from different stakeholders may be checked for consistency to assess the level of knowledge.

3.7.2 Patterns of interaction

Patterns of interaction (figure 3.1) are the actions that resource users take in the light of institutional arrangements and other situational variables, and their personal values and beliefs. These actions may well be very different from those stipulated in institutional arrangements if, for example, resource users do not accept the legitimacy of rules and/or enforcement is lax. It is therefore important to assess whether institutional arrangements do in fact have the intended effect on resource user's actions.

Further reading: The Institutional Analysis and Design (IAD) framework is well described in Oakerson 1992 and Ostrom 1990. For its application to the analysis of fisheries management systems see Pido et al. 1996. Hoggarth et al. 1999 describe co-management systems for river fisheries.

3.8 Synthesizing information and diagnosing the fisheries system

The aim of synthesizing information and diagnosing the fisheries system is to establish key factors determining the current outcome of fisheries resource use. This understanding forms a good basis for assessing how the changes brought about by an intervention such as irrigation development are likely to influence outcomes.

Having established a resource systems framework in Section 3.1 and discussed the effects of various attributes on outcomes, we now return to the integrated framework in figure 3.1. A possible approach for synthesizing information using this framework is described in tool 20, and an example applicable to the fishery system of southern Laos is given in box 3.8.

Tool 20. Describing and understanding the fisheries system

In order to assess the impacts of any intervention such as irrigation development on fisheries, it is important to understand the structure and functioning of the whole fisheries system. To achieve this:

1. The main attributes of the fisheries system must be described. The system diagram in figure 2.1 may be used to structure the description.
2. The interrelationships of these attributes must then be explored, with particular reference to those relationships that are crucial to determining outcomes. A useful approach is to work backwards through the framework (figure 3.1), starting from the outcomes (physical as well as livelihoods outcomes) and tracing these back to physical/biological/technical attributes and patterns of resource use (patterns of interaction). The factors determining the latter can then be traced back to the situational variables on the left hand side of the diagram.

It is recommended to repeat both steps iteratively throughout the assessment. Do not wait until the end of the assessment to "put things together"! Thinking about the whole system early ensures that all relevant information is obtained, and wasteful collection of irrelevant information is minimized.

A first understanding of the fisheries system may be gained on the basis of secondary information, key informant interviews and direct observation at the beginning of the assessment. This should be updated as more information becomes available from PRAs, surveys etc.

Further reading: Pido et al. 1996.

Box 3.8. A diagnosis of a fisheries system in southern Laos

This example from inland fisheries in Laos illustrates the diagnosis of a fisheries system, using tool 20.

Outcomes

- Virtually all rural households participate in fishing, mostly for subsistence.
- The poorest fishers obtain greater relative and absolute benefits from fisheries than other groups.
- Fisheries resources are very heavily exploited and returns to fishing effort are low.

Patterns of interaction

- Very high level of fishing effort due to importance of fish in diet, low opportunity costs of labour, underdeveloped markets for fish and labour, and
- The poor fish more than others due to lower opportunity costs of labor and unrestricted access to most aquatic resources.

Situational variables

Physical/biological

- Fisheries are naturally productive due to availability of habitat including large areas of rainfed paddy and wetlands.

Livelihoods

- Fish products are a key part of local diet.
- Agricultural production is largely for subsistence.
- Few opportunities are available for off-farm employment.
- Only partially developed markets available.

Institutional attributes

- Local communities have de facto authority over aquatic resources.
- Tradition of communal management of aquatic resources prevailing.
- Access restrictions may apply only to a small proportion of aquatic habitats.

Chapter 4

Impacts of irrigation development on fisheries

4.1 Overview

Irrigation development may have impacts on most aspects of the local fisheries system:

- Irrigation structures modify hydrology and habitat connectivity, with strong impacts on associated ecological processes.
- Exploitation methods will change in response to hydrological change and new infrastructure.
- Livelihoods are likely to respond to the opportunities and problems created by irrigation development, and the role of fishing may change.
- Active management of water resources becomes both possible and necessary, new institutional arrangements are likely to be created for this, and fisheries institutions must link up with them.

Overall impacts on fisheries are therefore likely to be complex, but this complexity is best approached by first identifying major impact pathways and then synthesizing this information and evaluating interactions.

Different impacts and mitigation options may arise in the different phases of irrigation development as follows:

- Conception
- Planning
- Design
- Construction
- Implementation (management, operation and maintenance)
- Rehabilitation
- Redundancy

The idea of the development is conceived and planning is carried out to assess the feasibility of the proposed development. This is followed by design and then construction, which in turn is followed by the implementation phase when the project (a dam, irrigation scheme, water supply network, new town, water treatment works, etc.) is managed, operated and maintained. Depending on the quality of the management, operation and maintenance, the project infrastructure may need rehabilitation after some years. In some cases development projects, which were required and feasible 30-40 years ago, are no longer required or functional and are being taken out of commission (this is happening with some dams and reservoirs). During any one of these phases action can be taken that will help to mitigate the impact of the development on aquatic resources and capture fisheries. It is thus recommended that these phases are considered explicitly in the impact assessment. Section 5.3.7 provides a checklist of potential impacts and mitigation measures in different phases.

4.2 The nature of irrigation schemes

Irrigation and drainage schemes are a complex interplay of physical, social and economic environments. Their basic aim is to supply (and remove) water to match the water demands of crops, either as a supplement to rainfall in humid zones or as the main source of water in arid zones. Their impact is, generally, to raise the level of crop production, enhance the security of food production and thus enhance the security and quality of livelihoods.

Associated with the development of the irrigation and drainage scheme, there may be other infrastructural development such as dams to store water for irrigation, river embankments to protect the irrigated area from flooding roads, houses and agricultural processing facilities.

The key objective in irrigation is to deliver water at the right time to match crop needs. The physical irrigation system facilitates the conveyance and delivery of water, while management processes govern, in most cases, the adequacy and timeliness of water delivery.

Ad hoc irrigation

Farmers often use ad hoc methods of irrigation, such as pumping water from local wetlands or rivers, or planting in wetlands as floods recede. Such methods require little infrastructure other than perhaps a mobile pump, or simple diversion structure, and are often referred to as "informal" or traditional irrigation. Although the individual impacts of such activities may be limited, widespread occurrence may remove significant amounts of water from wetlands or rivers and affect fisheries production.

Irrigation schemes and systems

A distinction can be made between irrigation schemes and irrigation systems. The scheme comprises the total irrigation and drainage complex – the irrigation and drainage channels, the irrigated land, villages, roads, etc. The irrigation (and drainage) system refers to the physical network of canals and drains and associated structures.

Irrigation systems comprise the canals and structures of the water delivery system (figure 4.1). Water is diverted from the river into the canal network either via a "free" intake with no structure, or via a diversion structure (weir or barrage) or by pumping. The canal network is sized to carry the design discharge at the different locations within the system, with bigger canals at the top end and smaller canals towards the tail (systems that allow for storage within the canal system may be an exception to this, with the canal size increasing in some lower order canals to store water overnight). Structures are required along the length of the canals (table 4.1) for a variety of purposes, and can be categorised into control, conveyance, access or storage structures. Control structures, such as weirs, gates, and measuring structures are required to divert, control and measure the flow, whilst conveyance structures, such as siphon underpasses, aqueducts and culverts are used to convey the water across or under obstructions such as drainage channels or roads. Access is generally provided on canal or drain embankments, both for maintenance purposes and for access to fields. Storage is provided in some systems to allow water to be stored overnight when irrigation is not taking place and used during the daytime.

An important concept in irrigation is that of "command", whereby the water level is sufficiently higher than the land level such that water can flow across the land under gravity flow. Due to the friction effect present in canals and structures when water is flowing, the command required above the field level might be 15-20 cm at the field, and 50-60 cm at some location in the canal network

Figure 4.1. Layout of a typical irrigation and drainage system.

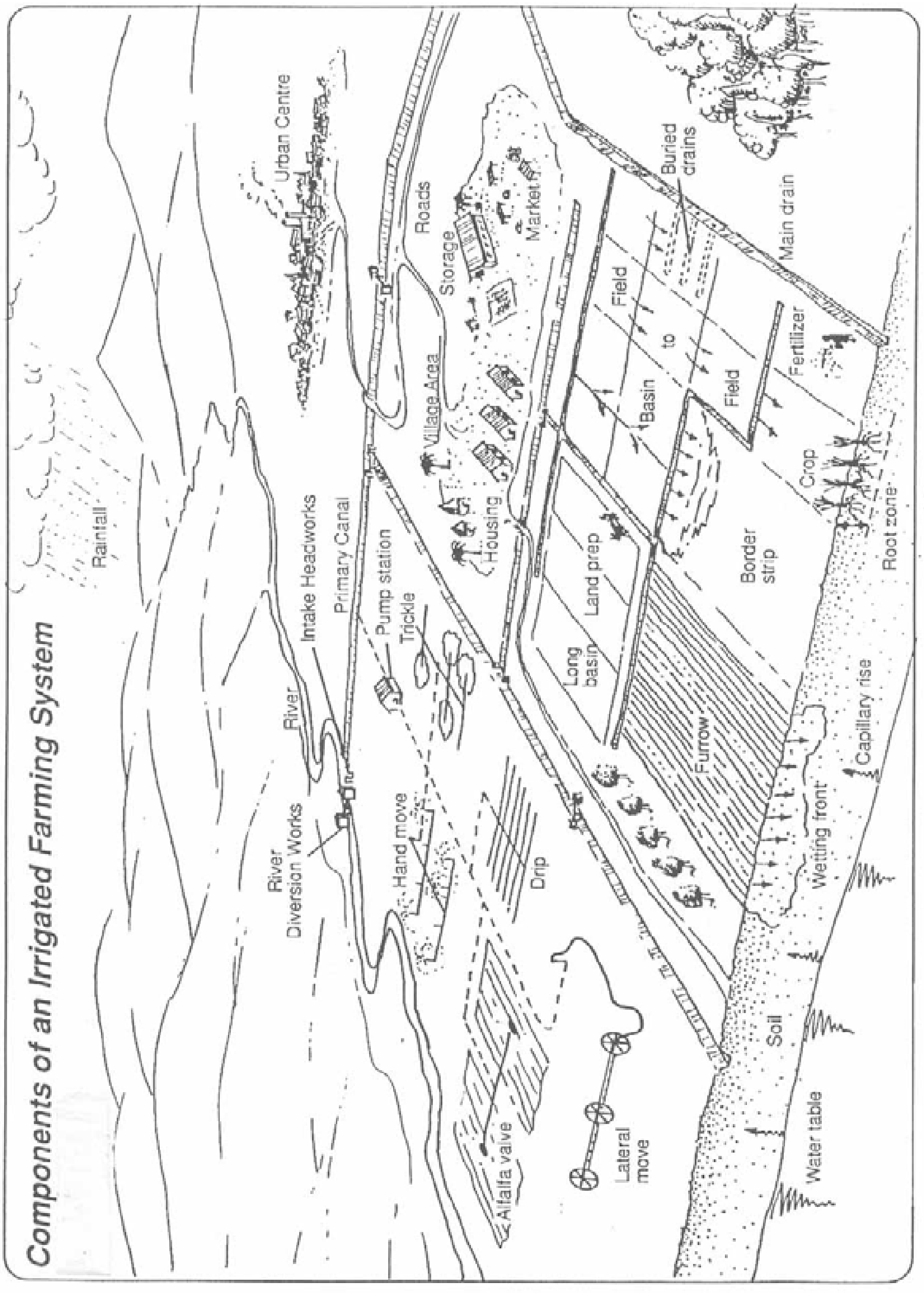
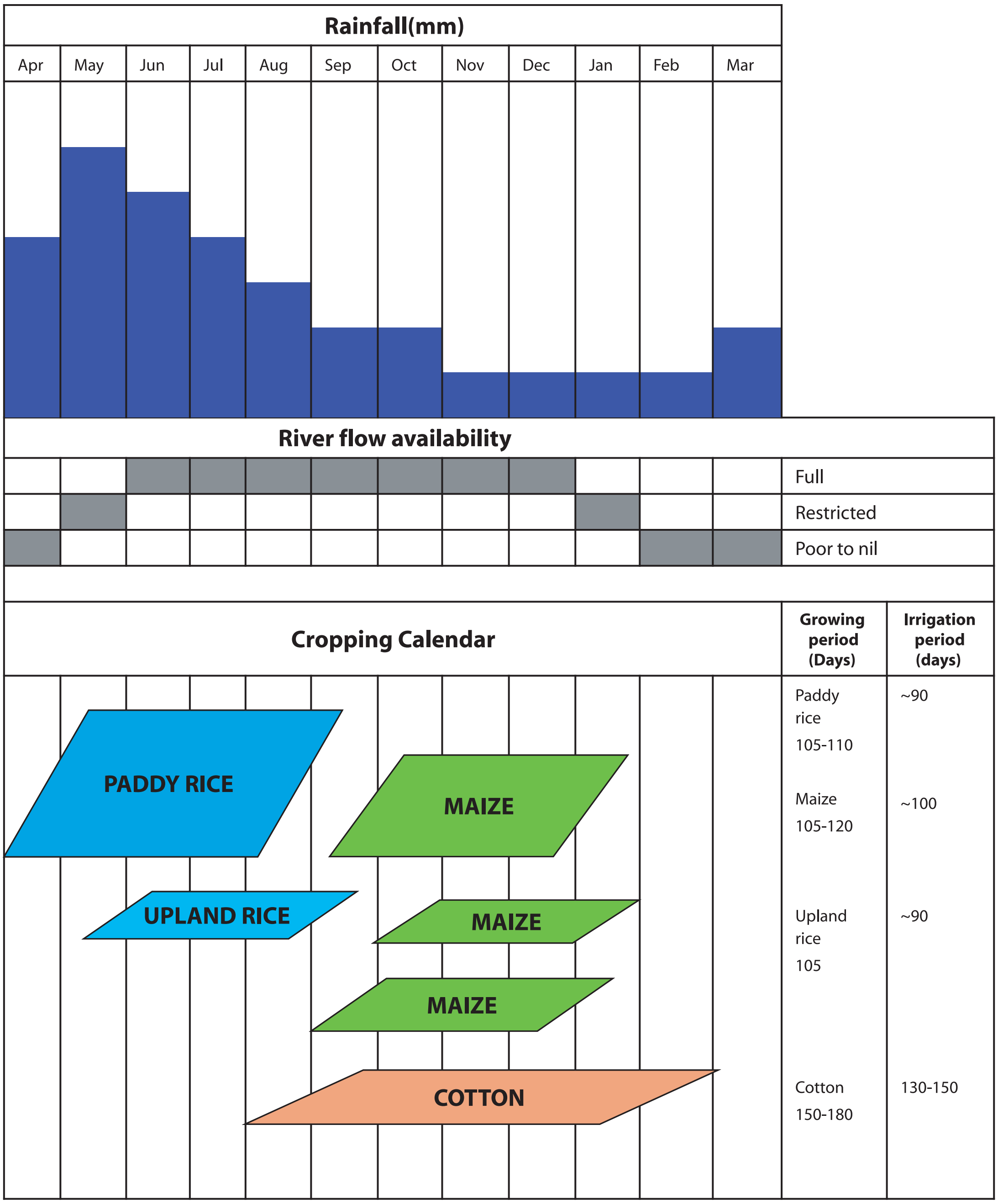


Figure 4.2. Matching the cropping pattern to the water availability from a river.



some kilometers upstream. Thus the crest of a weir across the river might be some 2 meters above the datum level of the land that is to be irrigated. The actual height will depend on the friction and head losses that occur in the canal network, and the relative datum levels of the irrigated land and the river. River structures, such as weirs and barrages[1], are thus required to maintain the desired water level in the river in order to command the irrigated area. They are an essential part of irrigation systems, but form a barrier to fish movement.

[1] Both structures are used to raise the water level in the river so as to command the irrigated land. A weir raises the water level by means of a fixed wall across the flow, whilst a barrage has gates, which when closed raise the water level and when open allow flood flow to pass.

The irrigation water diverted from the river is delivered to the land by the canal network (primary, secondary and tertiary canals) and then delivered to the field via the quaternary or field channel. Designs vary, but in general the primary and secondary canals are designed to flow continuously, whilst the tertiary and quaternary canals flow intermittently. The exception is for paddy rice irrigation where in some systems the canals flow continuously.

Within the field, applying water to the land can be through a variety of ways (termed “the irrigation methods”), e.g.:

- Basin irrigation
- Border strip irrigation
- Furrow irrigation
- Overhead and trickle irrigation

With basin irrigation the land is divided into horizontal basins, separated by earth bunds. With border strip, a sloping basin is created in the direction of the predominant land slope, with zero or very small cross slope. With furrow irrigation V-shaped furrows are formed, generally down the predominant slope. Overhead and trickle irrigation involves pumping the water from the secondary or tertiary canal and applying it to the land via sprinklers or small emitters.

With basin irrigation the water is fed into the basin and ponded until it infiltrates into the ground or is taken up by the crop. It is the main method used for irrigating rice (termed paddy rice if the water is kept ponded). In some countries, farmers prefer to have water continuously flowing through the rice field. Farmers argue that this brings in nutrients and maintains an ambient water temperature for the rice crop. With border strip and furrow irrigation, water is fed in at the top of the field and any excess, collected in the drainage system at the tail. To achieve high efficiencies the flow rate of the water has to be controlled to match the slope and soil type to maximize the water infiltrating into the soil and crop root zone. These two irrigation methods are used for “dry foot” crops, with border strip being suited to close growing crops such as wheat, and furrow irrigation being suited to row crops such as maize and sorghum. Sprinkler and trickle irrigation are also used for dry foot crops, such as sugar cane, vegetables and fruit trees.

The irrigation system is mirrored by a drainage system with field, collector and main drains picking up surplus irrigation water or rainfall from the fields and conveying the drainage water back to the river or natural drainage pathways. The drainage system will also have structures (table 4.1), including culverts, drop structures and outfalls. These structures may form a barrier to the movement of fish within the drainage network. Standing water in drains is a breeding ground for mosquitoes and therefore poses a health hazard, thus whilst drains may prove suitable habitats for fish, this has to be balanced with the need to keep them free of standing water to safeguard human health.

Flood control systems

Many irrigation systems also serve to control the flooding of low lying agricultural land, often this is a by product of water storage in reservoirs. There are also, however, systems that serve primarily to control flooding through the construction of embankments along rivers. Embankments may be equipped with regulators to allow controlled flooding, in particular of rice fields.

Table 4.1. Physical components of irrigation, flood control and drainage schemes.

Component	Levels	Purpose
Canals	Primary, Secondary, Tertiary, Quaternary	To convey irrigation water to the fields.
Drains	Main, Collector, Field	To convey irrigation water or rainfall away from the field.
River weir	River	To maintain the required water level to command the system, and to divert and control irrigation water supplies.
Embankment	River	To prevent flooding of irrigated areas.
Pump station	Main canal Main drain	To lift water to command level for gravity irrigation, or to lift and pressurise water for piped distribution. To remove water from drainage channels below river or natural drainage level.
Cross regulator	Primary and secondary canals	To raise and maintain water surface at the required elevation at control and division points in the system.
Head regulator	Primary, secondary and tertiary canals	To regulate discharge entering a canal, usually by means of a gate.
Measuring structure	Primary, secondary and tertiary canals	To measure discharge entering the canal.
Aqueduct	All levels of canal	To pass the canal over an obstruction (another canal, a drainage channel, road, etc).
Culvert	All levels of canal or drain	To pass the canal or drain under an obstruction (road, drainage channel, etc), or to pass an obstruction under the canal (usually a drain).
Drop structure	All levels of canal or drain	To “drop” the canal or drain bed level in a safe manner. Used to slacken canal or drain slopes on steep land to avoid erosion.
Escape structure	All levels of canals	Used to escape water safely from a canal into the drainage network in the event of oversupply.
Syphon underpass	All levels of canals	Used to pass the canal below an obstruction such as a road or drainage channel.
Distribution box	Quaternary canal	Simple distribution structure to distribute the water between quaternary channels.
Night storage reservoir	Main canal or on-farm	To store irrigation water during the night. Main canals thus operate 24 hours/day whilst lower order canals can be operated during the daytime.
Tubewell	On-farm	To abstract groundwater for irrigation. Can be used in conjunction with surface water system.
Bridges	Road bridges Foot bridges	To allow human and animal traffic over the canal or drain.
Roads	Inspection roads Access roads	To gain access to the irrigation system and villages. For inspection and maintenance.
Fields	Within tertiary unit	To cultivate the crop. Laid out for different methods of irrigation (basin, furrow, sprinkler, etc).
Access points	Main canals	To access the canal for human and animal traffic for obtaining water, washing, etc.

Management, operation and maintenance of the irrigation systems

The management, operation and maintenance of the irrigation system govern how efficiently and effectively the diverted irrigation water is utilized within the canal network. The management structure varies from scheme to scheme, with some schemes being farmer-managed and others managed by government or private agencies. The management form will influence who controls the operation and maintenance (O&M) of the irrigation and drainage system, and, importantly, who pays for O&M.

Irrespective of the management form, plans have to be made on a regular basis for allocating water to farmers or fields. Irrigation water has to be scheduled in an organized manner so that: (a) water is delivered in the quantity and at the time required by the farmer and crop; (b) effective use is made of the available water, and; (c) water distribution is equitable amongst farmers. Typically plans are made on a regular basis – either weekly, 10-daily or two-weekly – with data being collected on the demands for the coming period (through requests made by the farmers), and balanced with the anticipated levels of availability from the water source. Field staff are then instructed on the discharges that are required in each canal on each day, and gates adjusted to pass these discharges. The regulation and maintenance of stable discharges within a canal network is not easy, with fluctuations in flow entering the canal system, or adjustments to flows in the upper reaches rippling through the network.

The demand for irrigation water will vary with the needs of the crops during the growing season. Initially, except for rice, the demands are small (about 40 percent of the peak), then as the crop grows to maturity the demand increases to 100 percent of the demand at full canopy, falling off to approximately 60 percent just before harvest. As the root depths are shallow the intervals between irrigations are small at the start, increasing as the roots develop and increased storage becomes available in the (growing) root zone. For rice, the highest irrigation demand is often during the land preparation phase when large volumes of water are required to wet and puddle the land ready for rice planting. To reduce the total demand required at peak demand times, the cropping is often staggered. This not only reduces the water demand, but also the labor demand (at both planting and harvesting), allowing farmers to help one another with agricultural activities such as ploughing, planting and harvesting.

In locations where the water demand for an irrigation scheme is high relative to the river flow, the cropping is tailored to suit the water availability (figure 4.2). The high water demanding crops are grown during the wet season to maximize the water available from rainfall, with less water demanding crops grown during the dry season. The area planted is often reduced as well as the crop type is changed during the dry season.

Maintenance is carried out to different degrees on irrigation and drainage systems depending on a variety of factors including the management type, the value of irrigated agriculture, the general socio-economic conditions and the availability of finance and labor. Without maintenance, the irrigation system will deteriorate and eventually become inoperable. Maintenance can be divided into four categories:

- **Regular.** Maintenance carried out by irrigation staff on a regular basis, such as removal of trash from canals.
- **Periodic.** Maintenance carried out periodically during the irrigation season, such as removal of growing vegetation from canal sections.
- **Annual.** Maintenance carried out each year, either by direct labor or contractor, following an annual inspection to identify maintenance needs.
- **Emergency.** Maintenance carried out in emergencies, such as following a breach in a canal bank, or river bank during floods.

