Integrating Freshwater Ecosystem Function and Services with Water Development Projects

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This paper was prepared by Maria Isabel Braga, an IDB and World Bank consultant. It draws from the discussions and contributions of all participants at the workshop *Mainstreaming Freshwater Biodiversity in Water Development Projects*, White Oak Conservation Center, February 5-9, 1997, Yulee, Florida. Mike Acreman, Garry Bernacsek, John R. Bizer, Patrick Denny, Mark Hill, William M. Lewis Jr., Tony Whitten, and Ron Zweig submitted written contributions to this manuscript. Jerson Kelman made a number of substantive suggestions.

PREFACE

Integrating Freshwater Ecosystem Function and Services with Water Development Projects describes the conditions necessary to harmonize project objectives with the conservation of freshwater ecosystems. It also provides information on how to incorporate freshwater ecosystem biodiversity, function, and services with water development projects.

The paper is intended for managers and policy makers at the decision-making level. In order to make the study more interesting to the reader, one of the sections presents a description of biodiversity in the context of freshwater ecosystems, including a short description of those ecosystems. Subsequent parts of the paper describe the recommended approach to harmonize water development projects and the freshwater ecosystem function, as well as the role of the Environmental Impact Assessments in this process, and potential impacts of different categories of water related projects.

The work was prepared by Maria Isabel Braga, an IDB and World Bank consultant. It draws from her own experiences and from the discussions and the outline assembled by the participants at the workshop *Mainstreaming Freshwater Biodiversity in Water Development Projects* that was held at the White Oak Conservation Center, February 5-9, in Yulee, Florida.

We believe that the paper is an essential piece of information that will facilitate the implementation of the Integrated Water Resources Management Strategy of the Bank.

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INTRODUCTION

The secret is out! For most water development projects it is possible to harmonize project objectives with the conservation of freshwater ecosystem function and services. Negative environmental impacts can be minimized and projects can foster the conservation or restoration of freshwater ecosystems and their biodiversity if:

- there is a commitment to this objective from the early planning stages;
- the fundamental characteristics and requirements of such ecosystems are understood;
- the various design and management options that have already been tried, e.g. fishpasses, artificial floods, etc., are adopted in their original form or adapted to the specific project conditions; existing knowledge, experience, and creativity are used to devise novel solutions.

But why should our time and money be invested in efforts to protect and restore freshwater ecosystems? Our planet's supply of fresh water is finite while demand for fresh water and aquatic ecological goods and services continues to increase as the world's population increases. The sustainable development of Earth's freshwater ecosystems is our only hope to ensure the long-term existence of the fundamentally important benefits that humans derive from freshwater ecosystems, such as (Naiman et al., 1995):

a) Direct use of surface waters and groundwater

- Household and commercial uses.
- Agricultural irrigation.
- Water for livestock and aquaculture.
- Hydropower.
- Energy transfer (heating and cooling).
- Manufacturing and industrial uses.
- Fire fighting.

b) Products harvested from healthy freshwater ecosystems

- Fish and wildlife (commercial and subsistence harvest).
- Riparian forest products (e.g. timber, fruits).
- Vegetable products from floodplains, wetlands, and lakes (e.g. rice, reeds).

c) Services provided by healthy freshwater ecosystems

- Transportation (can also be provided by degraded systems).
- Freshwater storage (in glaciers, watersheds).
- Flood control (can also be provided by degraded systems).
- Nutrient deposition in floodplain agricultural areas.
- Natural purification of wastes.
- Habitat supporting biological diversity.
- Moderation and stabilization of urban and natural microclimates.

- Nutrient retention.
- Aesthetics and mental health.
- Recreation (sportfishing, hunting, boating, swimming).

However, water resource development and operational practices are aimed primarily at controlling water quantity, storing water through drought periods, preventing floods, transferring water to cities or irrigable cropland, providing commercial navigation, and generating hydropower. These engineered systems are generally optimized solely for the purposes for which they were created, but it is now necessary to optimize them with respect to conservation and enhancement of freshwater ecosystems in addition to their historical goals. The challenge for the future will be to design, construct, and operate civil works in ways that also sustain the long-term ecological integrity of freshwater ecosystems. Of particular importance are long-term effects of water projects on the amount and routing of water and waterborne materials along the flow path to the ocean as well as maintenance of sufficient habitat for the persistence of species with their natural genetic variability (Naiman *et al*., 1995).