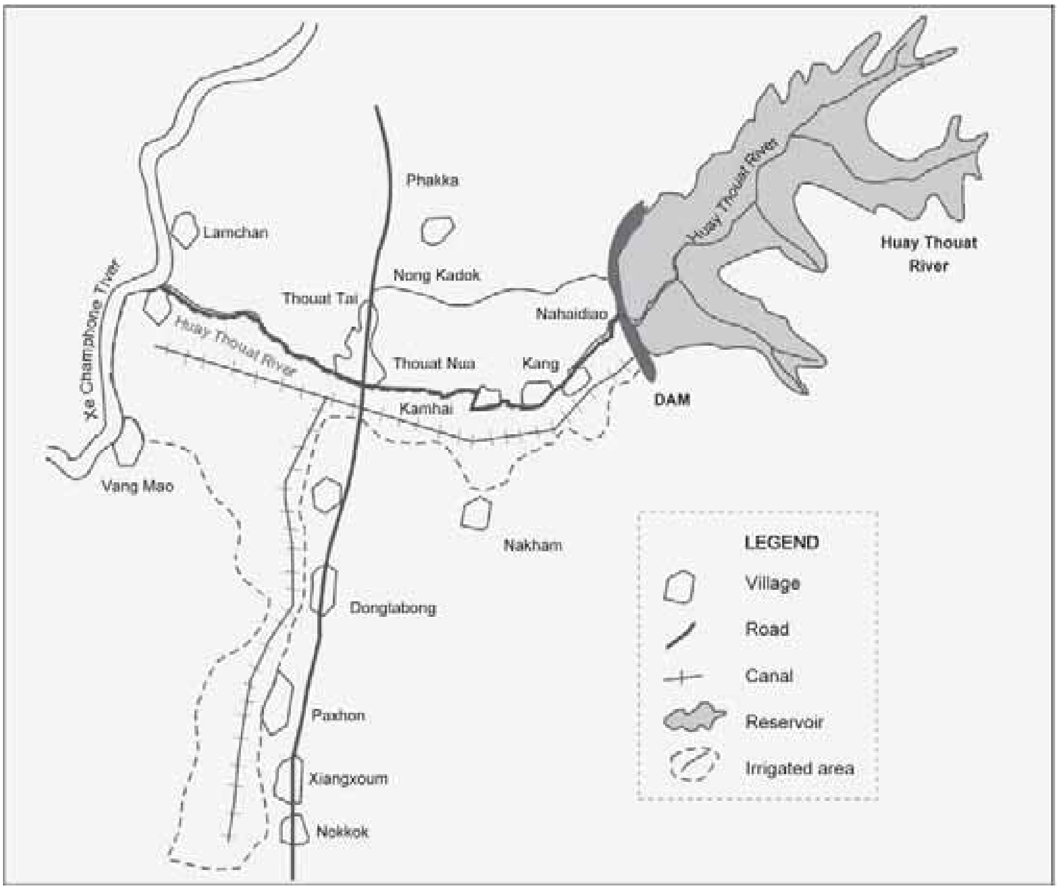
Maintenance can have a marked impact on fisheries, for example if herbicides are used to remove vegetation from drainage systems. In locations where canals and drains provide a suitable habitat for fish, maintenance practices which mitigate adverse impacts on fisheries should be considered, as discussed in later sections.

4.3 Impacts of irrigation development on physical habitats

The first step in any impact assessment is to gain an overview of the proposed irrigation system and its operation. For this it is useful to map the irrigation system on to the water body map (tool 21).

> **Tool 21. Describing infrastructure and water requirements of irrigation systems**
>
> Planned or existing irrigation infrastructure should be mapped onto aquatic habitat maps as a first step in impact assessment. This should include details such as control structures, culverts under canals etc. For an example, see figure 4.3.
>
> Water requirements of the irrigation scheme should be quantified in terms of total abstraction, process depletion (loss of water to evapotranspiration) and return flow (abstraction minus process depletion). Ideally this should be done as annual totals, and broken down on a monthly or seasonal basis.

Figure 4.3. Example of an irrigation system map overlaid on a water body map.



4.3.1 Habitats created by irrigation infrastructure

Three types of new aquatic habitats may be created by irrigation development: reservoirs, irrigation canals and drainage canals.

Reservoirs are standing bodies of water that nonetheless retain certain riverine characteristics such as a short residence time of water and large area and volume fluctuations. Reservoirs can provide good fish habitat, particularly if fisheries interests are taken into account during its operation. Temporary storage reservoirs often provide poor fish habitat due to rapid and extreme volume and area fluctuations.

Irrigation canals convey water to the fields. Large canals such as the primary canals of large irrigation schemes tend to convey water continuously throughout the season if not the whole year, and may provide suitable habitat for certain fish species. Smaller canals tend to convey water only intermittently and are usually unsuitable as fish habitat.

Drainage canals convey water from the fields to natural water bodies. Drainage canals tend to convey water continuously and, being mostly earth canals, often offer some structural habitat diversity. This makes them good potential fish habitats. However, drainage water is often polluted with agrochemicals, which may negatively affect aquatic life and pose food safety problems. Drainage water may also be saline or contain high levels of selenium.

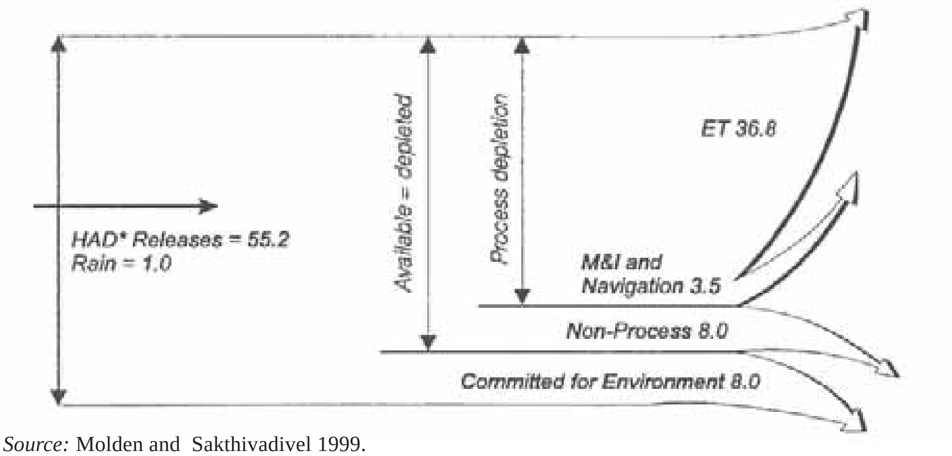
4.3.2 Hydrological change in existing habitats

The nature and extent of an irrigation development have impacts on hydrology. In many river basins irrigation consumes about 70 percent of the available water resources. Unlike water used for industry or domestic purposes, the percentage of return flow from irrigation systems is small, with the bulk of the diverted water being returned to the atmosphere through evapotranspiration. Water accounting provides a useful starting point for assessing hydrological impacts at the irrigation scheme catchment and basin level. The inflow of water into the water balance domain is accounted for in terms of outflow and depletion. Outflow consists of water specifically committed to the environment, and any additional flows that would be available for human use but are not utilized. Depletion is the loss of water from the balance domain, either due to intentional use such as irrigation (process depletion) or due to other processes that may or may not be considered beneficial (non-process depletion). An example of a water balance in an irrigated river basin (the Nile below Aswan high dam) is shown in figure 4.4. Virtually, all water other than that explicitly committed to the environment is depleted, and evapotranspiration from irrigated agriculture accounts for the largest share of depletion by far.

The net removal (depletion) of water from the basin combined with the use of reservoirs to store water and release it when needed have a dramatic impact on river basin hydrology and ecology. Clearly, irrigation development will reduce the total annual flow of a river from which water is abstracted. However, the impact on seasonal flows is differentiated according to the type of structure used to divert water into the irrigation scheme.

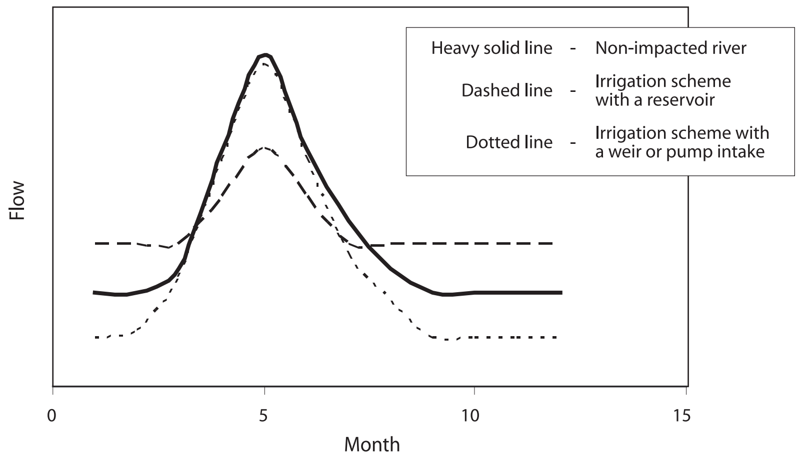
Dams or barrages store a significant proportion of the high flow and release water into the irrigation structures during low flow (dry season). As a result, dam schemes have the effect of smoothing the flood hydrograph seasonally. Part of the water stored will return to the river and other wetland habitats as irrigation drainage or seepage, and the net effect is a decrease in wet, but an increase in dry season water availability (figure 4.5).

Figure 4.4. Water balance in an irrigated river basin: Nile basin below Aswan high dam.



Source: Molden and Sakthivadivel 1999.

Figure 4.5. Impact of irrigation schemes on river flow below the intake structure.



Diversion weirs and pumps do not involve significant storage of water. They have little impact on high flows because there is generally no irrigation intake during such periods and even if there is, it is unlikely to account for a significant proportion of the total flow. However, such structures may divert a large proportion of the low flow during the dry season when irrigation demand is highest. The overall effect is therefore one of largely unaffected peaks, but much reduced low flows (figure 4.5).

Flood control drainage and irrigation (FCDI) schemes have hydrological impacts which are fundamentally different, in that their purpose is to prevent water from entering the floodplains at high flow, while retaining water in the floodplains at low flow.

For a fisheries impact assessment, it will be necessary to gain a quantitative understanding of impacts of irrigation development on the hydrology of aquatic habitats. For a rapid assessment of gross impacts on fisheries production potential and yield, the assessment must cover the total annual and seasonal river flows and seasonal water availability in floodplains and wetlands (tool 22). Chapter 5 gives guidance on more advanced assessment methods is given in Chapter 5.

In general, hydrological analyses should be carried out as part of project design and irrigation planning studies, and made available for fisheries impact assessments. It is important that such studies consider impacts on floodplain wetlands as well as the main channel.

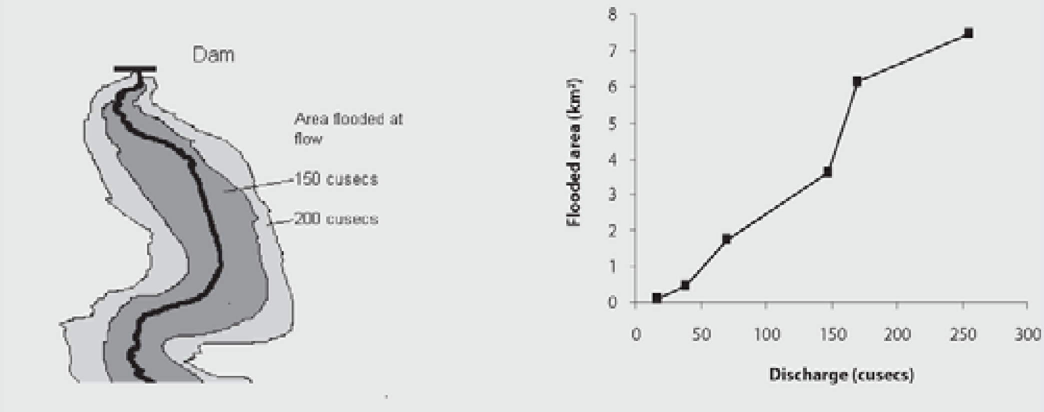
Tool 22. Simple methods for assessing gross hydrological impacts on habitats

The methods are described here for the case of irrigation abstractions, but analogous methods can be used to assess the impacts of additional flows received from inter-basin transfers.

Historical discharge data are crucial to most analyses. Such data are available for gauging stations in most river basins, and can be roughly extrapolated to the location of interest by comparing current flows at the location and the gauging station.

(1) Impacts on river flow. Measure discharge at the point of abstraction and at several points downstream (or use existing data). Total discharge will increase downstream as runoff and tributaries add to the total. Subtract the planned abstraction (or better, process depletion) from the flow to generate a profile of impact with increasing distance from the abstraction point, e.g. as proportional reduction of flow. This should be done on an annual basis, and per month or season. An approximate "area of impact" of the flow reduction can be delineated by the point at which the abstraction accounts for only a small proportion (1-5%) of the total at that point.

(2) Impacts on temporary flooding. The extent of temporary flooding is a function of discharge and topography. To obtain an approximate relationship between discharge at the abstraction point and the flooded area downstream, break the downstream area into finite sections and estimate empirical relationships between discharge and the flooded area for each section. This may be done by estimating the extent of historical floods through participatory mapping, and relating this to historical discharge data. The distance-discharge relationship established under (1) may be combined with the flooding-discharge relationships for each section to calculate overall impacts.



Establishing the relationship between discharge and the flooded area by mapping the flooded area for different discharge levels and plotting the flooded area against discharge.

(3) Impacts on floodplain lakes. Floodplain lakes may receive much of their water during the annual flood. Hence it is important to identify floodplain lakes and depressions that may no longer be flooded regularly. In such lakes, water levels may drop to the groundwater table, and the lakes may dry up altogether if the groundwater level is below the lake bottom. Where the waterbodies likely to be affected in this way are important, it may be necessary to conduct detailed water budget calculations.

(4) Reservoir creation. In cases where reservoirs are created to store significant amounts of water, details of their area, capacity and seasonal hydrology should be available from the design plan.

4.3.3 Habitat impacts of land use change

Irrigation development inevitably leads to changes in land use, which should be assessed (tool 23). Some of these changes are intentional, but others may be incidental and affect land outside the command area. The following are among the key changes that may be expected to impact on aquatic habitats.

- Natural wetland areas inside irrigation schemes are often drained and/or filled up intentionally to increase land available for agricultural production or habitation. This will reduce local aquatic habitat availability, but may increase runoff and stream/river flow during wet periods.
- Overall cropping intensity will increase through multiple cropping, new crops or varieties, and higher inputs of fertilizers and pesticides. Overall agricultural water use may increase beyond that envisaged at the planning stage. Drainage water may be high in nutrients and/or pesticides, it may also become increasingly turbid and/or saline.
- Paddy land is likely to be modified so that less water is stored in the fields, effectively turning them from aquatic into mostly terrestrial habitat. This may well be the most significant impact on fisheries of irrigation development in rice-based farming systems.

Fisheries impacts on land use change associated with irrigation development may be far more significant than is commonly realized. The comparison of land use in a small area of Bangladesh before and after flood control and irrigation development illustrates this (figure 4.6).

Impacts of land use on water quality may have positive as well as negative impacts on fisheries productivity of aquatic habitats. Nutrient enrichment (eutrophication) of standing waters may threaten the existence of aquatic biota adapted to nutrient poor conditions and also affect the utility of water for certain human uses such as drinking or recreation. The reduction and reversal of eutrophication is usually a key objective of catchment management programs. However, the total fish yield obtainable from a lake or reservoir is strongly and positively influenced by its trophic status.

Irrigated rice fields

Natural fisheries production in paddies depends on the up-migration of fish at the start of the rainy season, and much of the catch is achieved during the down-migration. Rice field fisheries may be largely unaffected by irrigation development as long as the rainfed crop cycle is managed traditionally, and sufficient dry season aquatic habitat and its connectivity with paddies are maintained. However,

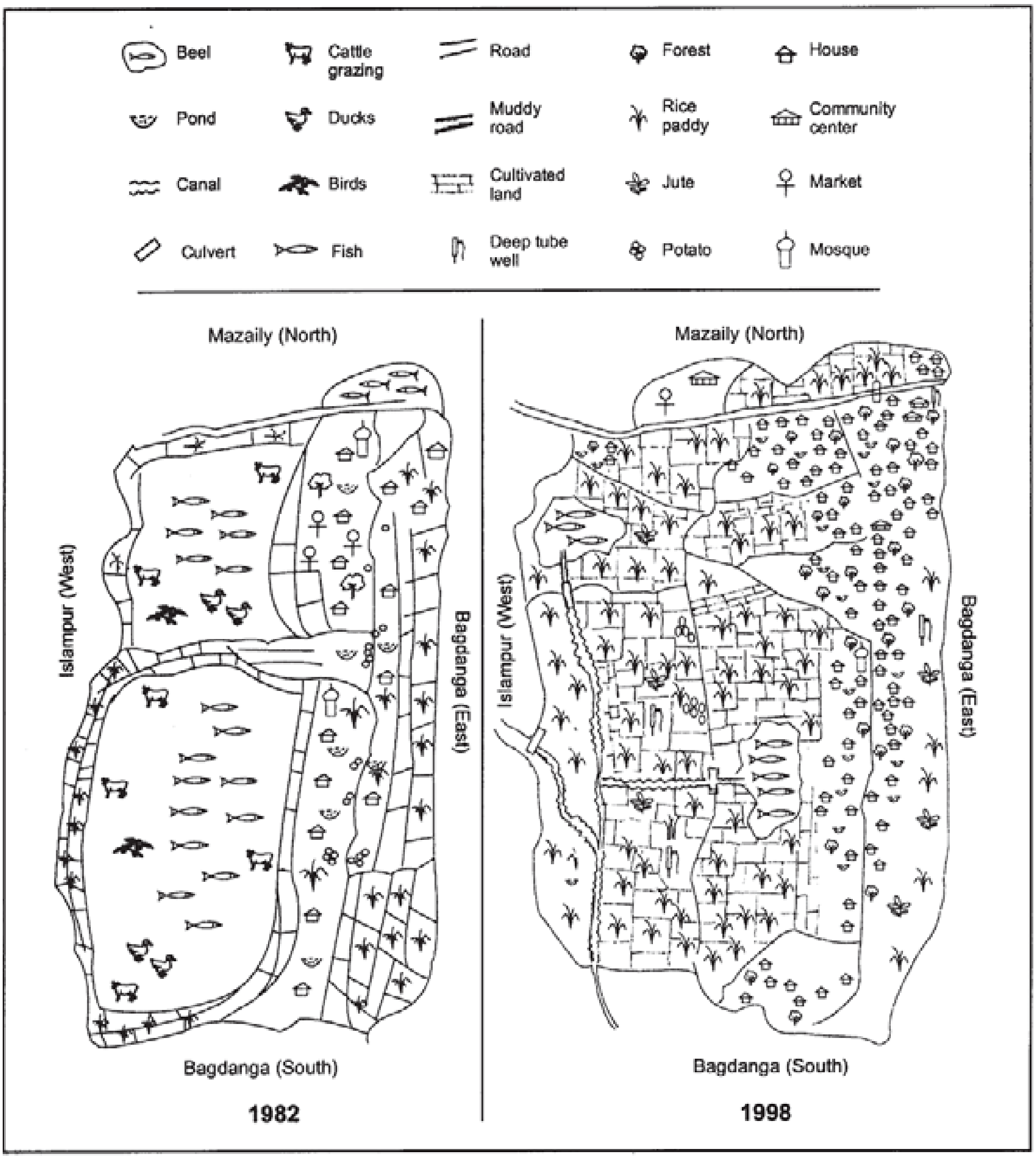
Tool 23. Assessing habitat impact of land use change

(1) Check design plans for planned land engineering, and discuss anticipated land use change with relevant stakeholders. Identify planned or likely land use changes on the water resources/irrigation system map.

(2) Evaluate likely changes in cropping patterns and inputs following irrigation development, with particular references to fertilizer and pesticide use, and possible effects on soil erosion and salinization.

(3) In rainfed rice systems, assess likely changes in rice field water management and their implications for fish habitat.

Figure 4.6. Land use change following the development of a flood control drainage and irrigation scheme in Bangladesh.



Source: Mazumder and Lorenzen 1999.

lower water levels even in the wet season crop (where the need to store sufficient water in the paddy is reduced by irrigation water availability), loss of permanent wetlands and connectivity, and increased pesticide use are likely to reduce fish production in irrigated paddies. Changes in habitats and connectivity may also change fishing practices and the vulnerability of fish to harvesting.

The irrigated crop cycle is unlikely to produce high fish yields because there is no natural up-migration and reproduction during the dry season. Some species may remain in the paddies if these are drained only briefly or not at all between cycles, but this is unlikely to add significantly to yield.

4.3.4 Changes in habitat connectivity

Changes in aquatic habitat connectivity (i.e. the ability of aquatic organisms to move between habitats) (tool 24) may arise from irrigation and associated structures, but also from hydrological changes:

- Dam or weir structures reduce longitudinal connectivity of the respective stream or river. Dams storing a significant share of the annual flow present major obstacles to fish movement at all times, unless suitable fish passage facilities are provided. Weirs on the other hand may have a strong impact under low flow conditions when much of the flow is abstracted, but little impact during high flows. Small weirs in tropical rivers may be fully submerged at high flow.
- Canals and access roads may reduce lateral connectivity of the floodplain, and/ or longitudinal connectivity in small tributaries. Culverts or bridges across drainage lines will maintain hydrological connectivity, but not necessarily ecological habitat connectivity. The latter will depend mostly on the current velocities through culverts and the height of any steps/cascades.
- Flood control levees reduce lateral connectivity between the river and floodplain habitats, but fish friendly operation of regulators may allow maintaining a degree of connectivity.
- Canals may increase connectivity between certain habitats, particularly where they convey water more or less continuously and the control structures are designed and operated in a fish friendly manner.
- Hydrological changes may have a strong effect on connectivity. For example, reduction in flooding may permanently isolate floodplain lakes. Complete abstraction or retention in a reservoir of dry season flows from rivers may break connectivity of rivers even where diversion structures in themselves are insignificant (e.g. pumps).

Structures pose barriers to migration principally when:

- Current velocities exceed the maximum short-term (darting) speed of fish.
- The maximum darting distance the fish would have to swim against a fast current is greater than the distance covered at darting speed in three seconds.
- The vertical height fish would have to jump is greater than the maximum jumping height.

Tool 24. Assessing changes in connectivity

(1) On the water body and irrigation system map, mark:

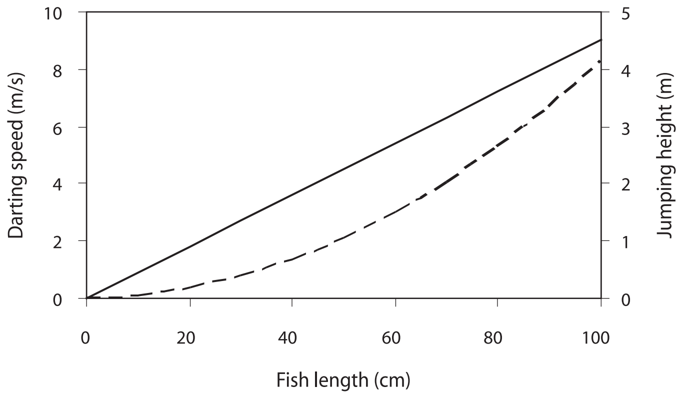
- Locations where irrigation and related infrastructure are likely to affect connectivity relative to the pre-impact situation.
- Locations where hydrological change is likely to affect connectivity relative to the pre-impact situation.

(2) For each location identified in (1), describe key characteristics of the barrier being created and any pathways potentially remaining (e.g. culverts below canals). Assess whether the barriers will be total, partial or insignificant obstructions to migration based on height, flow velocity, seasonality of hydrological connection etc.

(3) Identify those habitats that will be fully or largely isolated.

Darting speed and distance as well as jumping height are closely related to fish size as shown in figure 4.7. Hence many small barriers such as low weirs or culverts with moderately fast currents will allow passage of large fish, but not small fish.

Figure 4.7. Darting speed (solid line) and jumping height (dashed line) of fish in relation to their body length.



Source: Gallagher 1999.

4.3.5 The role of operational decisions

While some impacts of irrigation development are virtually inevitable as a result of infrastructure, others depend on operation of the irrigation system and agricultural practices. The types of crops grown for example will strongly influence water demand from agriculture, water depletion, and consequently amount of water available to support aquatic resources. It is useful at the assessment stage to highlight any impacts that are sensitive to operational decisions and agricultural practices, in order for these issues to be considered in assessing mitigation or enhancement measures.

4.3.6 Overall impacts on aquatic habitats and their connectivity

At the end of the habitat impact assessment, all expected changes in habitats and their connectivity should be clearly marked on maps and tabulated. This information is used in the next step to assess impacts on fisheries. Table 4.2 may be used to cross-check that key habitat impacts have been considered.

Further reading: Impacts of dams on flows and aquatic habitats are reviewed by the World Commission on Dams 2000. Roggeri 1995 deals with a wider range of habitat modifications in tropical wetlands.

Table 4.2. Summary of potential impacts of irrigation development on aquatic habitats.

Process	Impact
Physical system	
Storage of water for irrigation	Storage of water for irrigation significantly affects flow regime of the river, attenuating floods and increasing the available flow during the dry season. If abstraction from irrigation is directly from the reservoir there may be no additional base flow in the river during the dry season. Reservoirs often support productive fisheries that may compensate to some extent for reductions in riverine fisheries production.
Diversion of water for irrigation	In pumped irrigation systems fish may be killed in pump impellers, whilst in gravity flow systems fish may enter the irrigation network without harm but may then become en trapped. Screening may be used to reduce entrapment, but this may not necessarily increase fish abundance in the longer term because available habitat is also reduced.
Flood protection	Many irrigation schemes require protection to prevent flooding of agricultural land. Reductions in the extent or duration of flooding will have negative impacts on fisheries production.
Change in land use	Irrigation development on the uplands has limited direct impact on fisheries, however in floodplains, irrigation development will have a major impact due to the reduction of natural floodplain habitat for fish. Natural land forms will be incorporated in the irrigation design, with ridges being used for canals and troughs for drains.
Water delivery	Canals will be constructed to convey irrigation water. In general canals are poor fish habitat, but continuous operation at moderate flow velocities and creation of semi-natural habitat within them may allow some fisheries production.
Water removal	Drainage is a major part of irrigation systems in flood plains, in many cases development cannot proceed until the land is drained. Natural drainage lines are used for drainage pathways but these are often realigned to be straight sections joined by curves to fit in with the (usually) grid like pattern of field layout and irrigation network. Drainage channels generally offer better habitats for fish than irrigation canals, though pesticides in drainage water can be damaging.
Management	
Irrigation scheduling	Procedures for scheduling of irrigation to match crop water requirements influence the flow regime in canals, and abstraction from rivers. If fish are present in the canal network the irrigation schedules will impact on them
Maintenance (waterways)	Maintenance of the irrigation and drainage channels remove vegetation and sediment to maintain an adequate hydraulic pathway for water and this may adversely impact on the natural fish population by removing their habitat and damaging their spawning grounds. Use of herbicides for clearing of vegetation may severely impact the fish population.
Maintenance (embankments)	Maintenance to remove vegetation from canal and drain embankments is often carried out for aesthetic reasons, or to prevent damage by roots to the embankments. Removal of this vegetation and the shade provided can have an adverse impact on fish.
Land use	Farming processes can have negative impacts on fish populations in drainage channels, and by connection through to the natural waterways and the river. The incorrect use of pesticides and herbicides are the obvious causes of fish mortality, but poor land husbandry practices, such as bare soils during the rainy season leading to erosion through surface runoff, can also have negative impacts.

4.4 Impacts on fisheries ecology and yields

Irrigation development affects fisheries ecology through changes in habitat availability, quality and connectivity, and in exploitation. As discussed in Chapter 3, overall fisheries production from a river or lake can be predicted with reasonable accuracy from the physical characteristics of the water body and the fishing pressure applied. This is true even for heavily modified habitats, and it is therefore relatively straightforward to predict fisheries production potential and yield of aquatic systems impacted by irrigation development. Overall production impacts may be positive as well as negative.

The situation is different with respect to ecological integrity and biodiversity. Individual species may be very sensitive to subtle changes in hydrology, habitat structure, water quality, and habitat connectivity, and impacts on the structure of aquatic ecosystems cannot be predicted satisfactorily from basic physical characteristics of the water bodies concerned. Moreover, because habitat modifications will tend to change ecosystem characteristics from a more natural pre-impact stage, ecological impacts are negative almost by definition. Exceptions to this rule may occur where habitats and ecosystems are already heavily modified.

An important feature of ecological impacts is that they may take considerable time to develop towards a stable post-impact state. New reservoirs often undergo a surge in productivity based on nutrients from inundated terrestrial biomass that may last for over a decade before approaching a lower, but sustained level of production. Large and long-lived species of fish may remain present in catches for a long period even when the population does no longer replenish itself.

4.4.1 Impacts on fisheries production

Impacts of irrigation development on fisheries yields within the area of impact arise due to two factors:

- Change in production potential due to impacts on habitat availability, quality and connectivity.
- Change in the level of exploitation due to changes in overall or per area fishing effort, and the efficiency of fishing gear use.

In general, irrigation development will tend to reduce the extent and therefore the fisheries production potential of existing aquatic habitats within the area of impact. Where significant new habitat, principally, reservoirs for water storage, is created this may provide a degree of compensation and the net change in production potential may be either negative or positive. A positive net impact is possible, in particular, in regions where natural water retention is low and rainfall leads to negligible or only very short-term flooding.

Irrigation development will almost always change the level of aquatic resource exploitation. Even where overall fishing effort by the local fishers remains constant, this effort may be concentrated or diluted due to changing habitat availability. At the same time, the efficiency of fishing methods is likely to change as the use of many river-floodplain gear types is closely linked to hydrology and migrating fish may be very vulnerable to capture where migration routes are blocked (below dams) or confined (through culverts). Finally, changes in livelihood opportunities bring about an increase or decrease in the number of people engaged in fishing, or in the time and effort people expend on fishing. The effect of such changes in the level of exploitation depends on the pre-impact exploitation status. Based on the yield-effort relationship typical of multi-species fisheries, impacts are summarized qualitatively in table 4.3.

Table 4.3. Impact of irrigation-related changes in exploitation on yields achieved in the area of impact, in relation to pre-impact exploitation level.

	Pre-impact exploitation level, low	Pre-impact exploitation level, high
Concentration or dilution of effort due to change in habitat availability	Little impact on yield	Strong impact on yield
Change in gear efficiency	Strong impact on yield	Little impact on yield
Change in total fishing effort due to change in opportunity costs	Strong impact on yield	Little impact on yield

Tool 25. Forecasting impacts on fisheries production

Much of the information needed to forecast impacts on fisheries production has been generated in the habitat impact assessments.

(1) For each water body in the area of impact, including those destroyed or created by the intervention, tabulate pre-and post- impact area, per-area productivity, and total production. (For rivers without floodplains tabulate length, pre- and post- impact discharge, and total production). Productivity estimates per area or per discharge volume should be based on the values reported in table 3.2, unless reliable location specific estimate are available. Values reported in table 3.2 are based on well documented estimates, and provide a reliable indication of the range within which productivity of different water bodies is likely to lie. It is unlikely that productivity in particular locations is substantially different and any such claims must be treated with caution.

(2) Account for changes in connectivity where relevant. Seasonal habitat entirely cut off from perennial habitat will support very little production. For floodplain habitats cut off from the main stream but connected to other perennial water bodies, a 20-30 percent reduction in total production may be assumed as the worst case scenario to account for loss of lateral migrants.

(3) Calculate an overall pre and post impact balance of production. This can be repeated with different assumptions about impacts and productivity. It is suggested to construct balances for a “best guess”, as well as best and worst case scenarios. For the latter, assume the lowest realistic losses and the highest gains, and vice versa. Where this sensitivity analysis reveals considerable uncertainty about the magnitude and direction of impacts, field sampling and/or further participatory assessment of production assumptions should be carried out.

(4) Impacts of subtle hydrological changes, such as a moderate reduction in wet and increase in dry season flow, should be considered where these seem significant relative to the gross impacts of area or flow reductions.

(5) Where fishing effort is likely to change significantly, it may be useful to account for this by calculating production for different assumed effort levels from yield-effort relationships.

A quantitative evaluation of impacts on production potential and yield may be carried out through a budgeting approach, calculating the production potential and yield from habitats lost, created and those unaffected by irrigation development (tool 25 and box 4.1). The analysis may be carried out to different levels of detail, that is:

- Using average productivity figures for the different water body types, without considering fishing effort or hydrology;

Box 4.1. Fisheries production balance for the Kirindi Oya irrigation and settlement project (KOISP) in Sri Lanka

The KOISP is a complex irrigation project, establishing a reservoir and new command area above an existing ancient irrigation scheme. The layout of the project is shown in figure 4.8, indicating the new and old irrigated areas as well as permanent water bodies after the establishment of the scheme. A fisheries balance for the project is shown in table 4.4. The balance was calculated after the project had been carried out, hence in this case, the post-impact production figures were established by field sampling but pre-impact figures had to be estimated on the basis of secondary information.

Impacts on the various water bodies have been assessed as follows:

- Floodplain: Before KOISP, virtually the full natural floodplain was used for rice cultivation. The floodplain flooded regularly for short periods, and there was some fish production and harvest from the paddies. A yield of 50kg/ha/year was assumed on the basis of comparative data, and is likely to be an overestimate (short flooding and low importance of fish in local diets). The new Lunugamwehera reservoir has inundated about 2000 ha of floodplain (area reduction from 6200 to 4200 ha), and prevents flooding and therefore fish production from the remaining floodplain.
- Lagoons: Drainage water inflow has reduced salinity and forced frequent opening of the sandbar. Marine shrimp catches have been replaced by freshwater fish, while overall production has remained stable. The value, but not overall quantity of catches has been reduced.
- Lunugamwehera reservoir has been newly created. Its production has been estimated at 1344 t by catch sampling.
- The ancient reservoirs (Tissa Wewa, Yoda Wewa, Weerawila Wewa, Pannagamuwa Wewa and Debara Wewa) are assumed not to have been impacted.
- Several small tanks have been inundated by Lunugamwehera reservoir, hence the small tank area has been reduced from 300 to 200 ha, with an associated loss of production.

The overall fisheries production impact of the scheme is therefore assessed to be positive: increases in aquatic habitat area (11%), production (68%), and value of catches (30%). This conclusion is fairly insensitive to assumptions.

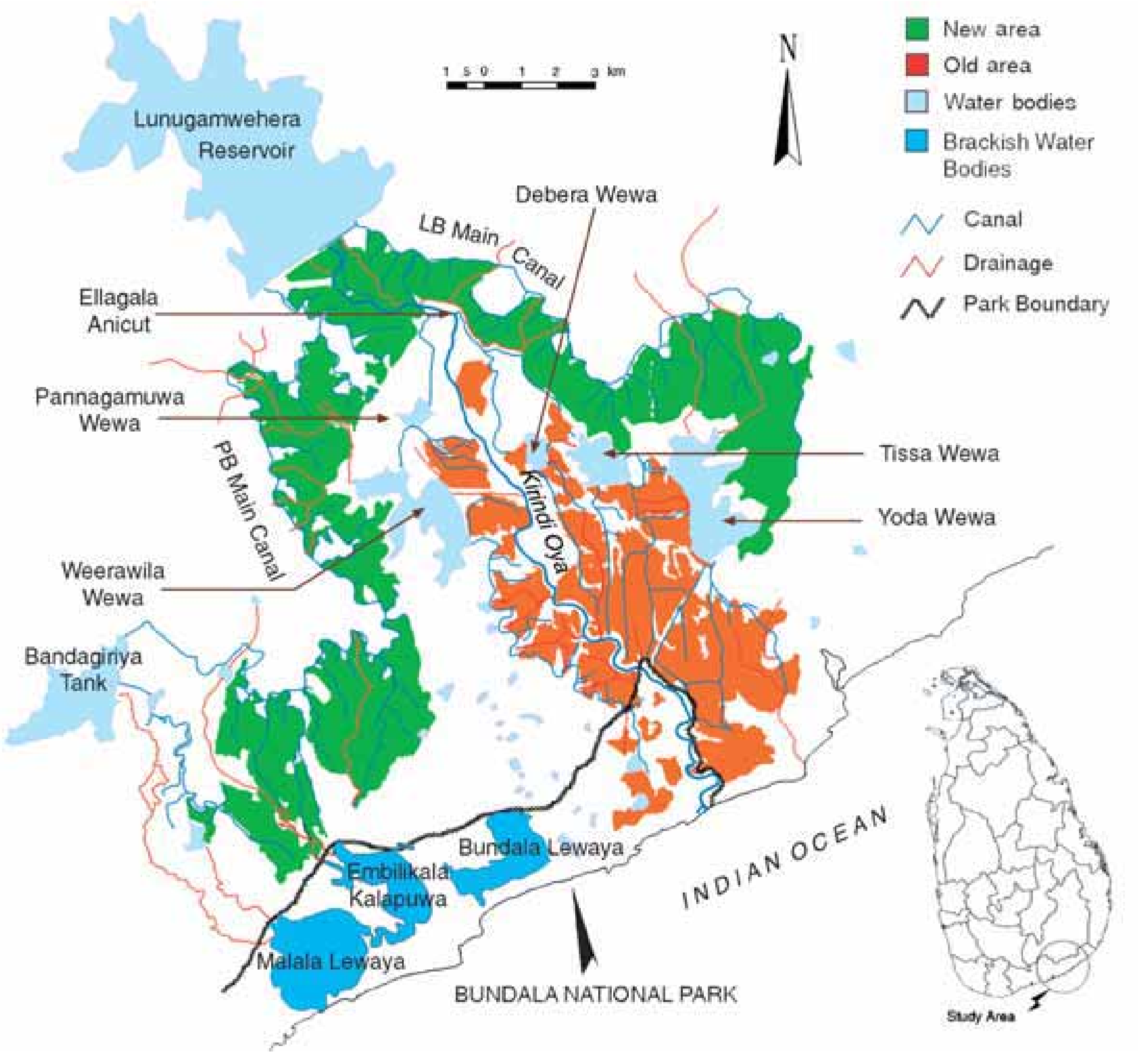
- Accounting in detail for hydrological changes such as an increase in dry season water availability; and
- Accounting for fishing effort by using yield-effort relationships and making assumptions about future effort levels.

A sensitivity analysis should be carried out, i.e. the budgeting exercise repeated for a range of reasonable assumptions.

The discussions in this section consider aggregated multi-species yields rather than yields of individual species. The reasons for this are practical (species-specific yield information is often not available), but also conceptual. Aggregated yields are reasonably predictable from physical habitat parameters and exploitation level, and similar relationships hold for quite different species assemblages. Yield from individual species may be much more variable, both spatially and temporally, than the aggregated total. This suggests that ecosystem-level effects do often (but not necessarily) compensate for changes in the abundance and production of particular species.

Forecasts of total fisheries production are important as a quantitative measure of fisheries impact. However, it should be borne in mind that yields alone may not adequately describe the availability of fisheries resources in the context of livelihoods. For example, the benefit of catching a moderate amount of fish from a reservoir during the dry season could be more significant than even a substantial loss of wet season river-floodplain catches. It is therefore important to consider not only yields but the role of fishing opportunities in livelihoods (Section 3.6).

Figure 4.8. The Kirindi Oya irrigation and settlement project (KOISP) in Sri Lanka.



Source: Matsuno et al. 1998.

The area of impact considered is the Kirindi Oya basin itself, and the lagoons receiving drainage water in a neighboring watershed.

Table 4.4. Fisheries production balance for the Kirindi Oya irrigation and settlement project (KOISP).

Before KOISP						
Water body	Catchment	Area (ha)	Productivity (kg/ha)	Production (t)	Value (kg)	Total. Value (US$)
Floodplain		6,200	20	124	0.4	50
Lagoons		1,500	100	150	1.5	225
Head reservoir		0	220	0	0.4	0
Ancient reservoirs		1,608	220	353	0.4	141
Small reservoirs		300	250	75	0.4	30
River	117,800		0.3	35	0.4	14
Total		9,608		737		460
After KOISP						
Water body	Catchment	Area (ha)	Productivity (kg/ha)	Production (t)	Value (kg)	Total. Value (US$)
Floodplain		0	20	0	0.4	0
Lagoons		1,500	100	150	0.4	60
Head reservoir		3,200	220	704	0.4	282
Ancient reservoirs		1,608	220	353	0.4	142
Small reservoirs		200	250	50	0.4	20
River	117,800			0	0.4	0
Total		6,508		1,257		503
Change		-3,100		520		43

4.4.2 Valuing production impacts

Once impacts on fisheries production have been quantified in physical terms it may be necessary to value them in economic terms. This may be as a means to assess their importance, or for inclusion in cost benefit analysis of either an irrigation scheme itself, or of measures proposed for mitigation of fisheries impacts.

Fisheries production can be valued simply as a commodity, whether as food or as an input to industrial processes such as fertilizer manufacture. Additionally, it can be assessed as a source of employment and livelihood for rural people (further discussion, in Section 3.6).

It will be necessary to quantify output in the pre-project situation and for financial analysis to value this using prevailing market prices. Account should be taken of seasonal volumes marketed and associated price variation. Their own consumption by fishing households should be valued using local retail prices for the same species, or if these are not available, for the closest substitute source of protein. For economic analysis, it may be appropriate to use shadow prices based on border prices for imported fish (or a close substitute source of protein and/or other important nutrients). Pre-project trends in these variables should be considered so that cost benefit analysis is based on projection of the future without project scenario and not just a static assessment of the pre-project situation.

Based on predicted project trends in productivity of the fishery, incremental change in output compared with the without- project scenario should then be valued using market or border prices as above. (Note that if change is progressive over time then seasonal or annual estimates of production over time may be needed). Standard techniques of discounted cashflow analysis will then be used for valuation in present value terms over the project life.

If the change in output resulting from project impact is large relative to the size of the market for fish affected then it may also be necessary to consider the effects of a change in price in terms of consumer surplus. However, accurate estimates of demand elasticities are unlikely to be available and such effects are rarely likely to be significant in terms of the national economy, particularly if fish is a traded commodity. Where markets are isolated and localized it will be more important to consider the livelihood impacts for affected groups of price changes, taking account of the range of issues discussed in Section 3.6.

Where production impacts are negative the economic costs of increased unemployment for fishers in terms of increased social security payments, compensation or migration to other areas might also be included in a cost benefit analysis. However, it is more likely that the inland fishery will tend to be an artisanal and/or part-time activity for households also engaged in farming or other rural production activities. Again it will be more appropriate to consider the impact on rural livelihoods as described in Sections 3.6 and 4.5.

Further reading: A guide to financial and economic cost benefit analysis is provided by Potts 2002.

4.4.3 Impacts on ecological integrity and biodiversity

As mentioned before, impacts on ecological integrity and biodiversity are far more difficult to predict than impacts on production potential and yield. This, plus the fact that such impacts are almost by definition negative and from a conservation perspective should be minimized, has led to a strong habitat focus in ecological impact assessments. The logic is that as long as habitats are preserved in much of their extent and characteristics, impacts on biota will be minimal. While it may be difficult to define exactly when a habitat modification should be regarded as significant, this is certainly easier than predicting and valuing ecological impacts per se.

The main approaches currently used to evaluate ecological impacts are as follows.

(1) Assessing the availability of suitable habitats for key species. In contrast to the two previous methods, this requires information on the specific habitat requirements of the species concerned. Common approaches (e.g. HIS, IFIM, PHABSIM; Welcomme 2001) use species specific preference scores for a range of factors such as water depth, current, and substrate. The approach may be adapted for rapid, qualitative assessments using local knowledge (tool 26).

(2) Holistic approaches are aimed at identifying essential features of the natural hydrological regime and they incorporate these into the modified regime (Arthington et al. 1992). A wide range of specific methodologies has been developed. They are effective methods for objective setting rather than impact assessment. These are discussed further in Chapter 5.

(3) Empirical models relating assemblage structure to hydrological and other habitat characteristics. This includes the index of biotic integrity (IBI) (Karr and Chu 1999) as a partially conceptual model, as well as purely empirical approaches (e.g. Pusey et al. 2000). Where no locally relevant empirical models exist, it may be possible to gain some insight from ad hoc comparative studies at similar impacted and non-impacted sites.

Assessing to what extent the habitat requirements of individual species are met (approach 1, above) is clearly limited in scope in diverse tropical systems, but may be useful where a limited number of species of particular interest can be identified. Holistic approaches may be more practical, but do not actually predict ecological impacts.

Tool 26. Forecasting impacts of habitat modifications on key species

(1) Identify key species of fisheries of conservation interest (being dependent on local knowledge this approach is unlikely to work for species of no fisheries interest).

(2) Working with experienced fishers (individually or in small groups), use the water body maps to discuss where different life stages of the species can be found and at what time of the year, and reconstruct the life cycle.

(3) Consider how the specific locations where different life stages are found, and their connectivity will be impacted on.

(4) For further analyses and assessment of mitigation measures, it may be useful to generalize the life cycle and its seasonality; and express habitat preferences of different life stages in terms of water depth, velocity, substrate, visual water quality, vegetation and other factors. The latter will be possible only where the local habitats are sufficiently diverse to allow the determination of such preferences.

4.4.4 Valuing ecological and biodiversity impacts

The difficulties of quantifying ecological and biodiversity impacts in physical terms have been noted above. Economic valuation of such impacts would need to take account of 'use values', 'non-use values' and 'option values'. This would be difficult in practice and discussion of possible valuation methods is beyond the scope of this manual. International standards and estimates of the economic value of biodiversity are starting to become available and it may be possible to compare any physical assessments that can be made with these.

Again, any assessment for the purposes of cost benefit analysis would require considering pre-project trends and projection of a future without project scenario. Estimates of the economic value of incremental change in biodiversity arising from project impacts could then be derived from the projected with project situation.

Given the difficulties, it is recommended that all practical assessments should focus only on description of biodiversity impacts in physical terms.

Further reading: A practical introduction and guide to concepts of environmental valuation and valuation methods is provided by Winpenny 1991 and Emerton and Bos 2004.

4.5 Livelihood impacts

Irrigation projects will not benefit everyone equally. Some groups will gain more than others and some groups may lose from the process. This also applies to the impacts of irrigation on aquatic resource use. It is generally not acceptable for poor people to become even more impoverished as a result of a development scheme and such an outcome will require changes to its design and implementation, or may result in its rejection. Assessment requires consideration of the structural aspects of poverty and in particular, differential access to resources and the distributional consequences of the proposed development.

At the local level differentiation can be seen in structures of caste, class, social status, age, gender, language and ethnicity. Differentiation in the distribution of project benefits or costs can arise as a result of one group, as defined by one or more of these characteristics, capturing the scheme benefits and excluding others. The reality is often complicated with different forms of social differentiation operating at different levels: household, community, command area, district or state.

Because the direct benefits of irrigation accrue to the owners of land and in proportion to the area of land cultivated, differences in wealth between large and small farmers, and between landowners and landless laborers are likely to widen. Despite this, the poor, typically marginal farmers and the landless, may still benefit in absolute terms from increased farm and non-farm employment opportunities. The assessment must examine whether or not the increased skew in assets and income distribution will cause significant problems for the poor. This requires indicators of impoverishment such as growing landlessness, food insecurity, and unfavourable trends in wages or food prices and decline in productivity of natural resources such as fisheries.

Where affected households are both farmers and fishers, negative impacts on fishing as a source of livelihood may be compensated by the farming benefits. In such a case, it is clearly important for the assessment to seek to estimate the relative magnitude of the gains compared to the losses and hence the net impact on livelihood. As emphasized in the discussion of poverty and livelihoods above, the assessment must be in terms broader than just income, including for example, the benefits and seasonality of fishing for diversification, nutrition, as a ready source of cash and for their role in culture and social networks (as illustrated in the Laos case, table 2.5). Net gains or losses evaluated using this broad range of criteria are, of course, unlikely to be uniformly distributed because of social differentiation, and the assessment must seek to clearly identify who are the gainers and losers.

As discussed in Section 4.3, the negative impacts of irrigation development for a fishery may be partly compensated by new habitat area created or changes in patterns of fishing effort and efficiency. Again, negative and compensating impacts are unlikely to be uniformly distributed, similarly creating both gainers and losers.

Where households are full-time fishers, they may be a minority, but negative impacts on the fishery may have severe consequences for their livelihoods. Clearly these will not be compensated by the direct benefits of irrigation for farming, and the assessment must judge carefully whether they can be compensated by irrigation infrastructure impacts on habitat area and fishing efficiency. Here again the heterogeneity of the full-time fishing community must be considered (box 3.5), and hence the distribution of impacts.

Expanding alternative employment opportunities in the rural economy stimulated either by irrigation or other developments will be open to labor from full-time fisher households, but as discussed in Section 3.6 for social, cultural or economic reasons fisherfolk may face greater barriers to enter into such work than other rural households.

Consideration of the potential impacts of irrigation development on the contributions of fisheries to livelihoods, and the factors influencing the distribution of those impacts, now focuses on seven key processes:

- access to or exclusion from resources
- participation in or alienation from rights
- change in househlods' own labor allocation
- improvement or impoverishment of livelihoods
- trajectories of change for livelihood strategies
- how livelihood improvement or impoverishments are distributed
- institutional development

4.5.1 Access to or exclusion from resources

Achievement of a desired distribution of benefits from irrigation development requires an understanding of the means by which people may be excluded from those benefits (tool 27). People can be excluded from diverse resources such as knowledge, information, technology, credit, skills (training), land, water, energy, livestock, labor and from other social, political and cultural institutions, activities and facilities.

Exclusion for certain groups can arise from differences in wealth, status, class, gender, ethnicity, language and location. Without the same means or qualifications for access, people do not receive the opportunities available to those who can. Those with good access can often improve their access further, while those with poor access may be unable to maintain their position. Elite and favored groups who control the majority of resources can then dominate project benefits.

Formal and informal rules, or institutions, control access to or exclusion from resources. The formal rules of local governments, or village and community organizations, are apparent and often amenable to change. Informal rules, the product of social interaction and socialization, are more difficult to discover and understand, and may be less amenable to change at least in the short term. Examples are considered in Section 4.6 below.

Efforts to diminish differential access or entitlement may be resisted by local elites and implementing change can be no easy matter. Consultation with and appropriate involvement of all stakeholders can thus be crucial, and project designers, assessors and managers must seek to work with the grain of local political structures rather than in opposition to them. Power relations and people's rights are also considered further below.

The institutions that determine seasonal and permanent rights of access to a fishery may be central to the distribution of impacts from irrigation development. The assumption that poverty drives people to fish as a livelihood of last resort rests on the assumptions that: access to the fishery is relatively open and fisher households who remain in an open-access fishery have the least alternative employment opportunities open to them. However, the Bangladesh case cited above (box 3.5) shows that often there is great differentiation amongst fishers and that access may be restricted by institutional factors, or other factors such as the capital cost of gear required for fishing in a given season. Thus under some circumstances it may be the poorest who are most excluded from the fishery.