The key to sustainable development is the inclusion of biodiversity and ecosystem function along with more traditional development objectives. Human communities have already shown their ability to anticipate and avoid environmental problems, once they understand the connection between ecosystem health and integrity and themselves, their children, and grandchildren.

This paper provides some information on how to incorporate freshwater ecosystem biodiversity, function, and services with water development projects. It is hard to protect what we don't understand, and for this reason Section II presents a brief discussion of biodiversity in the context of freshwater ecosystems, including a short description of those ecosystems. Section III presents the recommended approach to harmonizing water development projects and freshwater ecosystem function, and discusses the role of Environmental Assessments (EAs) in this process. Section IV presents some issues and design options regarding different categories of water development projects and their potential impacts on four basic characteristics of freshwater ecosystems: natural flow regimes, connectivity, water quality, and natural aquatic habitats.

FRESHWATER ECOSYSTEM SERVICES AND BIODIVERSITY

The services provided by freshwater ecosystems to all living organisms on our planet have been at the root of the development of the human race throughout the ages. Humans have learned by experience that a constant and reliable supply of clean water is fundamental to security of the species. Early settlements were located along major rivers, near lakes or springs, which provided not only water but also protein in the form of fish and other aquatic organisms, as well as transportation. Other areas were later occupied when people developed wells to access water in the dry season, canals to distribute water for agricultural activities over more extensive areas, and means to drain swampy or frequently flooded areas.

What humankind took longer to realize was that the services being provided by freshwater ecosystems, such as clean water, protein, and seasonal enrichment of floodplain soils, are the result of a suite of physical, chemical, and biological processes that constantly take place in and around those ecosystems, and are an important component of the hydrologic cycle. Some of these processes are easily seen and understood, such as the deposition of nutrient rich sediments by seasonal floods; others are less visible, such as the purification of surface waters by microorganisms that decompose organic matter.

We still don't fully understand all aspects of freshwater ecosystem functioning, but we have a much better grasp of the services they provide and of the effects of human activities on ecosystem functions that influence the availability and reliability of such services. Because most of the services provided to us by freshwater ecosystems result from the biological activity of the diverse assemblage of aquatic organisms within those systems, a brief discussion of the different aspects involved in the concept of biodiversity will follow.

Biodiversity

The biodiversity of a freshwater ecosystem comprises all aspects of biological variation that occur there. Biodiversity includes not only the inventory of species, but also the relative abundance of species (how many are common, how many are rare), and the characteristic genetic configurations of species populations.

> Design and operation of water develop-ment projects can often be adjusted to minimize effects of the project on aquatic biodiverstiy and ecosystem function. This is especially true and more cost effective when these considerations are incorporated into the inital stages of project identifi-cation and design.

Three basic principles for sustaining biodiver-sity must always be considered:

- Organisms have limited capacity to tolerate change in the physical or chemical features of their habitats.
- Organisms already stressed by a range of alterations in their environment will be especially intolerant of additional changes.
- Different species or genetic types use different parts of the environment, or habitats, and simplification of the environment will usually reduce biodiversity.

In general, a greater diversity of habitats will support a greater diversity of species because of the large number of conditions available for organisms to conduct their business. Complexity in freshwater habitats is found in many different forms, but all of them can be classified within one of two basic categories:

Spatial Complexity deep or shallow, fast or slow current, sunny or shaded, flat mud/sand or stony bottom, small gravel or large rocks, with or without aquatic vegetation, clear or sediment-rich water, small streams or large rivers, etc.

Temporal Complexity - alternation of low flow and high water conditions, seasonal changes between warm and cold water, variation over time in the amount of suspended sediments and available nutrients, channel-constrained or expanded into the floodplain, migration of alluvial channels, etc.