Tool 27. Assess access to or exclusion from resources

Assess access to fisheries for different groups and how this may change with the changes to be introduced by irrigation. Also assess access for different groups to the benefits of irrigation development and the use of other natural resources such as forest and grazing areas.

Make use of the information provided by:

- Tool 13: Inventory of livelihood assets
- Tool 14: Role of fishing in livelihood strategies
- Tool 15: Preparing socio-economic profiles
- Tool 18: Studying institutional arrangements in fisheries
- Tool 19: Assessing the level of compliance with rules
- Tool 20: Describing and understanding the fisheries system

Given heterogeneity amongst fishers, both in socio-economic status and fishery access, even for a crowded open-water fishery it may be incorrect to assume that fisheries productivity directly translates into the welfare of the poorest.

4.5.2 Participation in or alienation from rights

For people to have greater involvement in, access to and management of resources, the assessment needs to consider not only rules or institutions but also power relations. To what extent and in what ways do people, as individuals or in groups, have the desire, the right and the power to be involved in changes that affect their lives and livelihoods?

Power relations may be reflected in the relative strength of the bargaining position of, for example, patrons and clients, landlords and tenants, men and women, and different age groups. The imbalance of power between individuals or groups often influences both project design and project impact.

Alienation or exclusion from decision making structures may be on the basis of ethnicity, age, class, language, gender, or on other grounds. Projects designed without consideration of such issues may introduce or reinforce alienation of people from the decision making process.

Principles of participatory development are summarized in box 4.2. Participation by those ultimately affected by irrigation development will be limited, and/or the participants will be unrepresentative, if some or all of the affected persons lack the power to organize and get themselves fairly represented. Participation of all or some of those affected may not be in the political interests of other stakeholders, while collective action may exacerbate existing tensions within or between households. Thus

Box 4.2. Participatory Development - Principles and Approaches

1. Participatory development is important for at least two reasons:
   - It strengthens civil society and the economy by empowering groups, communities and organisations to negotiate with project management and bureaucracies, thus influencing public policy and providing a check on the power of government.
   - It enhances the efficiency, effectiveness and sustainability of development.
2. Stakeholder participation is defined as the process whereby all those with an interest (stakeholders) play an active role in decision-making and in the consequent activities that affect them (ODA 1995). Participatory development may be defined as a process by which people take an active and influential hand in shaping decisions that affect their lives. It may involve long and difficult processes, but potential benefits include: the use of local knowledge; increased relevance of objectives and outputs to needs; greater accountability of officials and contractors; and "ownership" of the activity by communities. Through empowerment, participation can also lead to changes in knowledge, skills and the distribution of power across individuals and communities thus improving social equity.
3. Empowerment is essential to participatory development. Empowerment is enhanced when the organisations in which people participate are based on a democratic approach, strengthening the capacity of members to initiate action on their own or negotiate with more powerful actors. It thus builds up the capacity of people to generate and influence development at various levels, increasing their access to and influence over resources and institutions, including by groups hitherto marginalised such as low-income populations and particularly women.

Source: OECD 1993.

> **Tool 28. Participation in or alienation from rights**
>
> Assess existing means for participation and empowerment in decision-making processes of all stakeholders in fisheries and irrigation.
>
> Consider how best to create the means for participation and an environment to facilitate empowerment in the process of impact assessment, and subsequent project mitigation or enhancement measures, as well as final project implementation and management. The assessment should identify the structures through which the voices of all groups can be heard, and develop procedures for consultation that can genuinely influence decision-making.

participation can challenge existing power structures, not only within the local community, but between communities and state bureaucracies.

If provision is made for participation in the project, then whose participation is encouraged? Those with least access to resources and knowledge are also likely to be the most poor and the most alienated. An objective to reduce poverty or to enhance the welfare of women, implies that participation of the poor and women must be encouraged in the project process. Then, is participation only to achieve a specific end such as operation and maintenance of the irrigation system, or will beneficiaries have a voice in the initial conception of the project, how it is designed and how it will be implemented?

Technical staff may find it difficult even to encounter the powerless, and the assessment should therefore be alert to categories of people not appearing at events organized for participation and consultation. Projects cannot empower people, as by definition this is something that people do for themselves, but projects can create the environment for empowerment. The assessment needs to identify the structures within society through which the voice of the powerless can be heard, and to develop procedures for consultation or decision making that could include them. It should also seek to determine what intended or unintended impact the project will have on local power relations?

4.5.3 Change in households' own labor allocation

As noted in Section 3.6, fundamental characteristics of households' own labor use in the households in rural areas of developing countries are:

- the prioritization of cultivation of subsistence crops, followed by fishing (and/or other hunting and gathering activities) when local food markets are unreliable or expensive (when ability to purchase food can be relied upon, priorities may switch to cultivation of income generating cash crops, or specialization in activities such as full-time fishing);
- the seasonality of fishing and farm labor requirements;
- the relationship between this seasonality and food security, nutrition and health;
- gender divisions by enterprise and task; and
- the existence of traditional forms of exchange or communal work arrangements.

These characteristics are clearly relevant to the potential impacts of irrigation development on aquatic resource use and rural livelihoods.

The key to the impacts of irrigation development on full-time fisher households will be the effect on the return per unit effort spent in fishing compared with that of the alternative available

Tool 29. Households' own labor allocation

Assess change in livelihood options and labour allocation. This may require consideration of:

- seasonality of farm labor requirements before and after irrigation (tool 16);
- periods of competition between the best fishing and farm work;
- change in availability of farm and non-farm employment;
- returns to labor (per hour) in fishing compared with farm work or other non-farm employment (tool 17);
- relationships of the above with gender divisions of labor by enterprise and task (tool 16); and
- change in patterns of exchange labor or communal labor.

employment. Changes in habitat area, productivity and efficiency of fishing effort will all affect this, and thus incentives for fishing compared with the alternatives. At the same time the stimulus provided to the rural economy by irrigation development may create new entrepreneurial or employment opportunities that offer higher returns to labor than fishing.

However, the majority of rural households may be farmers as well as fishers, and outcomes for them may be more complex. They will tend to give priority in labor allocation to the production of staple food crops, or cash crops that are a major source of income. Only when the production of these is secure will they devote labor to other activities such as fishing. Peak periods for fishing in terms of returns to effort may also tend to coincide with peak periods for farming operations, for example, the onset of the wet season as floods rise or when they fall around the time of harvest. However, assuming that travel distances to waterbodies for fishing are not prohibitive, fishing is an activity that can be carried out for periods of varying duration and frequency that fit around farm work requirements. It also generally involves less physical energy expenditure than farming, and can be done part-time either before or after work in the fields. Using passive rather than active fishing methods also allows it to be done in conjunction with farmwork where fishing locations are convenient.

Irrigation will tend to increase farm labor requirements within a given season by raising output per unit area, and often the associated input use. It will also tend to extend the growing season or even introduce a second, or even a third, season. Thus irrigation tends to result in a more continuous pattern of labor use in farming for more time of the year, although seasonal operations will still introduce labor peaks. Thus after introducing irrigation, labor availability for fishing will be changed and is likely to be more constrained for substantial periods of the year, again potentially coinciding with some of the best periods for fishing.

With regard to gender divisions of labor, men's farming activities are very unlikely not to involve women in some way, yet newly introduced crops and methods are typically brought in by men (since project and extension workers contact is mainly with men). Thus men may take the decisions regarding these crops and methods, and require women to perform additional tasks without diminishing their original responsibilities. By intensifying production, by extending the growing season, and by introducing a second or even third crop, the introduction of irrigation can increase the labour burden of women. Paddy rice production is very labor intensive compared with most other crops, and the transplanting seedlings a particularly burdensome labor requirement for women. Thus there are clear implications for the opportunities that women will have to continue fishing, though actual impacts will depend on the location of fishable habitats and the effort and methods of fishing required.

Labor exchange arrangements may help meet the increased labor requirements of intensive irrigated agriculture, but it may be that labor exchange will become less widely practised as modernization takes place, farm households become increasingly cash-oriented, and the outcomes of economic decision-making become more diverse.

Communal labor arrangements are a potentially valuable resource to call upon in improving project implementation or the managing of aquatic resources. But traditional communal systems of working together for community projects may be under pressure from modernization and commercialization of the farming system, or from tensions introduced into the community by changing patterns of access to resources, differential access to the benefits of the irrigation scheme, or changes in power relations.

4.5.4 Improvement or impoverishment of livelihoods

Impacts on livelihoods

The potential socio-economic impacts of irrigation development on aquatic resource use can be complex, taking the form of both direct and indirect impacts.

Direct impacts arise from the hydrological and ecological impacts of changes in water flow or storage in natural streams and waterbodies, and from the construction and operation of irrigation infrastructure. These are described in Sections 4.3 and 4.4 above. The impacts are mainly in terms of changes in the productivity, species composition, seasonality, and location of fisheries. These may also result in changes in the best methods for fishing and in the level of effort required to achieve a certain catch.

Indirect impacts arise from the development of irrigated agriculture. This will often result in an increase in farm labor requirements, particularly during part or all of the dry season when household labor will typically have been relatively underemployed or in surplus. Successful irrigation will also result in the intensifying and increasing commercialization of agriculture, as farmers have greater and more reliable surpluses for sale. This, in turn, will stimulate the development of markets and the rural economy, potentially creating a range of new livelihood and employment opportunities. Thus indirect impacts take effect mainly through changes in livelihood options which, in turn impact on these on households' own labor allocation.

A range of pre-existing or situational conditions, and the processes by which these evolve will mediate both direct and indirect impacts. These conditions include:

- the economic and policy environment, which through the level of market development and market conditions will influence livelihood opportunities and incentives;
- the institutional environment and power relations, influencing access to resources and the distribution of the benefits and costs of change; and
- the degree of empowerment and effective participation through which people themselves can influence the nature of outcomes.

As illustrated by the boxes for livelihoods and institutional attributes in figure 3.1 in addition to these factors, direct impacts will also vary for households or individuals depending on their physical location in relation to the location of natural fisheries and the newly constructed or enhanced irrigation infrastructure. The precise impacts for a given household or individual will further depend on:

- the relative importance of fishing as a livelihood strategy;
- who fishes (which household members);
- where they can fish and where they prefer to fish;
- when they fish (both seasonally and daily);
- how they fish (gear types, passive/active methods); and
- the incentives for alternative uses of labor, given the available opportunities and personal preferences.

Indirect impacts will tend to be more general in their incidence, but the full range of situational conditions listed above will still influence outcomes for households or individuals.

In assessing processes of livelihood improvement or impoverishment, analysis should start from an inventory of livelihood assets potentially impacted by irrigation development, for the situations before and after that development takes place. The resulting assessment of change in asset endowments should also seek to take account of sources of vulnerability, and how these may change with irrigation development.

Changes in natural capital

The socio-economic assessment must draw on the hydrological and ecological assessment to understand the changes in the status of fisheries as a natural asset that may occur (Sections 4.3 and 4.4). These changes may affect returns per unit time spent fishing, which together with change in the opportunity cost of time spent fishing (given the change in access to resources and markets, and new economic opportunities), will influence the level of harvesting effort and the actual productivity of the fishery.

Thus the potential impact on a fishery as a natural asset can be complex. This complexity is increased by the need to disaggregate the impact by its effects for different socio-economic groups particularly where they are differentiated by their fishing practices.

For example, lower and more uniform stream flows may make some fishing practices easier so that household requirements for fish, for subsistence or sale, can be met with less fishing effort (i.e. time and energy use per unit weight of catch). Households that are vulnerable because of labor scarcity, or for whom fishing is primarily carried out by women or the aged, may particularly value this effect. However, the danger that the increased ease of fishing may result in over exploitation of the resource must be remembered, particularly where people are fishing for sale.

Similarly, through diversion of water in the dry season, through seepage losses and through its influence on the height of the watertable, irrigation may extend the duration of seasonal waterbodies or increase the area of perennial ponds or lakes. These effects may extend the period during which fishing is possible, and/or create habitats that are in proximity to fields and homes. Such conditions may be particularly valued by women or aged members of households who are responsible for fishing, but for whom time and mobility is limited. This may be reinforced when fishing is possible by passive methods in conjunction with farm or other work, but again there is a danger of over fishing if these resources are too accessible.

Changes in physical capital

Again the livelihoods assessment must draw on the assessment of impacts on habitats and ecology (Sections 4.3 and 4.4), as irrigation infrastructure may create new or modified habitats for aquatic resource use.

The prime example may be reservoirs impounded by a storage dam forming a perennial waterbody for year round fishing. Irrigation canals and drains may also become habitats that can be exploited and water control structures offer some potential for management subject to trade-offs with the water needs of crops. Canals and drains may also offer suitable habitats for aquaculture, or provide the means to manage water levels in farm or village fishponds.

Extended rice paddies in the wet season, or irrigated dry season paddy fields may also provide a new and productive habitat, subject to connectivity with permanent water bodies though, as noted above, dry season paddies have less potential as a habitat because of the seasonal mismatch between fish migration and spawning patterns.

Each of these new or modified habitats may have the potential for greater ease, convenience and possibly efficiency of fishing compared with the pre-existing natural fishery. Thus they may enhance ability to meet subsistence needs or to fish for sale in a way that may be valued by women, the aged or other vulnerable and labor scarce households, even in cases where the overall productivity of the fishery declines.

Irrigation infrastructure may further impact indirectly on livelihoods by improving field and access roads, in particular all-weather roads constructed along canal embankments. Apart from a general improvement in communications and potential reduction in farm transport costs, these roads may also provide improved accessibility to fisheries such as the main river channel or reservoir.

Other infrastructure also supports livelihood opportunities. Particularly important are transport and communications infrastructure, physical market facilities, and infrastructure for health and education services. Well developed physical capital will help to facilitate development of a wider range of livelihood options, potentially mitigating some of the negative impacts that may arise from irrigation development.

Changes in human capital

Direct impacts on human capital may arise from increased risk of waterborne diseases following irrigation development. A decline in fishing effort or fishery productivity, resulting in reduced frequency or amount of household catches, may also have a negative impact on nutrition unless fish is substituted by other foods of equal nutritional value. This effect is likely to be particularly severe for the poorest and most vulnerable households if their access to fish is reduced.

There may also be a loss of human capital in terms of the loss of existing indigenous technical knowledge of the productivity and management of natural fisheries, as habitats are modified, destroyed or replaced.

In terms of indirect impacts, irrigation development is more likely to have positive effects. Infrastructural improvements, rising farm incomes and increased employment opportunities can be expected to contribute to increased effective demand for health and education services, but again it is important to be aware of the situation for any groups excluded from or marginalized by the changes.

Changes in social capital

Social capital can be diverse and varied in character and the impacts of irrigation development may be quite location specific. In Laos, for example, key features are the strong basis for communal management of otherwise open access resources such as fisheries, and the importance of kinship and social networks. The latter provides for the reciprocal exchange of labor for completing peak farming tasks and also the reciprocal exchange of fish and other food commodities in times of hardship.

Key areas of focus for a livelihoods assessment are the identification of such examples of social capital, the understanding of functions they perform in rural livelihoods and the prediction of changes relevant to aquatic resource use arising from irrigation development.

Irrigation development may help to build certain forms of social capital because of the requirement for managing communal water and the operating and maintaining of farm level infrastructure. However, increased intensification and commercialization of farming, often associated with a widening disparity in farm incomes, may also lead to change in traditional social and cultural practices, perhaps promoting greater individualism and weakening ties of social responsibility. Increased farm labor requirements can lead to increased use of hired labour, contributing to the decline of exchange labor systems.

Understanding changes in social capital is important, as again, it may be the poorest and most vulnerable households who become marginalized from community organizations and social networks for reasons of social differentiation.

Changes in financial capital

In livelihoods analysis, financial capital is defined as the availability of cash or equivalent, and thus includes both stocks in the form of savings or assets such as livestock or jewellery, and regular inflows in the form of earned income, pensions or remittances.

The availability of cash, or equivalent means of exchange, is an important livelihood asset that can provide the means for food security, or access to productive resources or economic opportunities. Cash may also be required to access health or education services, or to finance important social activities such as marriages and funerals.

Despite seasonality in fish catches, poor full-time fisher households may depend on frequent and regular catches to provide cash to meet household needs. For such households, in the absence of alternative livelihood activities and/or sufficient means to save during periods of best fishing, interruptions to access or productivity of a fishery arising from irrigation development could have severe consequences.

Even for part-time fishers, as in Laos for example, fish are a commodity with a ready market (even within remote villages), and hence the ability to catch fish provides access to a readily available source of cash. Here if access to, or productivity of, a fishery declines as a result of irrigation development then the ability to gain quick access to cash may be reduced. Again this may be a particularly significant impact for poor and vulnerable households for whom alternative sources of cash may be most limited.

More generally, the indirect impact of successful irrigation development may be an improvement in financial capital for irrigating households derived from greater and more reliable crop surpluses for sale. Marginal farmers and landless labor may also benefit from increased farm employment and wage rates. Secured rights to irrigated land may also act as improved collateral, enabling landowning households to access formal sources of credit. The liquidity of the local economy will expand, and the major concern is once more for any households excluded or marginalized by this process.

4.5.5 Trajectories of change for livelihood strategies

The importance of fishing as part of rural livelihood strategies may be directly reduced by irrigation if the development reduces the productivity or accessibility of a fishery. On the other hand, this effect may be partially or wholly compensated if irrigation creates new or modified habitats for fish in the ways described above. Sustainably managing these new or modified habitats at higher levels of productivity, or complementing them with aquaculture will increase the importance of fisheries to households.

For households who are both farmers and fishers, a significant change may be the increased labor requirements of irrigated farming combined with the potential to raise farm output, and hence a higher opportunity cost for time spent fishing. As discussed in Section 3.6 this opportunity cost will be much lower for fishing that can be performed conveniently as a part-time rather than full-time activity, or using passive fishing methods (e.g. set and wait gear) in conjunction with completion of farm work. For households with enough productive irrigated land to absorb their own labor, the importance of fishing as a livelihood activity is likely to decline. Fishing is likely to become even more of a part-time activity; tending to be practiced for recreational as well as productive reasons, or tending to become more opportunistic and practiced during periods when catches are at their highest in terms of returns to effort.

Successful irrigation will also stimulate entrepreneurial and employment opportunities in the rural economy. These arise from backward linkages (in the supply of farm inputs), forward linkages (in processing, transport and marketing of farm output), and consumption linkages (from increased demand for locally produced goods and services financed by higher incomes for landowners and farm labor). Thus again the incentives for fishing may be reduced if, compared with fishing, households can access alternative more renumerative, and/or less variable, sources of income for equivalent time and effort spent. Alternatively, growth in the rural economy may lead to increased local demand for fish, higher prices and thus increased incentives for fishing. Though as discussed in Section 2.6, unless there are barriers to entry to the fishery, the increased incentives will attract more fishers to the point where returns to labour in fishing fall to the level of the next best alternative source of employment for unskilled labor.

Given these possible trends, it is evident that it is the rural households excluded from the benefits of irrigation and growth of the rural economy who may come to rely more heavily on fishing as an ‘activity of last resort’. Excluded from other livelihood activities, they are likely to be condemned to low incomes if the fishery remains open access and potentially overexploited, or is directly degraded by irrigation construction.

Irrigation development will also tend to have an impact on the keeping of livestock as a livelihood strategy. It will tend to reduce the land available for free grazing, particularly in the dry season, at the same time as less labor is available to control grazing. This may be because crop labor requirements have increased or because households can now afford to send to school the children who may have supervised grazing. Livestock numbers thus tend to reduce, although this is often associated with adoption of more intensive livestock rearing methods such as stall-feeding. Increased

Tool 30. Predicting trajectories of change in livelihoods

Assess how the livelihoods of different groups may be improved or impoverished by the impact of irrigation development. Start from an assessment of any change in livelihood assets using an inventory of livelihood assets (tool 13), socio-economic profiles (tool 15), understanding of the role of fishing in livelihoods (tool 14) and fishery profiles (tool 20).

Natural capital
Use the assessments of hydrological, ecological and fishery exploitation impacts (tools 21-26) to determine change in the spatial distribution, number, area, seasonality and productivity of fisheries available in the potentially impacted project zone. Consider impacts on patterns of access and/or productivity for different socio-economic groups.

Physical capital
Assess any change in the inventory of infrastructure and goods that support livelihoods to facilitate prediction of livelihood changes/ trajectories. Also, consider the extent to which irrigation infrastructure itself creates new or modified fisheries, concentrated fishing points, etc. (tools 21-23).

Human capital
Assess:

- Change in patterns of fish consumption that may have nutritional and health impacts.
- Change in relevance of indigenous technical knowledge of fisheries.
- Risk of increase in waterborne disease.
- Change in access to health and education services and to information.

Social capital
Assess change in the role of fish in social and kinship networks or impacts on these networks of the reduced availability of fish and potentially rising prices. Assess stimuli to increased collective action, and access to wider organizations and institutions.

Financial capital
Assess the potentially diminished role of fish sales as a source of cash income. Also assess the impact of increased income from agriculture, improved access to credit and general liquidity in the local economy if this has implications for livelihood options.

Use all this information in seeking to predict trajectories of change in livelihood strategies and the role of fishing for different groups. Key factors to consider include:

- the relative level of development and development potential of the region, i.e. whether it is resource poor and remote, or relatively advantaged in terms of resources, infrastructure etc.;
- the potential for the rural economy in the region to diversify and to provide alternative livelihood opportunities to both farming and fishing;
- the main sources of vulnerability that may tip people into poverty;
- land pressure and trends in land tenure and in farm productivity by value;
- trends in farm and non-farm employment, and migration;
- trends in farm and non-farm wage rates; and
- trends in the productivity and accessibility of fisheries.

crop residues or fodder crops from irrigated cultivation are available, and quality and even quantity of livestock output can increase. Stall-feeding also allows manure to be more easily collected and used as fertilizer in the irrigated plots. Any impacts on aquatic resource use are indirect but must be factored into overall analysis of incentives for allocating labor by households and dietary changes, if fishing is reduced.

It is thus important to conduct a broad-based analysis of trajectories of change in livelihoods, as outlined in tool 30.

4.5.6 How livelihood improvements or impoverishments are distributed

It is necessary to combine the information from the assessments above (tools 26-29) and complete a disaggregated assessment of the potential impacts on livelihoods. In this assessment, it is also necessary to consider the pace of change in different aspects of livelihoods. Key factors to be considered are discussed below.

Successful irrigation will increase the amount and value of farm output bringing benefits to the owners and/or cultivators of irrigated land. It will also tend to increase the capital value of land owned. Thus it will often tend to widen income gaps within a community as those with the most or best land benefit to the greatest extent. However, poorer households who are marginal farmers with inadequate land, or the landless, may also benefit in absolute terms from increased and less variable farm employment, often at increased wage rates. They may also benefit from increased employment opportunities in the rural economy stimulated by the linkages described above.

A key concern is that some households may be economically marginalized by or excluded from these processes for reasons relating to social differentiation, to lack of resource access and to alienation of rights. For example, the aged or less mobile may not be able to participate in increased employment opportunities for the landless farm labor; certain groups may for ethnic or caste reasons not receive an equitable share of irrigation water; or women may be overburdened by the additional farm labor requirements and without the means to correct this by fully sharing in decision making or control of the resources generated. The poorest households may also be those least able to take advantage of new employment opportunities in a more dynamic rural economy because they face barriers to entry such as the need for minimum literacy levels, the need to travel to work or to have good health and appearance.

The range of possible outcomes are many and varied but it is likely that where fisheries play an important role in rural livelihoods they will be particularly important as a fall back or ‘survival’ activity for the poorest and most vulnerable households (though this is dependent on open-access rights as discussed below). Successful irrigation will stimulate diversification of livelihoods through the exploiting of new opportunities, but for the excluded or the marginalized, fishing may remain essential as part of a diversified survival strategy. The socio-economic assessment of the impacts of irrigation on aquatic resource use must recognize this and seek to ensure that any negative impacts are mitigated so that this livelihood option is preserved for the poor.

Most at risk from marginalization may be full-time fisher households, if the productivity of their fishery is severely negatively affected by irrigation development. For reasons of social differentiation such households may find it particularly difficult to take advantage of new employment opportunities, although as noted in Section 3.6 above, fishing communities themselves may be highly differentiated.

4.5.7 Institutional development

As noted in Section 3.7, many of the potential impacts of irrigation on fisheries or fishers may have an institutional or part-institutional root cause. It is not possible to predict precisely what effect institutional change will have on fisheries and fishers, or indeed how existing institutions will be affected, as these issues are very context-specific. However, it is possible to point out some of the potential 'problem' areas. Institutions are potentially relevant in three ways. These are:

1. The nature and the degree of success of the institutional change accompanying irrigation can have both physical and social consequences (affecting both the fishery and fishers).
2. The physical and socio-economic changes that accompany irrigation can affect the efficacy of existing fisheries institutions making them inappropriate, inadequate, or in some way requiring change.
3. Institutions may determine access to resources or economic opportunities, thus influencing how both the positive and negative impacts of irrigation development may arise for different groups.