In general, the higher the habitat complexity, the greater the biodiversity that can be sustained in the habitat. Because all species have specific habitat requirements, changes in biodiversity can usually be predicted from changes in the existing natural habitat. Documentation of the distribution of species and their association with specific habitat features must be an adjunct to biodiversity assessment.

Biodiversity studies that focus upon *just* naming and counting the species present rarely generate much public support, but are an important first step in understanding the functioning of a given ecosystem. On the other hand, biodiversity studies which also focus upon linkages among habitat-species-ecosystem services and people will usually command attention.

Main Characteristics of Natural Freshwater Ecosystems

Natural freshwater ecosystems, as all other ecosystems, exhibit a set of physical and chemical conditions, as well as spatial and temporal variability, that together give the ecosystem its character and support the communities and services within. The best bet for conserving freshwater ecosystem processes and biodiversity is to understand and preserve as much as possible the fundamental set of characteristics (physical, chemical, biological, and spatial and temporal variation) that define a particular freshwater ecosystem.

Running Waters (Rivers and Streams)

Running waters show all possible combinations of flow regimes and structural complexity, including substrate heterogeneity (boulders, cobble, gravel or sand), debris dams, rooted vegetation, and confined or braided channels. This variability results in a large number of different freshwater habitats within rivers and streams, and provide organisms with a range of water velocities to choose from - pools, riffles, rapids, etc. Inputs from terrestrial ecosystems provide food (leaves, fruits) and habitat (sediments, twigs and logs) for aquatic organisms.

Five critical components of the flow regime regulate ecological processes in running water ecosystems: the magnitude, frequency, duration, timing, and rate of change of hydrologic conditions. The natural flow of a river varies on time scales of hours, days, seasons, years, and even longer (Poff *et al*. 1997).

Marginal and riparian vegetation are especially important because, aside from being important sources of food, they create habitat for micro and macroorganisms, provide refuge from predators and swift water, protect the channel from erosion, filter surface and subsurface flow from adjacent uplands, and provide shade that curbs excessive growth of aquatic macrophytes and regulates water temperature.

The water quality of running water ecosystems is determined by the geology, climate, and human activities in the drainage basin. Water quality can be measured in terms of suspended sediment, dissolved oxygen, dissolved solids, nutrients, toxins, and temperature.

Running water ecosystems have complex food webs that are adapted to local conditions. In order to protect and maintain natural populations of most large freshwater species, which frequently have important commercial value, we must ensure the integrity of the natural food web to which those populations belong.

Natural Lakes

Natural freshwater lakes typically have water velocities less than 3-4 cm/s and exhibit relatively small fluctuations in water level. A lake's maximum depth is usually near its center, and its waters may turnover and mix as a result of seasonal changes in water temperature at different depths. Biological productivity of lakes is supported by its physical characteristics, and by its trophic state (nutrient status) related to the type and intensity of human activity in the catchment area.

Lakes have naturally evolved biodiversity that can be diverse or depauperate, and littoral vegetation is an integral component of lake biodiversity as it provides food, habitat and refuge for small organisms, and acts as a filter to reduce the amount of nutrients and sediments entering the lake from non-point sources. Most of the biodiversity is found closer to the margins due to proximity to sources of nutrient inputs into the lake, and where shallower conditions facilitate light penetration and the establishment of rooted vegetation.

Box 1
The Three "Musts' for Maintaining Healthy Rivers and Streams

Maintaining high quality rivers and streams that support naturally occurring aquatic communities requires that three environmental parameters be fulfilled simultaneously (Nielsen, 1995): 1) clean water is available in no toxic or eutrophic conditions, dissolved oxygen is available in necessary concentrations, and suspended sediments are present in natural amounts; 2) the amount of water available is enough to support natural biological processes; and 3) a variety of physical habitats is available. The natural variability in these three parameters must also be maintained.

Reservoirs are not equivalent to natural lake habitats because they are not natural, usually experience large fluctuations in water depth and velocity (sometimes on a daily basis), have their maximum depth usually near the wall, and are under human control through management plans often based only on financial and economic considerations.

Wetlands and Floodplains

Wetlands and floodplains (which typically contain wetlands) are usually linked to other freshwater systems such as rivers and lakes on the surface or through the water table. Wetlands often have large amounts of emergent vegetation adapted to both inundation and desiccation. This vegetation often is zoned according to the average amount of time that the plants are subjected to flooding, with the more flood-tolerant species closer to the river or lake margins. The water quality of wetlands is highly influenced by the associated aquatic ecosystem, soil, and type and amount of existing emergent vegetation.

The floodplains of rivers provide essential habitat and feeding grounds for breeding and rearing of many freshwater species, and must be considered as an integral part of the associated riverine ecosystem. Permanently flooded wetlands are important because of their usually rich plant biodiversity and constitute important habitats for wildlife as well as for riverine fishes.

Coastal Habitats

Coastal freshwater/brackish habitats are defined by the characteristic input of freshwater into the system (quantity, quality and timing) and the daily and seasonal influence of tides which cause daily and seasonal variations in salinity, temperature, turbidity, and energy flux. Biological activity in these areas is fueled by the constant influx of nutrients and sediments from upstream, and nutrient cycling occurs at high rates. The aquatic community in these areas are adapted to, and rely upon, this predictable variation and the stability of a pH-buffered environment.

Coastal freshwater/brackish habitats are extremely important as breeding and nursing grounds for many marine and freshwater aquatic species, but unfortunately constitute some of the world's aquatic habitats most threatened by pollution and other development impacts. Most of the world's largest urban areas are located in the coastal zone, and pollutants discharged throughout a river basin eventually find their way to the basin's coastal habitats.

THE RECOMMENDED APPROACH

Most impacts from water development projects stem from changes in habitat conditions or availability and access to those habitats. True integration of freshwater ecosystem function and services with water development projects requires the conservation of freshwater biodiversity, and preservation of natural freshwater habitats is crucial for this purpose. A successful plan to achieve this goal should include four major elements (NOAA, 1996):

Protect and Conserve: Assess human-induced impacts at levels ranging from sites to ecosystems, provide scientifically-based advice to reduce or eliminate those impacts, and form partnerships to protect and conserve habitats of living aquatic resources. Track natural habitat trends for perspective and to assess progress.

Restore and Create: Restore and create habitat, thereby reversing the net loss occurring from continued growth and development or resulting from natural events.

Understand: Obtain, interpret, and share scientific information needed to manage important habitats, increase awareness of habitat values, and enhance the role of relevant government agencies.

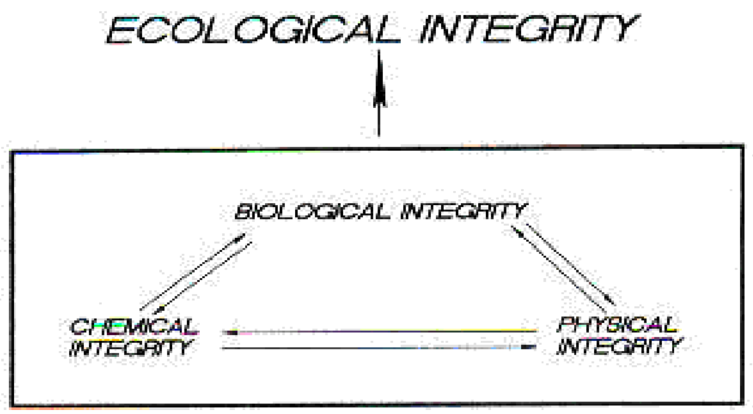
Manage and Operate: Support those actions by developing government policies, pursuing partnership agreements, leveraging funds, sharing staff, and other creative solutions that improve effectiveness and efficiency.

A basic principle for adoption by countries and private sector partners is that species or genetic diversity should not decline as a result of a water development project. This means the project does not cause the extinction or endangerment of any species, either during its construction or long-term operation. The specific means and difficulties to achieve this goal will vary from one project or region to another depending on project characteristics and the existing conditions of local biodiversity.

There may be rare occasions where it will be impossible to reconcile a proposed project and the long-term conservation of some aspect of natural biological diversity. Any final decisions made in those situations must be based on sound information —scientific, technical, social and economic— and the consequences must be fully explained to all stakeholders.