These issues are considered further in Section 4.6 below.

4.6 Impacts of institutional change accompanying irrigation

The assessment of institutions in relation to irrigation and fisheries is vital for three reasons:

1. Many of the potential impacts of irrigation on fisheries or fishers may have an institutional or part-institutional root cause.
2. As one of the principle means used to govern human behavior, the crafting or adaptation of institutions can play a fundamental role in the avoidance, or mitigation, of any harmful impacts of irrigation on fisheries.
3. The physical and livelihoods impacts of irrigation development may not directly change existing fisheries institutions but may make them redundant or inappropriate, or make it clear that new institutions are required.

An understanding of how well an irrigation system is working, or will work, is central to gaining an understanding of the effects it might have on a fishery, and how well the system works may depend largely on institutions. Hydrological and ecological impacts have already been discussed (Sections 3.3 and 3.4) and some of these will occur irrespective of human action.

For example, the construction of a dam (if well designed and constructed) will initially increase water retention, increase the availability of water during the dry season and obstruct fish migration. However, what happens after the dam is built depends on human action, which in turn depends on the set of rules designed to facilitate implementation, operation and maintenance of the scheme. If the infrastructure is not maintained then the dam may burst (leading to enabled fish migration but loss of dry season habitat). Alternatively if channels are not maintained they may silt up, leading to impeded fish passage. Similarly a breakdown in water distribution practices would have both hydrological and ecological effects.

To be successful, rules must be adapted to local circumstances in such a way that complying with them (both in terms of water distribution and system maintenance) is perceived to be beneficial by all concerned. This is one of the main challenges of irrigation management.

It is not only the actions of irrigators that need to be considered. If fishers perceive that an irrigation scheme will seriously affect their livelihoods then sabotage of the scheme may become one of the strategies they consider. This underlines the importance of understanding the livelihood strategies of those in the affected area pre-intervention.

Dissatisfaction with an irrigation scheme amongst fisher households is one potential source of conflict. Institutions introduced as part of an irrigation development will not be introduced into an institutional vacuum. There will already be authority relationships that specify who decides what in relation to whom. Introducing new institutions, particularly new water user groups and associations, if done without sensitivity to existing power relations can cause social tension. Possible solutions are extensive public consultation prior to implementation and, wherever possible, the utilization of existing user groups and/or power relations.

Examples of new institutions that may be required following irrigation development include the following:

1. Regulation of year round fishing rights to a newly constructed reservoir.
2. The control of traps in fish congregating areas such as culverts or below dams.
3. Preferential reallocation of fishing rights to full-time poor fisher households who lost access when habitats were modified.

These are also examples of possible mitigation measures requiring institutional change rather than further physical and engineering interventions.

A final institutional factor that may impact on fishers is any changes to tenure or usufruct rights as a result of land use change, or the modification of fish habitats. Privatizing or expropriating areas that were previously seasonal fishing grounds or newly created enhanced habitats can impact on fishers' access to the fishery with the privatisation or expropriation of areas that were previously seasonal fishing grounds, or of newly created or enhanced habitats. This may be particularly true in floodplain areas where competition for both land and fishing space may be intense if population pressure is high.

Access to a fishery is a livelihood asset, but one which is often scarce and unequally distributed, depending on habitat availability, population pressure and the competition for fishing space. For example in Bangladesh, flooded privately owned farm land is by law an open-access resource for fishing, but one that is becoming increasingly unilaterally privatized by landowners or communal action. Such privatization is often being enforced by physical violence and the appropriation of fishing gear (Bath University Centre for Development Studies 1994). Irrigation development may not directly influence this, but for poor households marginalized in other ways by irrigation impacts, the "open-access" floodplain fishery may increasingly no longer be an open access resource of last resort. This example also illustrates that it should not be assumed that the counterfactual, or without-irrigation scenario, will be that the poor will continue to have access to a fishery. Particularly, as it may be the most productive parts of a floodplain that are privatized first, access to the remainder depends on evolving access rules and a community's or group's relative power. The introduction of irrigation may in fact provide an opportunity for the reform of access rights, or the modification of habitats in favor of access by the poor.

Power relations are clearly relevant to the pre-existing pattern of access rights to a fishery and how they may evolve over time, either with or without irrigation development. Community management of the resource may be preferred, but may still be subject to domination by elite groups unless empowerment and participation for all are well established. The introduction of irrigation may provide a "window of opportunity" to challenge and reform existing hierarchies and power structures.

4.7 Interactions and synergistic impacts

Impacts of irrigation development on fisheries resource systems can arise through complex, indirect as well as direct pathways.

4.7.1 Hydrological and ecological impacts mediated by irrigation management

Although irrigation infrastructure and land use change impact strongly and directly on fisheries, maintenance and management factors vigorously moderate the effects. For example, if infrastructure is not maintained then dams or canals may break and effectively reduce the design impact of infrastructure. Water control is a major factor determining fisheries impacts, and certain institutional arrangements may result in a much more fisheries-friendly water control than others.

4.7.2 Direct impacts of institutional factors relating to agriculture on fishing practices

Irrigation development may, by design or by default, change property or usufruct rights and this may affect fishers' access to the fishery and therefore their fishing practices. For example, land development in irrigated areas may lead any remaining water bodies to become private property of farmers who own adjacent land.

4.7.3 Secondary interactions within the fisheries system

Various secondary interactions within the fisheries system may strongly impact on outcomes. Changes in the social and economic situation of fishers are likely to affect the labor allocated to fishing, and therefore fishing practices. Likewise, modified hydrological conditions may change fishing practices. For example, reduced peak flows may permit the use of barrier gear in the river channel at times when this would have been impossible before, and the increased fishing pressure may feed back into the ecological status of the fishery. Changes in fishing practices will almost inevitably affect the social and economic status of fishers, and this effect may be differentiated between groups. For example, a decrease in floodplain fishing opportunities may strongly reduce the fish catch obtained by women as part of normal household activities, while opportunities for dry season fishing in an upstream reservoir may benefit mobile men during periods of low labor demand.

4.7.4 Fisheries-independent impact on livelihoods of fishers

Finally, irrigation development can affect the social and economic status of fishers through fisheries-independent routes. Examples include changes in water availability for domestic purposes, or changes in the risk of contracting diseases such as malaria or schistosomiasis, or conflict and tension (a deleterious social outcome) which could lead to breakdown of institutional arrangements pertaining to fisheries.

Chapter 5

Mitigation or enhancement of fisheries impacts

There is a range of options for mitigating the negative, and enhancing the positive impacts of irrigation development on fisheries. The earlier in the development process such options are considered, the greater is the scope for effective mitigation or enhancement.

In this chapter we set out general principles for mitigation or enhancement, before providing more detailed guidance on the identification of specific measures in terms of infrastructure design and operation, land use, and fisheries management. We also touch upon institutional development issues and the possible need for compensation where effective mitigation is not feasible.

It should be noted here that we aim to provide guidance on the identification of mitigation or enhancement measures, but that specialist input from engineers, hydrologists, agronomists, and fisheries scientists is likely to be required to implement mitigation measures.

5.1 Overview

5.1.1 Principles

Management of the impacts of irrigation development on fisheries should in the first instance aim to sustain fisheries through the implementation of mitigation measures, but may also involve compensation for losses that are unavoidable or too expensive to mitigate. The priority given to direct mitigation over compensation is justified on the basis of the close linkages between biodiversity conservation, fisheries productivity and other ecosystem services: many (but not all) measures aimed at sustaining fisheries will have much wider benefits. At the same time, sustaining fisheries through mitigation measures is likely to be less disruptive to fisheries-dependent livelihoods than degradation of fisheries even if compensation is made available.

Mitigation of the negative and, where relevant, the enhancement of the positive impacts of irrigation development on fisheries is based on three principles:

(1) Minimizing loss and modification of existing aquatic habitats

(2) Developing new aquatic habitats (reservoirs, canals, etc.) to maximize their fisheries potential

(3) Maintaining or restoring ecological connectivity between habitats

Compensation through direct payments, or the development of alternative production and livelihoods options may be required if full mitigation is not possible or economical.

5.1.2 Principles into practice

The three simple principles for mitigation outlined above have multiple implications for the practice of:

- infrastructure and land development,
- water management,
- fisheries management,
- agricultural practices,

- institutional development, and
- economic and social development.

Key implications are shown in table 5.1 and explained further in subsequent sections of this chapter.

Table 5.1. Implications of mitigation principles for different aspects of irrigation development and management.

	Minimizing loss and degradation of existing aquatic habitats	Developing new aquatic habitats	Maintaining ecological connectivity	Compensating for losses
Infrastructure and land development	• Minimize conversion and modification of aquatic habitats	• Design and build 'fish-friendly' reservoirs and canals • Create or set aside areas for fisheries	• Maintain habitat network • Avoid obstructions or provide fish passage facilities	• Allow for pond or cage aquaculture where potential exists
Water management	• Maintain minimum flows and water levels to conserve biota • Induce larger flows and flooding to support biomass production	• Maintain minimum flows and water levels to conserve biota • Induce larger flows and flooding to support biomass production	• Maintain flows and water levels sufficient to allow movement	
Fisheries management	• Support adaptation of harvesting to reduced habitat availability	• Support development of fisheries in new habitats	• Control fishing at migration bottlenecks	• Enhance fisheries • Develop aquaculture
Agricultural practices	• Have cropping systems with low water requirements • Take soil and water conservation measures • In rice systems, manage aquatic habitat of fields			
Institutional development	• Recognize fisher's use rights to aquatic habitats • Ensure fishers are represented in decision making processes	• Recognize fisher's use rights to aquatic habitats • Ensure fishers are represented in decision making processes		• Recognize fisher's use rights to aquatic habitats • Ensure fishers are represented in decision making processes
Social and economic development	• Build local capacity and exploit indigenous technical knowledge and participatory assessment and planning processes • Compensate fishers financially for losses • Optimise alternative livelihoods by addressing barriers to entry, improving market access, and creating an enabling environment for private investment.			

5.1.3 Dealing with trade-offs

It is often possible to identify mitigation measures that do not involve significant costs, simply by taking fisheries considerations into account when planning, designing and operating irrigation systems. Such measures should always be sought and implemented.

However, irrigation development, by its very nature, almost always implies significant changes to aquatic habitats. Therefore, mitigation measures often involve significant trade-offs between intensifying agriculture and maintaining fisheries, and between fisheries in existing and newly created habitats. Such trade-offs must be made explicit and evaluated quantitatively where possible (Section 2.7). The presence of trade-offs does not imply a no-win situation: on the contrary, it is often possible through careful consideration to identify options that substantially improve the joint benefits of irrigation and fisheries management.

5.2 Infrastructure and land development

Infrastructure and land development has major direct implications for aquatic habitat structure and connectivity. It also defines fundamental constraints to future water management, including water allocation to environmental functions and fisheries. It is thus crucial that fisheries aspects are taken into account at all stages of infrastructure and land development.

Fisheries implications should be considered in the planning, design, construction and implementation of:

- intake and diversion structure,
- fish passage facilities,
- supply and drainage canals,
- flood control structures,
- canal and road crossings, and
- land development.

Key considerations are explained in following sections, and a tabular overview for each stage in the development of irrigation schemes is given in Section 5.3.7.

5.2.1 Intake and diversion structure

Dams should be constructed so as to allow controlled release of surface water from the reservoir into the river below. At a minimum, this requires an outlet connecting directly to the riverbed (not via the irrigation and drainage channels). Ideally, this should be fed from a high or mixed level intake, in order to provide warm and aerated water to the river. Failure to incorporate a suitable outlet for river releases in design and construction will severely limit the options for providing environmental flows for downstream ecosystems, fisheries and other uses.

Weirs should ideally be constructed in such a way that they can be opened or removed when not in use, for example, during the wet season when irrigation demand is little or nil. This may be achieved through removable gates or stop logs in small weirs, or gates that can be raised or lowered in larger installations. In the latter case, where weirs are partially opened, overshot operation is preferable to undershot operation because the high pressure and turbulence associated with the latter often causes injuries to fish. Where possible, design gates and openings for submerged flow with low velocities, allowing fish to pass upstream or downstream with ease.

Free intakes and those associated with weirs and pumps should be screened to minimize entraining and entrapping of fish in the irrigation system. An exception would be where there is significant wetland habitat within the irrigation command benefiting from fish recruitment via irrigation intakes. Only high and mid-level intakes at reservoirs require screening, and the screens may be removed when water is released directly to the river to allow downstream passage. Many different screening systems are available, from simple mechanical screens to sophisticated electrical or acoustic devices. The design of screening systems is a highly specialized field, and generally requires experimentation to identify systems that are effective for a given environment and fish assemblage.

Fish movement across diversion structures may most effectively be provided by opening or removing the structure during peak migration periods (often just before or during the wet season when irrigation water demand may be low). Where this is not practical or insufficient, dedicated fish passage facilities should be considered.

Further reading: Bernacsek 1984; Miranda 2000.

5.2.2 Fish passage facilities

Maintenance of habitat connectivity requires maintaining minimum water levels and flows, as well as fish passage facilities where structures such as dams, weirs and embankments obstruct migrations. Fish passage facilities serve to facilitate longitudinal and lateral migration of fish. In both cases, fish passage across physical barriers is likely to involve either upstream passage (towards a compartment with higher water level) or downstream passage (towards a compartment with lower water level.

Upstream passage involves migration against water flow. Whether or not an obstacle can be passed depends on the hydraulic conditions over and on the foot of the obstacle (velocity, water depth, aeration and turbulence) in relation to the species' swimming and leaping ability.

Dams and weirs usually require the construction of specific fish passage facilities. The principle of upstream passage facilities is to attract fish to their entrance at the downstream end, and facilitate upstream passage by creating hydraulic conditions that the species can negotiate. The general requirements for fish passes may be summarized as:

1. Sufficient capacity to deal with mass migrations over short periods of time. Many fish migrations are mass phenomena.
2. Adaptation to swimming abilities of fish, including slower species and life stages. Swimming ability increases with the size of fish, and small species and life stages require low flow velocities.
3. Permanent functioning over a range of flow conditions.
4. Ready accessibility of entrance positioned in the main stream (Cowx and Welcomme 1998).

There are a range of different options for upstream passage facilities, each with its specific advantages and disadvantages (table 5.2).

Overall, pool fish passes may often be the best compromise in terms of serving a wide range of species and life stages under different flow conditions, and having moderate space, investment and operational requirements. Pool passes with vertical slot interconnections and low head loss between pools have proved particularly effective.

Table 5.2. Fish passage facilities.

Type	Principle	Advantages	Disadvantages
Pool fish pass	Series of pools to break down drop into smaller steps	Well designed pool pass suitable for wide range of species	Larger and more expensive structure than Denil pass
Denil fish pass	Baffles dissipate energy in very steep flume	Small structure	Suitable only for species with high swimming/ leaping ability
Bypass channel	Longer, stream-like channel around obstruction	Offers flowing water habitat as well as passage, low maintenance	Large and expensive, requires much space, sensitive to water level fluctuations
Fish slope/ramp	Ramp within existing channel downstream of weir	Can be effective for a wide range of species, located within existing channel, low maintenance	High flow requirement
Fish lock	Periodically operating lock for fish	Low space and water requirements	Ineffective in attracting fish, most considered unsuccessful
Fish lift	Periodically operating lift	Low space and water requirements, insensitive to water level fluctuations	High operation and maintenance costs
Collection & transport ('Human fishpass')	Fish collected in trap and moved actively	Low investment costs, low selectivity, may use local expertise and labour	Labor intensive, cultural barrier to releasing fish caught
Temporary removal of obstruction	Removal and rebuilding of indigenous weirs, lifting undershot weirs at high water	May remove obstacle at key periods of migration	Expensive/labor intensive

Source: Compiled from Larinier 2001; Welcomme 2001.

'Human fishpasses', the manual collection and movement of fish can be an effective, easy and cheap option that is attracting increasing attention. In many locations, migratory fish aggregating below dams and sluice gates are subject to intensive fishing using methods such as lift nets that cause little injury to fish. Given suitable transport facilities, fishers can be paid to move and release all or part of their catch. This option may be preferable where technical fish passes would require major engineering works and may still be of unknown effectiveness.

Temporary removal of obstacles is a possibility for smaller structures. Indigenous weirs are frequently intentionally or accidentally broken at high flow and rebuilt at lower flow. Undershot gates in weirs or barrages may be lifted completely to allow fish passage at high flows.

Common problems with fish passage facilities include (Larinier 2001):

- lack of attraction to the downstream entrance;
- poor design with regard to water level fluctuations;
- poor dimensions: pools with small volume and high head loss;
- clogging up or obstruction of facilities due to inappropriate positioning or lack of maintenance;

- lack of maintenance or operation of active facilities; and
- velocities too high for fish to pass through.

Downstream passage may involve active migration of larger fish, but particularly important is the mostly passive downstream migration of juveniles of species that spawn in headwaters. Most upstream passage facilities will allow some downstream passage as well, but they will only account for a small proportion of downstream flow and therefore a small proportion of passive migration.

Fish passage facilities must be maintained regularly, or they will cease to function. Hence it is futile to invest in such facilities unless there is a realistic prospect that they will be maintained.

Further reading: Several excellent manuals for fish passage design and operation have recently been published including Clay 1995; Larinier 2001; FAO/DVWK 2002.

5.2.3 Supply and drainage canals

Irrigation and drainage canals may support productive fisheries, provided that they:

- contain water continuously or at least for extended periods; and
- offer, or are connected to suitable habitats for all life stages of the fish.

However, in many cases the production benefits from canals are small and while there may be opportunities to increase these, costs and likely benefits must be evaluated carefully.

Supply canals typically are characterized by highly variable hydrology and very limited connectivity to other aquatic habitats. Water reliability tends to be the highest in large canals, that is, primary canals of major irrigation schemes, and declines towards smaller/higher order canals. In some cases, it may be possible to operate cross regulators in a manner such that water is retained continuously in the canal sections above the regulators even when no water is being issued. Additional regulators could be put into place in order to retain water throughout the length of the canal where there is significant potential for canal fisheries or aquaculture.

Drainage canals are often characterized by more stable hydrological conditions, and also tend to be connected to natural habitats downstream. It may be beneficial to design such canals to mimic the conditions of natural streams or rivers, thus providing near-natural fish habitat. This may involve constructing sinuous rather than straight canals, including boulders and fast-flowing riffle zones, and encouraging bankside vegetation. Many water engineering projects in Europe now aim to create near-natural habitats even where the underlying hydrological modifications are substantial, for ecological as well as aesthetic reasons. There is as yet little experience with such approaches in developing countries, but they should be considered for new schemes or rehabilitation projects. Such measures are unlikely to be justified on fisheries production grounds alone, but may have additional benefits in terms of reducing maintenance, conserving biodiversity and protecting landscape. The design of the system will need to allow for water to be discharged into the drainage systems to maintain adequate flow levels.

Constructed wetlands may be integrated into drainage canals to reduce concentrating nutrients and agrochemicals in drainage water before it reaches natural aquatic ecosystems. Constructed wetlands have proved to be effective in treating irrigation drainage water, and should be considered wherever possible. Such measures are particularly important where there is concern that soil conservation measures and responsible use of agrochemicals may not be adopted.

Further reading: In-stream habitat improvements that may be applicable to the design of canals have been extensively covered in Cowx and Welcomme 1998 and Welcomme 2001. See Moshiri 1993 for further information on constructed wetlands.

5.2.4 Flood control embankments

Flood control embankments may be constructed to provide complete protection from flooding, or to exercise control over the height and duration of flooding without eliminating it entirely. The latter is the case, for example, in flood-prone rice farming systems. Also, controlled flooding of agricultural land is increasingly being used to alleviate flooding of urban or industrial land where flood damage would be extensive.

Areas subject to controlled flooding can provide excellent habitat, and support productive fisheries so long as infrastructure allows fish passage between the main channel and the floodplain habitats. Technically, the problems to be solved are equivalent to those of upstream and downstream passage, depending on the relative water levels in the main channel and the floodplain. Often these relative levels will change in the course of the flood cycle, as flood control schemes are operated to reduce flooding from the main channel at high water, but retain higher water levels in the floodplains at low water. This implies that the direction of upstream and downstream passage across the embankment will change and ideally, both should be enabled from both sides. However, as most fish species using floodplain habitat migrate into the floodplain at rising water and back into the main channel at falling water, the main migrations will be in the downstream sense in both cases. As described above, regulators and weirs should be designed to allow overshot operation, as overshot operation is far more conducive to downstream passage than undershot operation.

5.2.5 Canal and road crossings

Irrigation schemes often involve structures such as raised canals and access roads that cross natural drainage lines, streams and rivers. Such crossings should be constructed so as to minimize impacts on these natural aquatic habitats and the movement of fish within them. Culverts and to a lesser extent, bridge crossings designed without consideration for aquatic resources often present formidable barriers to fish movement. The most common problems preventing upstream passage are a large drop at the downstream end, and constricted width of the culvert leading to very high flow velocities. Both problems can be avoided by designing relatively wide culverts, which may be embedded in the natural stream bed. The difficulty with this is that culverts are often deliberately sized to maintain high velocities in order to flush sediments through. Bridge decks over the channel, rather than a pipe culvert, can be a feasible solution, leaving the channel section undisturbed.

5.2.6 Land development

Irrigation development often goes hand in hand with extensive land engineering to maximize the agricultural productivity of land in the command area. This may involve in particular leveling of land, in-filling of wetlands, and improved drainage. Minimizing in-filling and drainage of wetlands is an obvious measure to sustain aquatic resources and fisheries. Though this will cause the foregoing of some agricultural production, the costs of land engineering will be reduced and this approach may be overall beneficial in “difficult areas” where land engineering costs would be high.

It may also be possible to compensate for wetland loss in the command area by constructing new wetlands outside the command area. Wetlands constructed below the command area may receive irrigation drainage water and retain nutrients and agrochemical residues. It is also often possible to create new wetlands above the irrigation command area, with raised canals effectively damming small natural drainage areas.

Where aquaculture development is to be promoted (for example, as a form of compensation), pond construction can be combined with general land engineering. Indeed, this often happens through informal requests during the construction of irrigation schemes.

5.2.7 Mitigation throughout the irrigation development process

Mitigation or enhancement measures can be taken at different phases of the development process: planning, design, construction or implementation. Planning and design are the crucial phases of development as it is during these phases that the key decisions are made. It is preferable that consideration is paid on the impacts of irrigation development on fisheries at the outset, during the planning phase itself, as decisions made at this phase can then be followed through during subsequent phases. The policy on natural fisheries will be set during the planning phase. Possible mitigation/ enhancement measures to be considered at the planning phase in relation to the hydrology and hydraulic impacts are presented in table 5.3.

The design phase is crucial to the development process, and to the implementation of any mitigation/ enhancement measures. This is particularly so for new developments (rather than rehabilitation work) as the design will govern the amount of development that takes place. It is at this stage that areas can be deliberately excluded from development and left as natural habitats for fish. With the correct approach and understanding of the needs of fisheries the irrigation system can be designed around the natural features such as waterways, depressions and drainage paths to significantly mitigate the development impact. Islands of natural environment can be left at strategic locations within the development to provide for natural fisheries.

The design phase controls the physical structures that are built, their type, location and layout. It can also, through the contract documents, govern the working practices of the contractor building the works. Contract clauses can be included which limit the potential damage that might be caused to natural fisheries during the construction phase (such as limiting disturbance to, or pollution of, the natural waterways).

Tool 31. Identifying mitigation options in infrastructure and land development

Based on the mapping and characterization of aquatic habitats and the planned irrigation system (tools 3 and 21), and the detailed table of mitigation measures (table 5.3):

(1) Consider whether existing aquatic habitats likely to be impacted can be conserved.

(2) Consider whether new semi-natural habitats can be created through modifications in planned land and river channel engineering.

(3) For each component of infrastructure, assess mitigation options in the planning, design, construction and implementation of the irrigation scheme (tables 5.3a, 5.3b, 5.3c and 5.3d).

During construction, the contractor can be made aware of likely adverse impacts of construction methods on natural fisheries. For large irrigation projects, the contractor may excavate sand and gravel from the river, and use river water for washing the sand and gravel to remove silt. This work can adversely impact on natural fisheries, and can be lessened by proper understanding of the effects. An example would be to construct a settling pond to settle out the silt and sediment washed from the sands and allow clear water to return to the river.