The post-project ecological goal for the freshwater habitat at the project site, either *ecological health* or *ecological integrity*, will depend on past and existing uses of that ecosystem (Karr, 1996). Health implies well-being, vitality, or prosperity. An organism or ecosystem is healthy when it performs all its vital functions normally and properly; a healthy organism is usually resilient, able to recover from many natural stresses, and requires minimal outside care. Ecological health is usually the goal at sites that are intensively used, and which harbor a biological community rather different from the natural one originally found at the site. At these sites, integrity in an evolutionary sense cannot be the goal. At less disturbed sites ecological integrity —the sum of physical, chemical, and biological integrity— should be the final goal. Ecological integrity is a step beyond ecological health since it includes the capacity to support and maintain a balanced, integrated, adaptive biological system having the full range of elements and processes expected in the natural habitat of a region.

The likely effects of a project on biodiversity must be predicted more accurately *prior* to the final commitment of funds to the project. Project design and operation can often be adjusted to minimize project effects on biodiversity, and *this is especially true when biodiversity considerations are incorporated into the process from the very initial stages of project preparation and design*. Only on very rare instances would this process lead to cancellation of a project.



Components of Ecological Integrity
(Source: Toth, 1995)

Integration of Freshwater Biodiversity at the Project Level

Environmental and social issues must be considered upfront during project identification in order to effectively integrate conservation of freshwater ecosystem function with water development projects. The following five stages should occur to ensure true integration at the project level (Hill, 1997):

Stage 1. Initial Resource Inventory

Water development projects begin with the identification of problems to be fixed (e.g. flooding) or benefits to accrue (e.g. irrigation, hydropower) and the region or area where the project is needed. This is generally recognized as the *identification* stage where the host government and the donor/lender evaluate different project strategies. Project goals and general geographic area are established at this stage, and this is when an initial resource inventory should be initiated, in conjunction with initial hydrometereological, geological, and socioeconomic surveys. *The resource inventory must be initiated as early as possible to maximize the time available to collect long-term data and to minimize design and construction delays at a later stage.*

The level of intensity and detail for this initial inventory of freshwater biodiversity resources should match the predicted level of potential impacts (local vs. basin-wide), economic importance of existing resources, quality of the existing baseline information (if any), presence of known endangered species or habitats, and how well that particular freshwater ecosystem is already known. Box 3 offers some guidelines for this process.

When the inventory is complete, it is the responsibility of the investigative team to inform decision makers by presenting the information in such a way that intrinsic values of biodiversity and related environmental conditions are clear and understandable in the local and global cultural and biological context. The presentation of data should include not only the identification of threatened and/or endangered species, but must also illustrate as much as possible cause and effect relationships between biological communities and structural diversity at the habitat and ecosystem level.

Stage 2. Feasibility Study Input

The principal actions at the feasibility stage involve site selection, project sizing, and economic analysis. Sustainable development should be a shared goal at this stage. The project team comes together at this stage to exchange knowledge and to jointly prepare a feasibility report. *Biologists must be an integral part of the team at this stage; they must use the data and information gathered in the initial inventory to assist with site selection and project sizing.* The analysis of project alternatives will illuminate more discrete data gaps that become the focus of the next stage.

Stage 3. Preliminary Design Input

> When planning and designing an impoundment, the most effective environmental and social mitigation measure is **good site selection**, to ensure that the proposed dam is inherently benign in the first place (Ledec et al., 1997). However, the number of technically and economically viable alternatives for dam sitting is usually small.

This is the stage at which the basic project has been decided upon and the site, size and magnitude of the project is fixed. This establishes a more discrete geographical area within which to focus the more detailed inventories of biodiversity and other resources that will be directly affected by the project. *At this stage, a thorough evaluation of cumulative impacts (e.g. the synergistic interaction of multiple water projects in a watershed or river basin) can be made.* As an example, a new hydropower dam, Corpus, has been considered for construction in a free flowing 200 km stretch of the Parana River between Itaipu and Yacyreta Dams. Although the design of this potential new dam would result in less environmental impacts than the existing Yacyreta, the cumulative effect of the three dams would be to transform most of the Parana River into a continuous reservoir, with very damaging consequences for the riverine aquatic communities already affected by the other two existing hydropower dams (George Ledec, pers. com.).

The more detailed inventory to be conducted at this time should include information on:

- Organisms with potential to be used for biological monitoring of the freshwater ecosystem.
- Keystone, umbrella and flagship species.
- Endangered or threatened species.
- Species particularly vulnerable to predicted project impacts.
- Critical habitats and processes such as migration corridors, floodplain depth and habitat connectivity.

Stage 4. Design Modification

The final design and project alternatives are decided upon prior to full project funding and implementation, and include the selection of the preferred alternative. The objective at this stage of project development is to provide decision makers with enough information so that the consequences of their decisions are clear. *It is important that decision makers make informed decisions and that are well aware of the consequences of their decisions and actions.* In the end they may decide on an action that increases the threat to a species, or cause its extinction even, but they must do so fully informed of the consequences of their choice.

At this stage the project team makes final modifications to the design with these priorities in mind:

- interventions needed to conserve, protect, and/or enhance biodiversity thresholds,
- avoidance of environmental impacts,
- minimization of environmental impacts,
- mitigation of unavoidable and irretrievable impacts.

Stage 5. Mitigation Planning and Project Cost Integration

Mitigation plans must be formulated early in project planning and the cost must be included in final project budgets. Mitigation costs should not be viewed any different than the cost of steel and concrete —both are necessary project expenses and must be financed accordingly—. Early planning should result in enough time for the purchase of land or other structural elements that normally require some time for selection and negotiation. Design criteria for pilot scale studies, such as experimental fish ladders, must also be addressed early in the process.

Long term monitoring plans are an important budget consideration in the project financing. Early development and implementation of monitoring plans will result in an early supply of data to guide and support adaptive project management during both construction and early operation phases.

The Role of Environmental Assessments (EAs)

In most water development projects the appropriate amount of time is spend on finding the optimum dam site for maximum power production and maximum dam safety. Finding the optimum dam site is important to engineers and they *expect* to have enough time and money to do it right. So why is it that, once the best site and configuration has been painstakingly identified, the environmental evaluation is almost an after-thought? Why should first rate engineering be followed with second rate understanding of the environmental implications of a project? *The notion that an environmental impact analysis coming at the end of the project design is adequate, and that after-the-fact mitigation will compensate for biodiversity losses, is a totally false one!*

Intelligent and useful biological input to the development process is absolutely dependent upon having reliable data and information on the resources that will be affected by the development project. Biological systems do not conform to project development time frames, and as long as a "point-in-time" understanding of biological systems is perceived as sufficient information for decision making, freshwater biodiversity will continue to decline.

Predicting Project Impacts on Existing Freshwater Biodiversity

An inventory of the freshwater ecosystem must be conducted at a level compatible with the potential effects on the biodiversity, function and services of the freshwater ecosystem. Inventories must be habitat based to have meaning in terms of biodiversity, cultural diversity, and sustainable development. One example of what can happen when biological inventories are not done appropriately is illustrated by the one issue not flagged by the original EA for the Yacyretá Hydropower Dam: the presence of five morphs of the freshwater snail *Aylacostoma* in some rapids now inundated by the reservoir. These snails are not known from any other areas, probably because they are poor dispersers - there is no planctonic larva, the young live on the adult's shell and feed on algae growing on that same shell. *Aylacostoma* are adapted to shallow, highly oxygenated rapids, and feed on algae growing on the rocky bottom. Although the water quality in the reservoir remained suitable for the snails, the increased water depth has curtailed light penetration to the bottom, and the resulting lack of algal growth caused the known remaining snails to starve to death. Luckily, prior to the filling of the reservoir in the early 90s, a scientist familiar with the snails collected and transferred a large number of them to aquaria in the Museum of Natural Sciences in Buenos Aires. One morph did not survive the captive conditions, but the other four are growing and reproducing well.