During the implementation phase, the mitigation measures are a mixture of management, operations, and maintenance procedures linked to the infrastructure development. Management relates to institutional issues, such as enforcing bans on fishing at certain locations (culverts) or times of year (migration). Operation procedures can dramatically impact on the natural fisheries, for example, the timely operation of a dam to allow controlled release of flood waters at the right time to trigger and sustain fish migration in the river channel, thus maintaining the fish cycle. Failure to operate in the correct manner may mean that the migration does not occur. In addition flood flows can be controlled to allow certain degrees of flooding of downstream flood plains, thereby sustaining natural fisheries. “Fish friendly” maintenance procedures can make a significant difference on mitigating the impact of irrigation development on natural fisheries. The fish friendly procedures go against the grain of O&M engineers, who prefer to have straight canals and drains clear of vegetation and overhanging trees. However, sensible maintenance procedures can help, for example, cleaning only one side of a drain and leaving the other side to act as a habitat for fish. Careful maintenance and replacement of screens on hydroelectric turbine intakes and irrigation and drainage pumps can also make a significant difference.

Tables 5.2a, 5.2b, 5.2c and 5.2d provide a detailed overview of mitigation options that should be considered in different phases of the project cycle.

Table 5.2a. Principles of mitigation of irrigation and drainage impacts from infrastructure – planning phase.

Infrastructure	Component	Possible mitigation measures
Overall	Consider the impact of the development overall, and individual component parts on fisheries. Look at hydrological and fisheries processes and look to applying the principles and approaches set out in table 5.1. Look at the extent of the development, and the proportion and timing of the river flow that will be stored or diverted.	
Dam	Dam section	Plan and budget to incorporate fisheries protection systems in dam design. Consider procedures for dam operation that allow some part of the flood flow downstream to facilitate flooding/inundation of designated areas, and allow fish migration.
	Outlet	Consider possibility of high or mixed level outlet to allow discharge of warm and aerated water and downstream transport of juvenile fish.
Reservoir	Water body	Plan and budget to remove trees from reservoir bed where forested.
Barrage	Gate sections	Plan and budget to incorporate fisheries protection systems in barrage design. Consider operational procedures that allow passage of flood flows and facilitate fish migration.
Weir	Weir section	Plan and budget to incorporate fisheries protection systems in weir design. Consider operational procedures that allow passage of flood flows and facilitate fish migration.
Irrigation intake	Pump	Plan and budget to incorporate fisheries protection systems in pump station design. Consider use of different types of impeller/water lifting mechanism (e.g. Archimedean screw type).
	Gated intake	No particular measures applicable.
Flood embankments	River channel	Plan to leave river channel section alone, without excessive river training works or "straightening".
	Flood plain	Plan and budget to set flood bunds at a distance from the river bank top to form low velocity flood plain section during floods. Legislate to maintain this flood plain section free of human habitation and/or cultivation.
Water delivery system	Canals	For large canals consider merits of fish friendly design, with oversized canal section with riparian vegetation and selected trees.
Fields furrow, sprinkler, etc.)	Irrigation method (basin,	Consider potential for fish culture on paddy fields. Make allowance in plans for setting aside some areas for natural fisheries. Don't seek to use all the area for cultivation - leave difficult areas, marshland, depressions, old river channels, etc. for natural fisheries and maintain connectivity to the river.
Water removal system	Drainage channels	Consider potential for using drains as fish pathways. Plan to leave natural drainage pathways without "straightening".
	Drainage pump station	Plan and budget to incorporate fisheries protection systems in pump station design. Consider use of different types of impeller/water lifting mechanism (e.g. Archimedean screw type).
Flood relief	Flood relief channels, structures and flood relief depressions	To compensate for taking out floodplain areas for irrigated agriculture allow other areas, either upstream or down stream, to be flooded to attenuate potentially damaging floods. Plan to partially remove vegetation as necessary to support fisheries from the area to be flooded.

Table 5.2b. Principles of mitigation of irrigation and drainage impacts from infrastructure – design phase.

Infrastructure	Component	Possible mitigation measures
Overall	Consider the impact of the development overall, and individual component parts on fisheries. Look at hydrological and fisheries processes and look to applying the principles set out in table 5.1. Review standard design procedures and designs to see if they can be adapted to lessen impact on fisheries.	
Dam	Dam section	Design suitable fish pass, fish ladders or bypass.
	Turbines	Design suitable screens to intake(s).
	Low level outlet	Allow sufficient energy dissipation, mixing and storage to provide opportunity for water temperature to rise to match downstream channel ambient temperature.
Reservoir	Water body	Consider filling and emptying cycles and impacts on fisheries. Design to maintain a minimum water body as dead storage to sustain fish species and aquatic life.
Barrage	Gate sections	Consider flow velocities during key flow periods for fish (migration). Design-in alleviation measures.
Weir	Weir section	Design suitable fish pass, fish ladder or bypass.
	Sluice gate	Position gate and size opening to allow a range of flow velocities – high flow to scour sediment out, lower flows to allow fish passage upstream.
	Sediment excluder	Designed to maintain high scour velocities, so mitigation measures not possible.
Irrigation intake	Pump	Design suitable screens to or around the pump intakes.
	Gated intake	Low hazard, no cost effective mitigation measures feasible.
	Free intake	Low hazard, no mitigation measures proposed.
Flood embankments	River channel	Consider flow velocities in river channel post-construction.
Water delivery system	Canals	For lined canals there are no feasible mitigation measures. For unlined canals, can consider oversizing canal by designing for a higher Manning's friction factor, thus allowing for vegetation growth on canal banks. For large earth canals, can incorporate deflectors to form pools and silt traps in the canal, and can allow for selected types of trees to grow on canal bank.
Fields	Irrigation method and slope across field	For dry food crops design fields to avoid soil erosion, which might impact on sediment levels in the river. For paddy rice systems provide connectivity with the river, either through the canals or the drains.
Water removal system	Drainage channels	In design keep head losses across structures and velocities in drains low. Design structures to facilitate fish movement upstream.
	Drainage drop structures	Endeavour to maintain longitudinal connectivity for fish, for example by having a drop structures with a shallow sloping downstream face rather than a vertical drop, or staged drops similar to a fish pass.
	Drainage culverts	Conflict here is between the need to maintain high velocities to scour out the culvert (in some cases) with need to maintain low velocities to allow fish movement upstream. If sedimentation is not a problem oversize culvert and maintain low velocities.
	Drainage outlets	As for drainage drop structures, design outfalls to allow fish movement upstream.
	Drainage pump station	Design suitable screens to or around the pump intakes.
	Drain outlet flap gates	Fit adjustable flap gate that can be maintained in open position if required. Position opening low enough to ensure connectivity between river and drainage channel at low river flows.
Flood relief	Flood relief channels, structures and flood relief depressions	Design flood relief channels, structure and areas to be flooded to sustain fisheries. Maintain connectivity between flooded areras and the river, avoid zones of high velocity.

Table 5.2c. Principles of mitigation of irrigation and drainage impacts from infrastructure – construction phase.

Infrastructure	Component	Possible mitigation measures
Overall	Consider the impact of all construction work on fisheries. Look at hydrological and fisheries processes and look to applying the principles set out in table 5.1. Look to scheduling construction work to fit with fish patterns, especially in relation to migration. Limit pollution and disturbance of the water way, minimize vegetation clearance in the waterway and riparian lands. Plan use of explosives with impact on fisheries in mind. Consider and mitigate impact on fisheries of sand and gravel extraction for construction from rivers. Limit erosion and runoff to natural drainage channels and rivers from bush clearance prior to construction of channels, roads and irrigated fields.	
Dam	Dam section	Maintain connectivity during construction with bypasses/ through flow, especially in migration period.
Reservoir		Avoid withdrawing all river flow during the first filling of the reservoir, allow environmental flows during this phase as well as routine operation.
Barrage	Gate sections	Maintain longitudinal connectivity with bypasses. Plan construction taking account of fisheries (migration, habitat)
Weir	Weir section	Maintain longitudinal connectivity with bypasses. Plan construction taking account of fisheries (migration, habitat). Limit disturbance and pollution within watercourse.
Irrigation intake	Pump	Fit suitable screens
	Gated intake	Limit disturbance within watercourse, and pollution of watercourse with construction materials
Flood embankments	River channel	Avoid interfering with instream habitat.
Water delivery system	Canals	Limit removal of topsoil besides canal sections. Use topsoil to finish off embankments to facilitate vegetation growth.
Fields	N/A	Limit damage to natural waterways within irrigated area (if allowed for in the design).
Water removal system	Drainage channels	Limit damage/reforming of natural drainage pathways (if allowed for in the design).
Flood relief	Flood relief channels, structures and flood relief depressions	Remove designated vegetation from area to be flooded. Implement construction at times/seasons that minimize impact on any existing fisheries. Maintain connectivity for any existing fisheries during construction.

Table 5.2d Principles of mitigation of irrigation and drainage impacts from infrastructure – implementation phase.

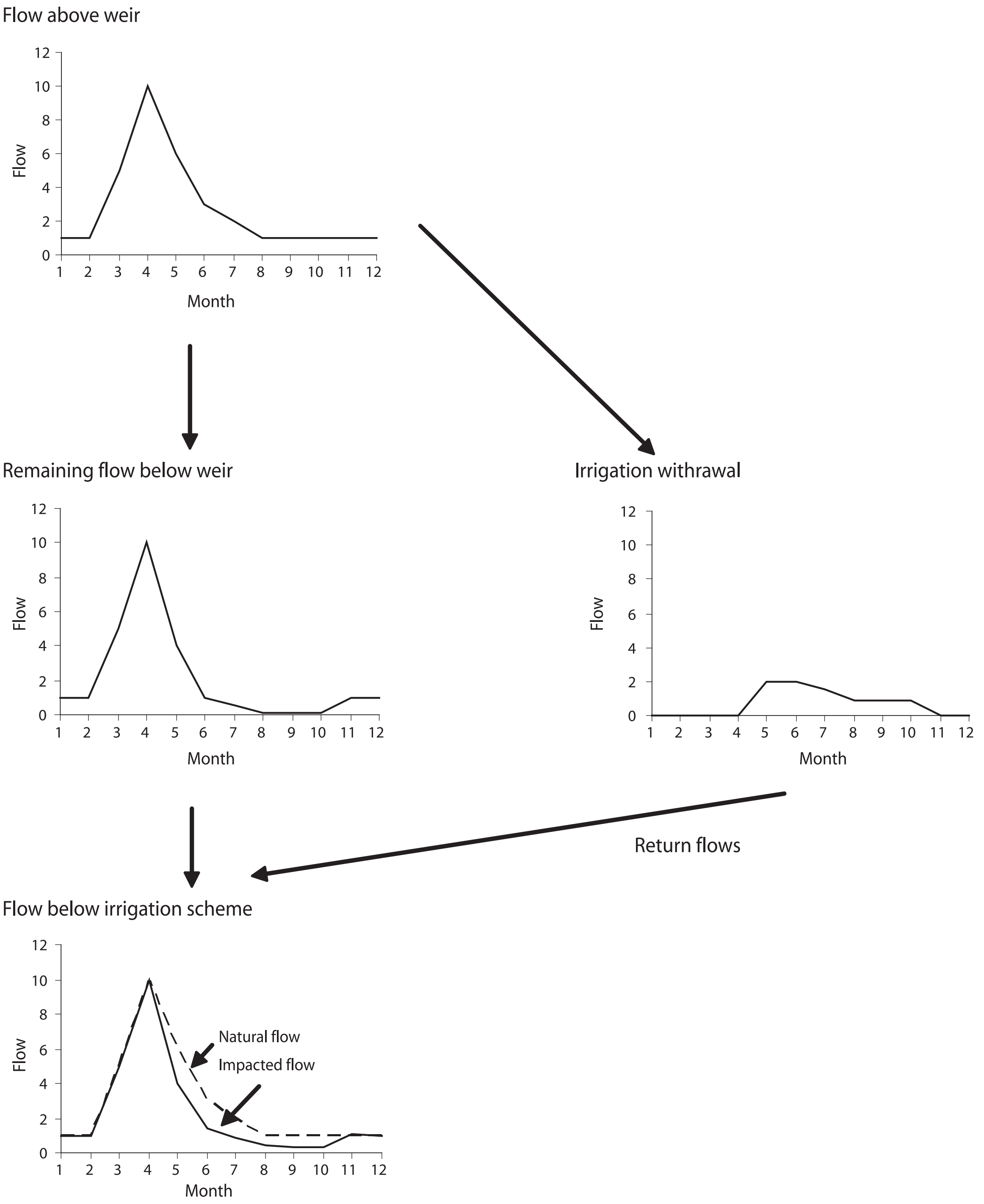
Infrastructure	Component	Possible mitigation measures
Overall	Seek to manage, operate and maintain the river network and irrigation and drainage system with an understanding of the potential impacts (and associated mitigating measures) on fisheries. Seek to apply the principles set out in table 5.1. Manage fisheries in relation to constructed infrastructure by effecting control of fishing at key locations and times.	
Dam	Dam section	Ensure adequate flows through fish passes, ladders and bypass channels. Keep fishers away from passes during migration period. Maintain the passes.
	Turbines	Maintain fish screens on turbine intakes and keep cleared of vegetation.
	Low level outlet	Operate with understanding of likely impact on fisheries downstream. Main issues are low water temperature and low oxygen content, alleviated by mixing with warmer and aerated waters.
Reservoir		Regulate reservoir level as far as possible with needs of fisheries in mind, both those within the reservoir and those downstream.
Barrage	Gate sections	Operate to pass flows during key periods, such as migration.
Weir	Weir section	Operate to pass flows during key periods, such as migration.
	Sluice gate	Operate to scour at certain times, and to allow passage of fish at other times.
	Sediment excluder	Limited possibilities for mitigation. May be operable at low flow periods to benefit fish.
Irrigation intake	Pump	Maintain fish screens and keep clear of debris and vegetation. Protect from damage by river debris during floods
	Gated intake	No particular measures.
	Free intake	No particular measures.
Flood embankments	River channel	Limit disturbance of river channel, limit weed and sediment clearance. Limit removal/cutting of vegetation on river banks and in flood plain zone between river bank and flood embankments.
Water delivery system	Canals	Limit disturbance of canal section and vegetation on canal edges. Enforce legislation to limit pollution of canal, especially from local industry (e.g. tanneries).
Fields		Limit and manage use of agro-chemicals to reduce hazard of runoff into drainage pathways.
Water removal system	Drainage channels	Limit disturbance of channel. If maintenance is required leave alternate sections on either bank for fish habitat, or clear/ clean one side only each year.
	Drainage culverts	Keep clear of debris and sediment, maintain pathway for fish. Enforce measures to prevent netting of young fish at these locations.
	Drainage pump station	Maintain fish screens and keep clear of debris and vegetation.
	Drain outlet flap gates	If adjustable, open during low river flow periods to maintain connectivity between river and drainage system.
Flood relief	Flood relief channels, structures and flood relief depressions	Operate flood relief system to maintain connectivity with river. Maintain vegetation in an appropriate manner for fisheries. Pay attention to land use if area is flooded infrequently.

5.3 Water management

5.3.1 Overview

Water management in irrigation systems with respect to fisheries concerns all aquatic habitats that make a significant contribution to fisheries production. In irrigation systems that do not involve storage of water in a reservoir (i.e. those using a free intake, weir or pump), management of abstraction to maintain adequate downstream flows is the primary issue. The problem is illustrated in figure 5.1.

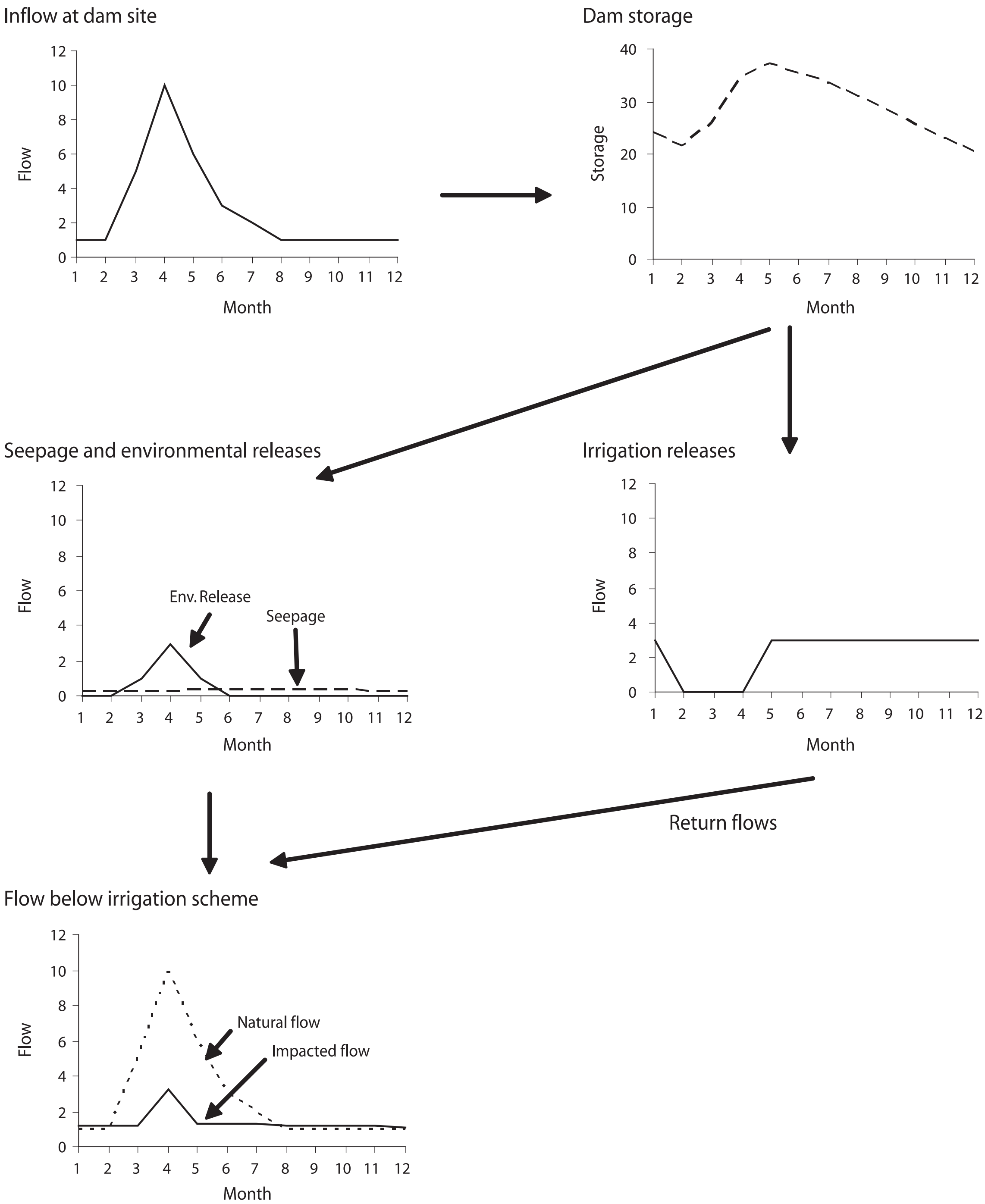
Figure 5.1. Schematic illustration of water management in an irrigation scheme with a weir intake.



Abstraction at the intake site (e.g. weir, figure 5.1) directly reduces the flow remaining in the river below the intake. Irrigation return flows will augment the river flow to some extent, but a large share of the irrigation water is normally lost to evapotranspiration. Because irrigation water demand is typically the highest during the dry season, abstractions tend to occur at times when river flows are relatively low. The primary concern in this case is the maintenance of dry season flows sufficient to sustain aquatic ecosystems and fisheries.

In irrigation systems involving storage of water in a reservoir, fisheries-related water management issues tend to be substantially more complex. Both the reservoir and the river will normally support fisheries, and allocation of water between these habitats may involve direct production trade-offs.

Figure 5.2. Schematic illustration of water management in an irrigation scheme with a reservoir.



As illustrated in figure 5.2, irrigation reservoirs typically retain a large proportion of the annual flow at the dam site. The stored water is then released for irrigation during the dry season. River flow directly below the dam is normally very low and is provided only through seepage, but this may be augmented by overspill at the height of the wet season, or by environmental releases. Again, irrigation return flows will augment river flows further downstream, often to such an extent that dry season flows are higher than under natural flow conditions. In the case of dam irrigation schemes, a major reduction in river flow occurs during the natural high-flow period, and provision of adequate flows during this period is of major concern. Provided that a suitable outlet has been incorporated into the dam design (Section 5.2), it is technically possible to provide natural or even higher levels of downstream flow as required. However, this will be at the expense of the stored water volume and surface area of the reservoir, with direct costs to both irrigation water availability and reservoir fisheries.

Water management decision making in irrigation and flood control systems often involves direct trade-offs between sectors such as agriculture and fisheries. Addressing these trade-offs and maximizing overall benefits involve making these trade-offs explicit and investigating how changes in irrigation operation and cropping patterns might influence fisheries production. A good example of such an analysis is given in Shankar, Halls and Barr (2004).

Ways of assessing the appropriate magnitude of downstream flow releases, and the implications of reservoir water management for fisheries are given in the following sections.

5.3.2 Downstream (environmental) flows

Downstream flows are usually the most important aspect of irrigation water management with regard to maintaining the character of the existing aquatic ecosystem and the services it provides. For this reason, downstream flows are often referred to as environmental flows. As shown above (Section 5.4.1), downstream flows comprise (a) a component of inadvertent flow due to seepage, spillover and irrigation drainage; and (b) additional intentional releases to benefit ecosystem functioning and services including fisheries.

Although downstream flows are expressed and managed in terms of flow rates (volume per unit time), it is important to consider that flows influence other hydrological parameters such as flood extent and duration, and that the flow rate as such may not be a most important variable to consider when assessing impacts. It may thus be important to establish the relationship between flow and flooding, particularly in tropical floodplain rivers where flooding is the most important variable driving fisheries production and exploitation. In natural river-floodplain systems flow and flooding are closely connected. In regulated rivers with dams and/or flood control embankments this relationship may be altered and partially disconnected. In rainfed rice farming landscapes, paddy fields may account for a large share of functional floodplain habitat which in this case is largely independent of river flow. It is thus important to consider flow and flooding separately where the direct link has been weakened.

There are several established approaches to setting environmental flow targets.

Hydrological-statistical approaches

Hydrological-statistical approaches to flow target setting are based on the premise that the flows most likely to maintain the character of the downstream ecosystem are the natural flows. The approach to the identifying of environmental flow requirements is therefore to characterize the natural flow regime, and design impacted flow regimes that retain as much of the pattern and magnitude of the natural regime as possible. This approach does not involve explicitly considering the impact of flow changes. It simply aims to retain as much of the natural hydrological regime as possible. The advantage of hydrological approaches is their relative simplicity and lack of requirement for ecological knowledge. The disadvantage, however, is that they provide no basis for assessing the impact of different flow transformations, or prioritizing features that are most critical to maintain. This means that hydrological approaches are most suitable in situations where transformations are of limited magnitude – a situation less likely to be found in irrigation systems than in any other form of water resources development such as hydropower because typically a large share of the available water will be abstracted and lost to evapotranspiration.

There are two main hydrological-statistical approaches to setting flow targets for fisheries.

1. **Minimum flow or flood indices.** Where historical records are available of flow or flood extent, target minima may be set in relation to the distribution of long-term values. Common criteria include a level that was exceeded 95 percent of the time, or 10 percent of the mean flow. **Further reading:** Tharme 2003.

2. **Flow regime methods.** These methods are an extension of minimum indices, they involve examining the temporal pattern of flows and floods as well as their overall magnitude. Different criteria may be used for different times of the year, e.g. relatively more water may be allocated to fisheries at times of fish migration. **Further reading:** Richter et al. 1996; Tharme 2003.

Ecological-functional approaches

Ecological-functional approaches to flow target setting involve explicit consideration of the functional significance of flow patterns for ecological processes and fisheries exploitation. Such approaches thus require ecological and fisheries knowledge in addition to hydrological expertise. Their advantage is that even substantial transformations can be systematically assessed (though the quality of the assessment depends on the information base). The approaches also relax the assumption that the natural flow regime is necessarily optimal and thus represents the target condition. When multiple uses and criteria are considered, the optimal flow regime may well be one that is somewhat modified from the natural regime: for example, lower than natural dry season flows may increase the efficiency of fishing, or higher than natural flows may alleviate water quality problems.

There are four main ecological-functional approaches to flow target setting:

1. **Conceptual-functional analysis** which disaggregates flow regimes into elements that are important to the maintenance of various biological functions. The most well-known of these methods is the South African Building Block Methodology. An example is given in tool 32. **Further reading:** King and Louw 1998.

2. **Holistic flow methods** which tend to consider the requirements of a wide range of organisms in a qualitative or semi-quantitative way, and may also include social considerations. Effectively these are extensions of the conceptual-functional methods. **Further reading:** King, Brown and Sabet 2003, Brown and Joubert 2003 and Brown et al. 2005.

3. **Habitat modeling**, that is, modeling the availability of suitable habitat for fish in relation to flows. This is based on a combination of hydrological modeling with empirically based habitat preference information, usually for particular species of fish. Note that these methods do not predict fish abundance or fisheries yield, but merely the availability of suitable habitat. A widely used physical habitat modelling approach is PHABSIM (Bovee 1982).

4. Fish population or production modeling, using approaches that explicitly model linkages between hydrological variables and fish population dynamics or fish production. Population models for tropical river-floodplain fisheries with explicit consideration of hydrological conditions include Welcomme and Hagborg 1977 and Halls and Welcomme 2004. No such population models are currently available in user-friendly software packages, and their use has thus remained restricted to experienced modelers.

Which approach to use?

There are currently several hundred environmental flow assessment methods in use worldwide. Most fall under one of the broad approaches outlined above, and many are variants of the same method using slightly different definitions or standards. Which approach to choose? On scientific grounds, this question is surprisingly difficult to answer. All methods are conceptual tools of varying complexity. There has been little cross-comparison, let alone empirical evaluation of the fisheries outcomes of using different flow methods. Methods that integrate scientific and/or local ecological knowledge are likely to be more useful in evaluating major flow modifications than purely hydrological approaches, not least because they make the key concern explicit and allow inputs from a wide range of stakeholders. We thus recommend implementation of ecological-functional approaches where possible.

There have been several recent surveys of flow methods and we refer the reader to these for further guidance.

Further reading: Tharme 2003, Arthington et al. 2004, Dyson, Bergkamp and Scanlon 2003 and Acreman et al. 2000 for environmental flow and flood release overviews. For specific methods see references above.

5.3.3 Reservoir water management

Reservoir water management has important implications for fisheries production within the reservoir and downstream. The importance of discharges for downstream flow and flood patterns and dependent fisheries has already been discussed (Section 5.4.2).

Reservoirs are water bodies that share characteristics of both rivers and lakes. Typically, reservoirs are characterized by a low residence time of water (less than one year in seasonal reservoirs, and 1-2 years in most others), and very pronounced fluctuations in water level and area (in shallow reservoirs). Irrigation reservoirs show a highly seasonal hydrology which in turn drives fisheries dynamics, with catches being highly seasonal and responsive to inter-annual variation. The interaction between hydrology and fisheries arises from physical, biological and socio-economic factors such as:

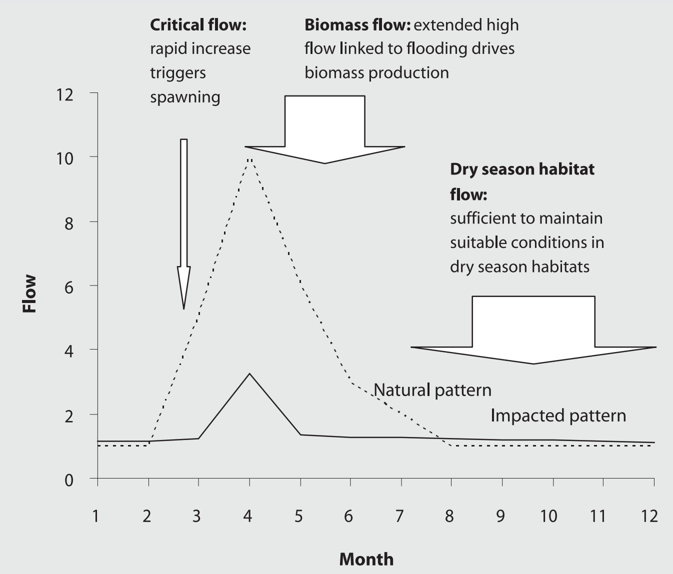
1. Physical dilution and concentration of fish biomass with fluctuating water area, which affects the efficiency (catchability) of fishing gear;
2. Variation in habitat availability and ecological carrying capacity with water area; and
3. Variation in total fishing effort in response to varying efficiency of gear use (cf. point 1) and the seasonality of labor demand in other sectors.

Tool 32. Simple functional approach to setting flow and flood targets for fisheries

There are various approaches to setting flow or flood targets but many will be too complex, costly or data intensive for smaller irrigation schemes. In such situations, the following conceptual-functional approach can be implemented in a workshop setting.

1. **Obtain seasonal flow and flood data.** The data should cover at least one year, longer records are preferable in order to gain an understanding of inter-annual variability.
2. **Assess how seasonal flow and flood patterns will be changed by the irrigation scheme.** This may be based on simple water budgeting (see 5.4.1). Ideally provide several scenarios for different design and operation options.
3. **Assess the likely functional significance of flow changes for aquatic resources.** This should be done on the basis of scientific and/ or indigenous knowledge. For each period where a flow change is expected, the following questions should be addressed:
   (a) Is the change likely to affect a critical flow, i.e. one known or suspected to trigger migration, reproduction, or other important life history changes?
   (b) Is the change likely to affect a biomass production flow or flood, and what is the likely magnitude of the production impact? This is particularly important in floodplain rivers where there is a direct relationship between flood area and duration and aquatic resource production. Quantify such impacts using the relationships given in Section 4.
   (c) Is the change likely to affect the quality of the aquatic environment, e.g. temperature, dissolved oxygen, or sedimentation?
   (d) Is the change likely to affect connectivity of habitats? For example, will sections of the river become too dry to maintain connectivity?
   (e) Is the change likely to affect the use or efficiency of fishing gear? Many traditional fishing gears can be used only under certain flow or flood conditions (see 3.4.2). Low flows and water levels tend to concentrate stocks and allow very efficient fishing.

A hypothetical example of an analysis of functional flows is given in figure 5.3. Three aspects of the natural flow pattern are identified: (1) a critical flow at the beginning of the wet season which triggers fish spawning, (2) a biomass flow during the main high water period which drives downstream flooding and fish production, and (3) a dry season habitat flow which maintains



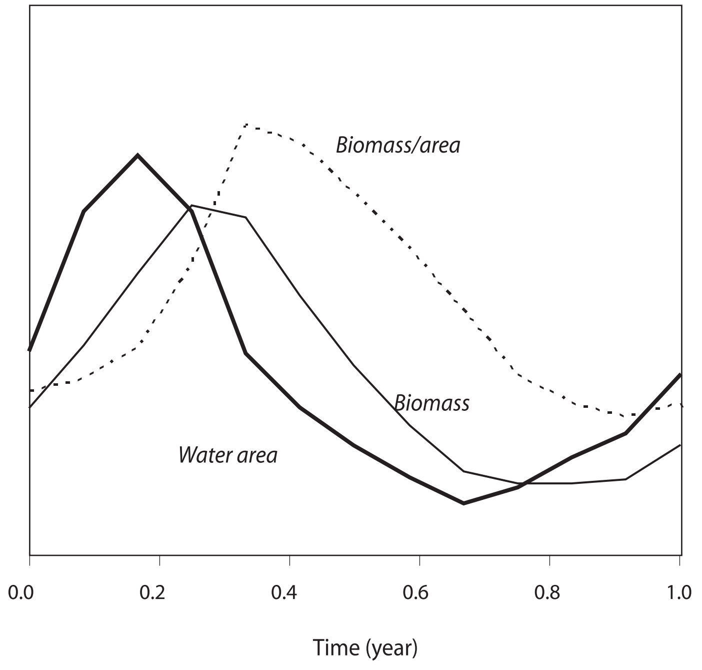
appropriate habitat for dry season survival of fish stocks. In the hypothetical example shown here, the impacted flow pattern has lost the critical flow, and much of the quantity but not the pattern of the biomass flow. The dry season habitat flow on the other hand has not been compromised. In order to improve impacted flow for fisheries, consideration should be given to shift the peak flow to the early wet season (restoring the critical flow), and to increase the overall magnitude and duration of the biomass flow.

4. **Consider how the modified flow regime can be adapted ('re-regulated') to improve fisheries outcomes.** This may involve small changes, such as a brief period of increased flow to trigger spawning, which may have limited consequences for irrigation water availability. Other changes such as maintaining a downstream flood may involve major tradeoffs with irrigation operation as well as reservoir fisheries. Individual flow components can be manipulated independently, but ecological linkages should be considered (e.g. maintaining a critical flow to induce spawning may not be effective unless some floodplain habitat for juveniles is also maintained).
5. **Retain or induce inter-annual variability.** Because of the diversity of fish species in their migratory and spawning behaviour, it is unlikely that any one set of flow and flood conditions will affect all species equally. It is therefore important to maintain a degree of inter-annual variability in the regulated flow pattern.

Further reading: The approach suggested here is adapted from the 'Building Block Methodology' (King and Louw 1998), while the classification fisheries-relevant flows was inspired by Welcomme and Halls 2004.

The basic physical and biological mechanisms driving the fisheries response to the flood cycle are reasonably well understood (figure 5.3). Flooding after the dry season vastly increases the ecological carrying capacity of the water body as a large area is inundated and nutrients and organic matter become available to the aquatic system. This phase is associated with rapid growth and reproduction

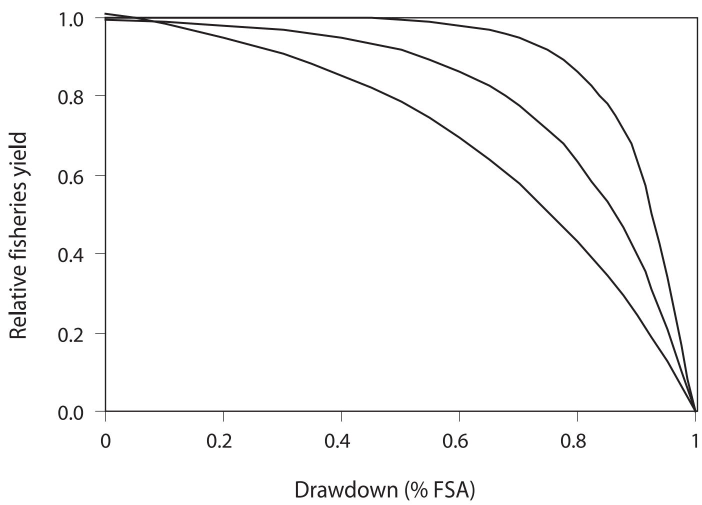
Figure 5.3. Schematic overview of the seasonal dynamics of water level and fish biomass in shallow tropical reservoirs.



of many fish species, leading to very rapid overall biomass growth. As water levels recede again, the stock becomes highly concentrated and may suffer strong reductions from density-dependent natural mortality. At this time the stock can also be harvested very efficiently, and there is often a peak in annual fishing effort and catch.

A large drawdown of the reservoir in the dry season causes a large concentration effect and thus benefits fisheries in the short term through high catch rates. However, it also reduces production during the dry season and if drawdown is so large that dry season habitat is a very small proportion of wet season habitat, stocks may not be able to produce sufficiently to expand fully into the wet season habitat. The resulting relationship between drawdown and production (figure 5.4) shows that production declines only moderately with increasing drawdown at first, i.e. even if the water area is reduced by 60-80 percent relative to the wet season area, fisheries production will still be only slightly reduced relative to a situation where water area is maintained at the maximum. However, further drawdown would result in a much steeper decline in fisheries production. While the precise relationship between drawdown and fisheries production will vary between reservoirs, it will generally be of the shape indicated in figure 5.4.

Figure 5.4. Schematic overview of relationships between reservoir drawdown and fisheries production.



In other words, the per-unit fisheries productivity of water will increase as water becomes scarce. Allocation decisions towards the end of the irrigation season will have a drastic effect on fisheries production in the following year and therefore the long-term average.

Where reservoir fisheries are significant, trade-offs between releases for irrigation and downstream environmental/fisheries purposes and the maintenance of reservoir fisheries production should be evaluated carefully. Where floodplain fisheries have declined substantially and reservoir fisheries are the primary aquatic resource use, fisheries production considerations may favor retention of water in the reservoir over flood releases. Biodiversity considerations on the other hand are likely to attach greater importance to releases.

For production within the reservoir itself, discharges for irrigation or to meet downstream ecological or fisheries requirements carry costs.

Further reading: Bernacsek 1984; Lorenzen, De Graaf and Halls 2002; Shankar, Halls and Barr 2004.

5.4 Fisheries management

There are several mitigation and compensation issues that fall within the broad area of fisheries management, i.e. the regulation of fishing and various measures to enhance fisheries production. These are:

- Adaptation of fishing rules,
- Development of reservoir fisheries,
- Fisheries enhancement, and
- Aquaculture development.

5.4.1 Adaptation of fishing rules

The modifications to habitats and habitat connectivity imminent in irrigation development often require the rules for fishing to be adapted. In this section we focus on changes in operational rules.

Fishing restrictions at migration bottlenecks. In modified environments where ecological connectivity is maintained by opening weirs and regulators or by dedicated fish passage facilities, fish must pass through very constricted passageways on their migrations. Such bottlenecks allow very efficient harvesting and typically attract high fishing effort unless effective restrictions on fishing are in place. It is therefore important to restrict fishing at man-made bottlenecks of fish migration such as culverts, sluice gates or fish passage facilities. In river-floodplain systems, such restrictions are most important during the period of down-migration.

Fishing restrictions in dry season habitats. Reservoir operation and modifications to the seasonal hydrology of river-floodplain system may result in populations being confined and concentrated into very small dry season habitat areas. As in the case of migration bottleneck above, such habitats allow efficient harvesting and may attract very high levels of effort. Fishing restrictions in such refuge habitats may be required to safeguard future recruitment, and are most important where dry season refuges are small (less than 10-20 percent in area) relative to the wet season habitat.

5.4.2 Development of reservoir fisheries

Reservoirs provide conditions for fish as well as fishers that are very different from those found in natural rivers-floodplain systems. Helping fishers adapt to these new conditions may thus be an important mitigation measure.

Fish assemblages in smaller reservoirs are typically based on riverine assemblages, but with a much stronger representation of species that are tolerant of lacustrine conditions. Many species will continue to rely on the upstream river environment for reproduction, and will show pronounced seasonal migrations between the reservoir and the river. Typically, these species will have a preference for littoral (near-shore) habitats. In larger reservoirs, the pelagic (open water) habitat may support large populations of typically small-bodied pelagic species. In some cases such species have been introduced into newly created reservoirs and led to the development of important fisheries.

Reservoir-associated fisheries often comprise three distinct types: fisheries in the reservoir itself (near-shore and pelagic in larger reservoirs), in the lower reaches of the river entering the reservoir, and directly below the dam where riverine ‘whitefish’ may aggregate during their upriver migration. Fisheries in the river above and below the reservoir exploit seasonal migrations in a way similar to traditional river fisheries. Fisheries in the reservoir itself, however, tend to use different technology (boats with gill nets, seines or lift nets) and are less seasonal than river fisheries.

The relatively non-seasonal nature of reservoir fisheries and the opportunities they provide for economies of scale (fishing with many nets and motorized fishing craft) may lead to the emergence of full-time professional fishers where river fisheries only supported part-time seasonal fishing. This process can be facilitated through development projects to improve capture and post-harvest technologies, marketing, and the developing of fishermen's organizations.

Fisheries yield from reservoirs tends to change dramatically over the first years to decades after impoundment as a result of expanding of fish populations in the new habitat, changes in nutrient availability, and changes in fishing effort. Initial yields tend to be low as fish populations have not yet expanded into the new habitat and fishing effort is also likely to be low. This is followed by a fisheries "boom" as fish populations colonize the new aquatic habitat, and breakdown of organic matter from inundated terrestrial habitats provides very high nutrient levels. Fishing effort may also expand rapidly during this period as catches are good. Resident fishers learn to exploit the reservoir fisheries, and additional fishers may be drawn from outside the new area. The "boom" is usually followed by a phase of slow decline in catch rates and possibly total catch. It is important to consider such likely temporal changes when developing reservoir fisheries.

Further reading: Bernacsek 1984 provides an overview of key aspects of reservoir fisheries management with a focus on Africa. A series of workshop proceedings (De Silva 1988b, 1992, 2001) synthesizes much information on the development of reservoir fisheries in Asia.

5.4.3 Fisheries enhancement

Fisheries enhancements are interventions aimed at increasing fisheries production to levels over and above those achievable by exploitation of the natural aquatic resources. They combine attributes of aquaculture (intervention in the life cycle of aquatic organisms) and capture fisheries (exploitation of common pool resources).

The rationale for enhancements is that, under certain conditions, targeted stocking or habitat modifications can substantially increase yields. Stocking of hatchery-reared seed fish, for example, can substantially increase the yields of desired species where natural productivity is high but recruitment of desired species is limited. This may be the case, in particular, of highly modified systems such as reservoirs and canals, which may offer limited spawning and nursery habitat for desired species. Habitat enhancements, such as creation of spawning habitat can have similar effects. Because enhancements rely largely on natural productivity in common pool aquatic resources, they may provide higher returns to investment and are more accessible to the resource poor sections of inland and coastal aquatic resource users than aquaculture. Moreover, introduction of enhancement technologies in common pool resources may facilitate institutional change leading to more efficient and sustainable exploitation of resources.

Widely practiced enhancement technologies include:

- stocking to create culture-based fisheries, that is, fisheries based predominantly on the recapture of stocked fish;
- stocking to enhance or supplement self-recruiting populations;
- habitat modification to improve levels of recruitment and/or growth; and
- fertilization.

Culture-based fisheries, where yields are based predominantly on the recapture of stocked fish, can be effective in increasing yields when natural recruitment of desired species is lower than the environmental carrying capacity. This may be the case in certain modified ecosystems (for example, reservoirs), or where intensive harvesting has reduced spawning stocks to very low levels. However, recruitment limitation can also arise naturally in seasonal and/or isolated freshwater bodies. Stocking is probably the most widely practiced form of fisheries enhancement, but not necessarily the most effective or efficient. Moreover, the release of large numbers of hatchery fish, possibly of non-native species, raises conservation concerns in its own right. Where stocking programmes are considered, these issues should be carefully assessed.

A wide range of habitat enhancements are being carried out in inland and coastal fisheries, using traditional as well as recently developed technologies. The effectiveness of these measures has often proved difficult to evaluate due to the time scales involved in responses, the levels of natural variation in natural habitat and recruitment, and institutional impediments to monitoring and evaluation. As a result, little scientific guidance can be given with respect to the choice of habitat enhancement technologies.

Enhancements are frequently associated with institutional change, including arrangements for access to resources. Examples are community management of culture-based small waterbody fisheries; leasing of seasonal water bodies to individuals; and granting of exclusive rights to particular social groups. Concerns about the socio-economic consequences of such restrictions have been voiced, but investigations in small water body fisheries have shown that communities are often capable of adapting management systems to minimize any negative effects of access restrictions and avoid potential conflicts. This may be different where resource users are very heterogeneous in terms of wealth and power, and resources are perceived as highly valuable. In such cases, a degree of external regulation of resource use (e.g. by government) may be required to avoid highly non-equitable allocation of resources.

Enhancements require significant and often regular inputs, such as stocking or the maintaining of habitats. To sustain such inputs into the management of common pool resources requires conducive institutional arrangements. Under open access conditions, technically effective enhancements would attract additional effort into a fishery. The result would be rent dissipation, so that individual fishers would be no better off than before and would be unable and unwilling to contribute to the costs of enhancements. Hence institutionally sustainable enhancements are usually associated with access restrictions.

Further reading: A general overview of fisheries enhancements is given in Lorenzen et al. 2001. Guidance on the management and development of aquaculture-based enhancements is given in Lorenzen 2006, Lorenzen and Medley 2006 and the *EnhanceFish* decision support tool (Medley and Lorenzen 2006). Williams et al. 1997 and Cowx and Welcomme 1998 provide guidance on habitat enhancements. While focused on temperate climates, many of the concepts and measures discussed are likely to be of interest in tropical situations.

5.4.4 Aquaculture development

Aquaculture development is often seen as a key compensation measure where impacts on fisheries are unavoidable. However, it must be realized that fisheries and aquaculture are very different activities, and that it is not usually possible to simply replace fisheries with aquaculture. The main reasons for this are:

- Fisheries exploit common pool resources. Their exploitation requires access, but no land and very little capital. Aquaculture is the farming of aquatic organisms owned privately, and it requires private rights to land or an area of water, and substantial capital.
- Aquaculture is a farming activity, and requires inputs such as seed fish, feed and/or fertilizer, if yields are to be raised over and above "natural" levels.
- As a result of these characteristics, fisheries present livelihood options for a wide range of people, but particularly the poor. Aquaculture is often taken up predominantly by better off households, although successful uptake by the poor is possible.
- To develop, aquaculture needs supply industries, in particular seed production and distribution networks. Where such networks don't exist, substantial support may be required for their development.
- Aquaculture produces a small number of mostly large-bodied species which provide high quality protein, but may not replace the diversity of micro-nutrients available from small wild fish eaten whole.
- There are also cultural barriers to the development of aquaculture and its uptake by particular groups. For example, because aquaculture is essentially a farming activity, it is rarely taken up by full-time fishers.

For these reasons, it must not be assumed that aquaculture development is necessarily a suitable compensation measure for loss of fisheries yield. The fact that both activities produce fish does not mean that one could, or should easily replace the other. Rather, aquaculture development should be considered as one of many possible options to compensate for loss of food or income previously derived from fisheries.

While aquaculture cannot easily substitute fisheries, irrigation development can offer positive opportunities for developing aquaculture. Certain irrigation structures such as reservoirs and canals provide suitable environments for the establishment of aquaculture facilities. Also, irrigation water may be used to supply farm ponds and extend the 'growing season' for aquaculture.

Irrigation construction often requires substantial quantities of earth, which may be obtained in part from the excavation of fish ponds. The costs of pond excavation are rarely justified by the benefits achieved from small-scale rural aquaculture, but where the pond is constructed as a by-product or primarily for a different purpose (e.g. water storage), its use for aquaculture may be highly beneficial.

The potential for cage aquaculture in irrigation reservoirs and canals depends on hydrological conditions in as much the same way as the fisheries discussed earlier. Wherever water availability is intermittent over short periods of time, there is little potential for aquaculture development. However, where water is available seasonally for at least three months at a time, there may be good opportunities for aquaculture development.

An overview of yields typically obtained in different types of tropical aquaculture systems is given in table 5.3. When considering the yield potential of aquaculture systems, such empirical information from operational farms should be used, rather than theoretical estimates of potential from on-station research.

Table 5.3. Fish yields obtainable from different aquaculture systems.

System	Inputs	Yield (kg/ha/year)
Extensive ponds or cages	Stocking only	600 [100-3000]
Semi-intensive ponds	Stocking, fertilization, some feeding	1500 [500-4000]
Intensive ponds or cages	Stocking and feeding	5000 [2500-10000]
Rice-fish culture	Stocking	250 [50-500]

Source: Michielsens et al. 2002.

Further reading: Pillay 1989 for a general overview of Aquaculture; Subasinghe et al. 2001 for Aquaculture development trends and issues, and Beveridge 2004 for cage aquaculture as may be developed in reservoirs or canals.

5.5 Land use and agricultural practices

5.5.1 Maintaining habitats

Wherever possible aquatic habitats should be maintained and protected from conversion to agricultural land, settlements or other uses. Maintaining habitats is the most fundamental requirement of fisheries conservation under the influence of irrigation systems. Obviously, connectivity can only be maintained between habitats that exist. Secondly, virtually all permanent water bodies sustain local populations of some species, and many support productive fisheries even when their connectivity with neighbouring habitats is limited. As a rule of thumb, connectivity is more important for biodiversity conservation than for fisheries yields.

Mitigating of negative impacts from agricultural management practices comprises principally:

- soil conservation measures and control of salinization;
- choice of pesticides that pose a low risk to aquatic biota; and
- measures and facilities to treat drainage water (see 5.3.3).

5.5.2 Soil conservation and control of salinization

Soil conservation and control of salinization are key issues in irrigated agriculture generally, and must be considered even where there are no fisheries issues to address. Readers are referred to existing irrigation management and soil and water conservation manuals for further guidance (Stocking and Murnaghan 2001).

5.5.3 Pesticide use

Pesticides differ widely in the level of risk they pose to living aquatic resources, depending on:

- The pesticide's fate in the environment, which determines the level of exposure. Key factors affecting fate are the route and quantity of release, persistence of the chemical, and certain properties such as lipophilicity that determine in which environmental compartments the chemical will persist.
- The pesticide's toxicity to aquatic organisms, which together with the level of exposure determines its ecological effect. Toxicity to aquatic organisms varies widely, but many of the commonly used pesticides are highly toxic.

How best to minimize pesticide risk to aquatic resources depends on the particular agricultural and aquatic system of interest, and involves considering both fate and toxicity. For example, many modern pesticides such as pyretroids combine high toxicity to aquatic organisms with very low persistence (short half-life). Such pesticides can be quite safe if applied to dry field crops (where they break down before reaching aquatic habitats), but would be highly dangerous if used in paddy rice systems where the agricultural and aquatic systems are virtually one.

Further reading: See Brink, et al. 2003 and Brink, et al. 2005 for an overview and decision support system for risk assessment of pesticides in tropical aquatic ecosystems. Cagauan and Arce 1992 discuss risks from pesticides in rice-fish culture.

5.6 Institutional development issues

Managing impacts of irrigation on fisheries effectively will require institutional development in four areas:

- Integrating fisheries considerations into all relevant areas of irrigation development and management.
- Adapting the existing institutional and legal framework.
- Institutional learning through adaptive management.
- Improving management capacity through strategic assessment.

5.6.1 Integrating fisheries considerations

Fisheries considerations should be integrated into all aspects of irrigation development. This is important not only within individual projects, but also at watershed or ecoregional level in order to deal with large-scale and synergistic impacts. Representation of fisheries interests should involve both the government department(s) concerned with fisheries and biological conservation, and the fishers and any organizations representing them.

5.6.2 Mitigation via the institutional and legal framework

Any negative impact that has inappropriate human behaviour as its root cause is potentially ameliorable by institutional mitigation. Even if not totally institutional, most mitigation measures are likely to have an institutional component to them.

When changing institutions, it is recognized that changing operational rules is easier than collective choice rules, which is easier than changing constitutional choice rules. Thus when looking for mitigation measures, always start at the operational level.

Operational mitigation measures could include the introduction or improvement of any of the institutions described in Section 3.5. Collective choice mitigation measures could include the improvement or alteration of the conditions of collective choice described in Section 3.5.

Where necessary new legislation should be introduced or existing laws, modified to facilitate and support planned mitigation measures.

5.7 Maintaining livelihoods from fishing and development of alternative livelihoods

It is difficult to be specific about means of mitigation processes of livelihood impoverishment or enhancing processes of livelihood improvement, arising from impacts of irrigation development on fisheries. Actual interventions that are possible and appropriate will tend to be location specific and will depend on hydrological, ecological, socio-economic, institutional and political conditions. Successful irrigation development and fishery management will involve certain processes as well as specific measures or interventions. A number of general principles are necessary to the achievement of success and these are listed below.

5.7.1 Mitigating or enhancing livelihood impacts

- Based on hydrological and ecological conditions, and on engineering constraints, attempt to sustain a viable fishery and the livelihood activities depending on it, focus particularly on sustaining fishing for poor and vulnerable groups with fewest livelihood alternatives (Sections 5.1-5.7 for possible measures to achieve this).
- Take full account of indigenous technical knowledge about fisheries in project design and, wherever appropriate, harness this for improving livelihoods and effective implementing of the project.
- Recognizing that it may not be possible to sustain the original fishery in a viable form for all previous user groups and that there may be explicit trade-offs between irrigation benefits and fisheries costs, seek to optimize compensation measures including:
    - development and effective management as fisheries of new or modified habitats such as reservoirs, canals, drains and rice paddies;
    - development of culture-enhanced fisheries and/or aquaculture in irrigation reservoirs, canals, drains or farm ponds; and
    - provision of capacity building and training for management of new/modified habitats, replacing or supplementing indigenous technical knowledge for pre-existing habitats.
- Recognizing that fishing may decline in importance for some full-time or part-time fisher households, seek to develop and optimize alternative livelihood opportunities by:
    - addressing barriers to entry into farm and non-farm employment (such as those related to mobility and poor communications, poor health, access to information, literacy and education, access to credit and discrimination in labour markets);

- improving access to input and output markets, and the integrating of local markets in the wider economy; and
- creating a facilitating or enabling institutional and policy environment for private sector entrepreneurial activities.

(These recommendations include broader development measures for which more general provision may be in place. In this context, the important issue is that they should be effectively targeted at those negatively impacted by any declining importance and value of fishing as a source of livelihood.)

- Design and implement mitigation or compensation measures as “development projects” in which negatively affected people are defined as project beneficiaries, and are planned to be benefited in such a way that they will be better off than before. This may involve carefully targeting, i.e. structuring the rules of access to project resources so that they reach certain groups rather than others. Designing a project to respond to the expressed needs of a target group is an effective way of ensuring that those intended to benefit do so. The key is to understand the constraints to involvement, and access to resources and benefits, for certain groups. There is also a need for contingency plans to be in place to deal with any failure of planned measures to enhance livelihood chances of affected people.
- Budget separately for mitigation/compensation components so that financial allocation will not be compromised by other components of the irrigation development.
- Provide adequate resources for supervising and monitoring of the mitigation or compensation components.
- Clearly allocate responsibilities of implementing mitigation or compensation measures to agencies or adequately strengthened community organisations.

5.7.2 The role of participation by affected people in the decision making process

- The principle of participation is central to successfully mitigate or enhance impacts of irrigation development on aquatic resource use. All stakeholders, and particularly negatively affected people, must be effectively involved in the decision making process from the start of the overall project. This is not an easy issue as the affected population is rarely homogeneous and is often differentiated greatly in access to resources and social influence. Obstacles to participation may also arise from time and funding constraints, power relations, narrow professionalism and cultural factors.
- Planners should recognize gender differences and build gender empowering goals into the project design. Women’s land, water and fishing rights, as well as labor demands and access to rural services should be part of the discourse and design process. Ultimately this can only be fully achieved through the adequate participation of affected women.

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Appendix 1.

Possible development phases for river basins with growing water scarcity

	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6	Phase 7	Phase 8	Phase 9
	Infancy	**Early control**	**Full control**	**Quality control**	**Demand management**	**Environmental stewardship**	**Groundwater integration**	**Economic regulation**	**Globalization**
Broad activity	Development	Construction	Construction and management	Management	Management and regulation	Regulation and management	Regulation and management	Commodity management	Water trading
Main activities	Simple diversions Local control Flooding	Formal engineered diversions Irrigation schemes HEP/Dams/ Reservoirs Pump stations Flood control Navigation	Storage construction River basin planning Establishment of hydrometric network Water transfers	Legislation to control pollution Enforcement of legislation Construction of water treatment plants River flow management	Promotion of demand management measures Monitoring of water use Performance assessment	Protection of the natural aquatic environment Amenity development Re-allocation of water to the natural environment	Legislation to control groundwater abstraction Implementation of groundwater legislation	Allocation of water based on economic value Economic valuation of water-based production	Trading in goods on the basis of their water base (Virtual water trading) Reassessment of water use strategy
Physical Extent	Limited within riverine plain	Riverine plain Project focused River channel Upper catchment	Project focused Basin-wide Neighboring basins	Basin-wide Urban and industrial centres	Basin-wide	Basin-wide River channel Wetlands Coastal lagoons	Basin-wide Predominantly in the plains	National Basin-wide	International National Basin-wide Farm level
Socio-political extent	Very localized	Mainly localized, some national	Basin-wide Regional National	Basin-wide	Basin-wide Sector wide (irrigation, water supply, industrial, etc)	International (Ramsar sites) National, Regional Basin-wide	Localized to aquifers Urban and rural communities alike	International National Regional Basin-based	International National, Regional Basin-wide Farm level

(Continued)

Possible development phases for river basins with growing water scarcity *(Continued)*

	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6	Phase 7	Phase 8	Phase 9
	Infancy	**Early control**	**Full control**	**Quality control**	**Demand management**	**Environmental stewardship**	**Groundwater integration**	**Economic regulation**	**Globalization**
Main actors	Riverine population Farmers	National government Civil engineers Economists	National government International funding and donor agencies Regional government Civil engineers Planners Hydrologists Economists	National government International funding and donor agencies Regional government Chemists Hydrologists Environmenta-lists	National government Regional government Water resource managers Utilities managers Public relations/ advertising specialists Farmers	National government International and national environmental groups Environmentalists Water resources managers Urban populations NGOs	National government Basin Councils Regulatory authority Water resource managers Police Lawyers Law courts	National government International agencies (WB, etc.) Economists Planners Water resources managers Utilities managers Environmenta-lists	National government International trading organizations Politicians International traders Farmers in water resource rich locations Planners Macro-economists
Main objective(s)	To use available water for basic needs	Utilization of natural resources for economic and social development	Full utilization of natural resources Alleviation of water shortages	Control levels of pollution Revival of aquatic environment	To limit and reduce the demand to match with available supplies	To protect the natural aquatic environment and re-allocate water to the environment	To reduce the drawdown and exploitation of groundwater to sustainable levels	To treat water as an economic good and allocate it to most productive use	To rationalize water use nationally and call on international reserves of water resources
Impact	Limited to riverine area	Stabilizes river flow regime Controls flooding Settles riverine plain Supports increased population	Creates more water for growing demand Starts to severely impact on natural environment Supports rural populations	Releases dilution water for other uses Improved aquatic environment Improved amenity value	Creates public awareness of value and shortage of water Temporarily reduces overall demand	Quantification of water needs of environment Reduced supplies to irrigation Strengthening of pollution controls	Reduction in irrigation area Increase in efficiency of water use	Changed thinking from water as a public good to a commodity	Significant impact on irrigation. Increased emphasis on industrialization and urban growth to take people off the land

(Continued)

Possible development phases for river basins with growing water scarcity *(Continued)*

	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6	Phase 7	Phase 8	Phase 9
	Infancy	**Early control**	**Full control**	**Quality control**	**Demand management**	**Environmental stewardship**	**Groundwater integration**	**Economic regulation**	**Globalization**
Areas of conflict	Access to water by non-riverine population	Access to and availability of water, mainly amongst irrigators	Rural vs urban conflict Pollution of water source	Increasing urban vs rural conflict Water use by agriculture	Urban community beginning to dominate	Environmentalists (primarily urban based) vs other users (irrigation, HEP, water resource planners)	Availability of water utilities vs independent users	Assessment of value of water between different users Allocation principles and practices	Government with rural communities as support for irrigation falls
Terminal crisis		Drought Repeated water shortages	Drought Outbreak of water-based epidemic Restriction of amenity use of polluted waters	Drought Repeated water shortages	Drought Repeated water shortages	Repeated water shortages	Power shortages Urban water shortages Limited development opportunities for industry	Conflict between rural poor and urban population over livelihoods	

Appendix 2.

A guide to multi-criteria analysis (MCA)

MCA is one element in a process of participatory decision making. It is a method of choosing between a set of alternative options on the basis of a set of defined evaluation criteria. It is particularly relevant to decisions where there are conflicting objectives and stakeholder preferences. It provides a framework to display alternatives and outcomes, to rank alternatives, and to reveal stakeholder preferences in the form of weights.

The methods or tools available for this type of decision making can be placed under the general heading of MCA. They can range from very simple processes to more major and complex exercises. MCA is inherent in any multi-disciplinary assessment and planning process, and the chosen approach to analysis depends partly on how formalized the MCA process is made to ensure openness, transparency and participation.

The key elements or stages of MCA are:

- Assembly of an inventory of options or alternatives;
- Identification of criteria;
- Scoring of alternatives against each criterion, that is, estimating of the impact of each alternative on each criterion;
- Engaging stakeholders to assign priority weights to criteria;
- Comparison of alternatives across criteria and overall preference ranking; and
- Assessment of risk and uncertainty.

Assembly of an inventory of alternatives

The potential complexity of the systems under study has been noted above, and there will be many sources of uncertainty in seeking to predict socio-economic and ecological outcomes. Often only part of the required information will be available but this cannot justify the absence of decisions. All available knowledge, information and results must be presented in a way that facilitates and optimizes informed decisions.

Resources to draw on include:

1. Principles, concepts and models from the knowledge base;
2. Secondary sources of data;
3. Impact assessment results;
4. Possible mitigation/enhancement measures already identified;
5. Stakeholder inputs in the form of local knowledge, perceptions of impacts and possible compensation measures; and
6. National policy priorities and technical guidelines/ regulations.

The role of the study team is to organize available information and structure the problems perceived by stakeholders in helping them to identify options and alternatives.

To achieve this, the following approaches are suggested:

- Providing of a database and/or information centre accessible to stakeholders.
- Use of appropriate models as tools for assessing the consequences of different management options (examples are provided in Chapter 3 of the Knowledge Base).
- Capturing and describing the system dynamics by defining cause-effect relationships and linkages with other key issues (as in the example of figure 3.7).
- Considering local opportunities and constraints, and identifying windows of opportunity.
- Highlighting of knowledge gaps and areas that require further research.
- Utilizing of stakeholders' local knowledge to build a full range of alternatives (with any assumptions made explicit). In some cases it may be necessary to amalgamate related suggestions into one clear and viable design or management option, excluding unrealistic elements in the process. In order to guide stakeholders in filtering out scenarios that are unrealistic or not well adapted the following list of questions is suggested:
  - What actions would need to be taken?
  - What constraints are there to action?
  - Any institutional/legal requirements?
  - Who will benefit?
  - Who will lose?
  - What are potential areas of conflict?
  - What trade-offs will arise when implementing measures?
- Use of the knowledge base and relevant national level technical expertise to validate stakeholder proposals and assumptions. For example, a common tendency is to overestimate the mitigation of impacts of irrigation that may be provided by new or enhanced fisheries in reservoirs (particularly in project feasibility reports). The role of the study team is to test the feasibility or otherwise of such assumptions in the local context.
- Structuring problems and possible solutions in a hierarchy of impacts, as any intervention will have more effect at the top of the hierarchy. In particular, mitigation of primary direct impacts will have most effect because it will reduce and/or avoid occurrence of consequent impacts.
- Selection of the most relevant and important options for further scrutiny and decision making by stakeholders with input from the study team. The alternatives must be distinct from each other, clear, possible and realistic, and substantiated by existing information as far as possible.

Identification of criteria

Criteria that reflect the impacts or outcomes of the alternatives identified should be compiled through discussion with both experts and stakeholders. In addition to the main TOA forum, various methods can be used to be engaged with stakeholders and reveal their preferences. These include focus groups, informant interviews, structured interviews, open interviews and group or open meetings.

Stakeholders should have the opportunity to include or exclude as broad a range of criteria which they feel is important. All stakeholders from local residents, to specialists in government agencies should be involved. The choice of criteria reveals how participants conceptualize and "frame" the problem.

The following approach is suggested:

- List all criteria suggested by stakeholders.
- Apply the following screening:
  - Complete - Are all issues of concern to decision makers and primary stakeholders included?
  - Operational – Are criteria specific enough for evaluating and comparing alternatives?
  - Independent – Criteria can be evaluated independently of other criteria.
  - Outcomes, variable – Outcomes for different alternatives vary for the criterion (there is no need to use the criterion in the analysis if the outcome is the same for all alternatives).
  - Measurable – Criteria are required to be evaluated by a suitable qualitative or quantitative measure.
  - Minimized – Include the minimum criteria to save costs and resources for data collection.

In practice the identification of criteria will tend to be integrated in an iterative way throughout the whole assessment protocol. Likely criteria will emerge during screening and scoping, and as part of the prediction of impacts. The MCA methods to be used during the TOA stage and the availability of secondary data should also be considered during those early stages. The primary data collection that will be required during the impact assessment phase can then be planned.

Table A2.1 shows a generic list of criteria proposed for fisheries and irrigation developments.

Table A2.1. Generic criteria for MCA of irrigation developments and fisheries.

Main criteria	Indicators or measures (illustration)
Economic viability	Household income Returns to investment (NPV, IRR) Capital cost Recurrent cost/financing requirement Potential for cost recovery, financial autonomy and financial sustainability
Poverty alleviation	Livelihoods impact Incidence of benefits and costs Access to employment opportunities Impacts and opportunities for women Access to resources Social and economic exclusion
Environment	Impact on biota Impact on ecosystem integrity Water quality
Practicality	Ease of implementation, operation and maintenance and management Potential for local level implementation Time-scale Reliability Supportive institutions
Other risks	Potential for conflict Cultural change Political risk

The role of cost benefit criteria

Cost benefit analysis can be viewed as a restricted form of MCA used to assess economic impact. This is commonly measured using the internal rate of return (IRR) and net present value (NPV) criteria. Such economic criteria can be integrated as one criterion within a larger MCA framework that will typically include a much broader range of technical, environmental, social and risk criteria as in table A2.1.

Scoring of alternatives against criteria

The scoring system used should be kept as clear and simple as possible. The results of scoring are best displayed in an effects table (e.g. table A2.2). This is a table with the alternatives as column headings and the criteria as row headings. Numbers entered in the cells show how each alternative affects each criteria, i.e. how each performs according to that criterion. The table often initially contains values in different units of measure, but these can be scaled to enable comparison (see below).

For criteria that can be quantitatively measured, estimated values can be directly shown. Examples include monetary estimates of costs, and measures of economic impact over time such as IRR and NPV. Direct comparisons between alternatives for these criteria taken in isolation are clearly possible.

Scores for qualitative issues could range, for example, from –5 to +5, where –5 stands for very bad or detrimental, 0 for neutral and +5 for very good. (Scoring sheets used with stakeholders should explain in detail how the scores are to be derived). Comparisons for a given qualitative criterion are only possible after scaling.

For any given criterion, stakeholders may consider more detailed issues at stake (sub-criteria) when formulating an assessment or score. For example, for a “livelihoods impact” criterion sub-criteria could include:

- the number of people to lose fishing as a main source of livelihood;
- the proportion of these belonging to vulnerable groups;
- the availability of alternative sources of livelihood to those affected; and
- the likelihood of conflict arising.

Table A2.2. Illustrative effects table.

Criteria	Alternatives			
	A1	A2	A3	A4
Economic viability (NPV, ‘000 US$)	15	25	10	-5
Local employment (no. of jobs)	2500	3000	500	3000
Water quality (g N/l)	1.5	1.4	2.2	0.9
Local level implementation (score –5 to +5)	-2	0	4	2
Risk of conflict (score –5 to +5)	-4	1	3	0

Each of these sub-criteria needs to be given a relative weight in the determining the score for the criterion, the total weight being 100 percent for that criterion (see further discussion of weighting below).

Comparison of alternatives across criteria or overall preference ranking.

Numerous ranking systems are available for MCA that are both numeric and non-numeric. Various statistical methods can then be used to aggregate across criteria to show the overall preference ranking of options. The degree of statistical rigor appropriate will depend on the number and nature of the criteria and the scale and significance of the decision. There are also various statistical and graphical ways to present results of MCA. These range from preference matrices to grouping of options by categories, to simple rank order listing. Only simple forms of the analysis are further considered here. More complex variants are described in the sources listed in the references.

The simplest ranking procedure is to simply rank the performance of each alternative against each criteria from the best performing to the worst. Very crudely the most preferred alternative will be that with the best composite ranking across all criteria (table A2.3). Participants would draw on the information summarized in the effects table above in formulating their ranking. Thus according to this procedure A2 is the preferred alternative in the illustrative example (table A2.3).

Table A2.3. Simple ranking of alternatives.

Ranked criteria	Alternatives			
(1=worst to 4=best)	A1	A2	A3	A4
Economic viability	3	4	2	1
Local employment	2	4	1	4
Water quality	2	3	1	4
Local level implementation	1	2	4	3
Risk of conflict	1	3	4	2
Composite rankings:				
Total ranking	9	16	12	14
Mean ranking	1.8	3.2	2.4	2.8

It is unlikely that participants would give each criteria equal weight as in table A2.3 above, and hence weights could be applied to the ranking for each criteria before the determination of the composite ranking.

Weights indicate the relative importance to be applied to each criterion in assessing the overall attractiveness of options. A ranking system is thus developed whereby each criterion gets a particular weight to reflect its importance as determined by stakeholders. In aggregating across criterion, the sum of the weights should add to 100 for ease of use. The simplest form of this procedure will be to allocate equal weight to each criterion as in the first ranking example above.

A recommended procedure using criteria weights and scaled scores from the effects table is as follows.

Criteria values in the effects table are scaled from 0 to 100, where 100 is the most preferred outcome. It is first necessary to decide whether the criterion represents a benefit or a cost, that is whether higher values in the effects table represent a gain or a loss. This depends on the objective being considered and may vary by the stakeholder group. For example, increased access for fishers to a fishery may be considered a benefit in terms of increased livelihood opportunities for landless people, but a risk to the conservation of stock and/or biodiversity. (The scaling procedure is explained in box A). Values in the effects table are replaced with the scaled scores (table A2.4).

The best alternative for any one criterion can then be easily identified (again A2 in this example). The overall mean scores also provide an overall preference ranking in which each criterion has been given equal weight. It should be noted that this is just an ordinal ranking, indicating an order of preference but not by how much one scenario is preferred to another.

Box A. Scaling criteria values/scores

- Assign least preferred outcome, a value of 0
- Assign most preferred outcome, a value of 1 (or 100)
- Assign other values for the same criterion scores relative to their distance from these upper and lower limits.

1: Scaling a benefit value or score

$$X_s = (X - X_{min})/(X_{max} - X_{min})$$

Where:

X_s = scaled value
X = value or score from effects table
Xmax = maximum value or score for that criterion
Xmin = minimum value or score for that criterion

2. Scaling a cost value

$$X_s = (X_{max} - X)/(X_{max} - X_{min})$$

Where:

X_s = scaled value
X = value or score from effects table
Xmax = maximum value for that criterion
Xmin = minimum value for that criterion

It is convenient to multiply each of the scaled values by 100 for ease of presentation.

Table A2.4. Effects table with scaled values or scores and equal criterion weights.

Ranked criteria	Alternatives			
(1=worst to 4=best)	A1	A2	A3	A4
Economic viability	67	100	50	0
Local employment	80	100	0	100
Water quality	54	62	0	100
Local level implementation	0	33	100	67
Risk of conflict	0	71	100	57
Composite ranking, mean	40	73	50	65

The next step is to elicit preferences from stakeholder groups that can be expressed as weights. Weights can take the form of nominal, ordinal, interval or ratio data[2], but although potentially more difficult for stakeholders to express, it is anticipated that ratio data will usually be used. Thus the preferences or priority to be allocated to each criterion are expressed as a percentage weight reflecting its importance to stakeholder interests (the sum of the weights for all criteria will be 100 percent). The weights are applied to the scaled scores in the effects table (box B), and a weighted preference ranking is derived (table A2.5).

It can be seen that including criteria weights has now changed the preferred alternative from A2 (table A2.4) to A4 (table A2.5), reflecting the fact that in this illustrative example stakeholders give more priority to local employment and to the potential for local implementation than to aggregate economic viability.

Box B. Applying criteria weights to the scale effects table

Illustrative stakeholder weights:

Criteria	Weights
Economic viability	0.10
Local employment	0.25
Water quality	0.15
Local level implementation	0.30
Risk of conflict	0.20
Total	1.00

To determine the impact of stakeholder priorities on the ranking of alternatives such weights are multiplied by the scaled values from the effects table (Table E).

Example:
Alternative A1
Economic viability: 67 x 0.10 = 6.7

Table A2.5. Effects table with scaled values multiplied by criterion weights.

Ranked criteria	Alternatives			
(1=worst to 4=best)	A1	A2	A3	A4
Economic viability	6.7	10	5.0	0
Local employment	20	25	0	25
Water quality	8.1	9.3	0	15
Local level implementation	0	9.9	33	20.1
Risk of conflict	0	14.2	20	11.4
Composite ranking, mean	7.0	13.7	11.6	14.3

[2] Nominal: mutually exclusive categories, e.g. criterion is important? Yes or No.

Ordinal: ranked in relation to a created scale, e.g. importance of criterion on a scale of 1 to 3.

Interval: ranked like ordinal in relation to a created scale but with equal intervals between scale points and no absolute zero e.g. temperature scale.

Ratio: an interval scale with an absolute zero point, i.e. a continuous quantitative variable, e.g. money, probability.

For more detailed discussion of the application of these alternatives see Brown et al. 2001.

It should be noted that the weights allocated by individuals or stakeholder groups are not additive because it is not possible to make interpersonal comparisons of utility. Thus if consensus between groups cannot be achieved for the value of the criteria weights to be applied, the overall ranking exercise may need to be completed separately for each distinct interest group. The outcomes from this process may then provide the basis for further discussion, consensus building and conflict resolution as discussed further below.

Assessment of risk and uncertainty

In basic approaches to MCA it is implicitly assumed that alternatives can be compared with one another for each criterion with a reasonable level of certainty or confidence. This may not always be true, either because of a lack of knowledge (uncertainty) concerning the systems being compared, or because the outcomes may be dependent upon future uncertain events such as economic or climatic conditions (risk).

Approaches to address this include:

- Including identified risks as one or more criteria in the MCA, e.g. the risk of conflict between interest groups.
- Performing sensitivity analysis on the results of the analysis for relevant input variables. For example, criteria weights can be varied to test the sensitivity of the ranking process to the weighting selected. Criteria values for alternatives in the effects table can also be varied based on error margins for estimation, historical variability of such outcomes, or predicted future variability.
- Scenario planning: repetition of the entire analysis for different scenarios representing uncertain or future conditions. This is most relevant to exploration of the effects of variation in exogenous conditions, e.g. the macro-economic environment, climate change, changes in governance. Those alternatives that are revealed to be good compromises under all scenarios will tend to be the preferred options.