A recent amendment to the Yacyretá II loan requires, as part of the environmental management plan, that (a) Yacyretá pays for the recurrent costs to maintain the existing captive snail populations; (b) the project builds a second laboratory at the project site to maintain a second captive population; (c) the project pays for a survey of potential *Aylacostoma* sites in a 200 km river stretch upstream from the dam since no wild populations of the snail have been found in another 200 km stretch below the dam; and (d) the project should identify suitable sites for reintroduction of captive snails into the wild —a potentially suitable site has been identifified just below the navigation locks. Box 1 offers some guidelines for conducting appropriate biodiversity work in eas.

Biological inventories must be hierarchically organized to maintain ecological integration, scale, content and context for all resources at all levels of investigation and planning. The first step in the inventory of the freshwater biodiversity resources within a river basin is an ecological classification that differentiates landform down to river channel types while maintaining scale, content, and ecological context. Once classification, preferably using GIS techniques, of the river basin is complete the real inventory begins on the basis of prior ity habitats. Inventories can be conducted at different levels of effort and expertise, and focus on different objectives, depending on the existing conditions at the project site and level of predicted impacts.

The United States Environmental Protection Agency adopts this concept in its 1989 manual *Rapid Bioassessment Protocols for Use in Streams and Rivers*. That document presents five protocols that can be followed depending on the specific situation (Plafkin et al. 1989):

- Protocols I and IV are subjective because an investigator or agency may conduct any level of investigation deemed necessary, and the presence or absence of ecological impairment of the freshwater habitat is supported by a limited analysis of the biological communities. They should be used mostly as screening and reconnaissance techniques for discerning biological impairment.

- Protocols II, III, and V are progressively more rigorous and are intended to provide more objective and reproducible evaluations than protocols I and IV. Protocols II, III and V are designed to be semi-quantitative and utilize an integrated analysis technique to provide continuity in the evaluation of impairment among sites and seasons. The primary difference among these three protocols is the level of taxonomic resolution (i.e., family level vs. genus/species level identification) necessary to perform an assessment.

Box 1. Appropriate Freshwater Biodiversity Work in Environmental Assessment (Kottelat and Whitten, 1996)

Planning Stage. Consider the nature of the project and its likely impacts on an aquatic ecosystem. An initial prediction of potential impacts (usu ally referred to as "scoping") can greatly improve the efficiency of subsequent data collection and management interpretation.

The scoping exercise is dependent on:
(i) the existence of a sufficient species inventory for the aquatic system, (ii) an understanding of the habitat requirements of critical species, and (iii) some knowledge of the impact similar development/industrial projects have had on comparable aquatic systems. Where such information does not exist, an initial baseline inventory must precede scoping. Scoping should be prudent and inclusive: it is better to eliminate issues from consideration later on than discount important impacts at the beginning.

The nature of the project and its likely impacts on the freshwater ecosystem, e.g. toxicity, temperature rise, or increased sediment load, will help in the design of the fieldwork. Tributaries, swamps and ditches near to the project site should also be noted and surveyed because they may act as refuges or as breeding sites. The filling in of a swampy area may have as much impact as an effluent discharge.

Fieldwork Stage. A single sampling of a lake or of a stretch of river is unlikely to give a very good picture of the species present or their relative abundance or life histories because of diurnal and seasonal movements, and of year to year natural variations in abundance. The project proponent should not be expected to compensate for the shortcomings of government fisheries or academic inventories, but at least one full year of sampling in the zone of potential impacts should be regarded as the minimum requirement for an impact assessment.

The first step is to undertake a survey and mapping (at an appropriate scale) of the major aquatic ecosystems in the area of potential project influence. The mapping should then be used to organize subsequent sampling of species distribution and abundance. Such sampling should be taken at regular intervals (e.g. once per month) and include both night-time and day-time sampling. Sampling on each occasion should continue until repeated efforts result in no significant number of extra species. Sampling of fishermen's catches and market stalls can provide some useful information if the location of the catch can be verified, but there is no substitute for survey workers catching the fish themselves, or at least accompanying fishermen. Smaller meshes than those used by fishermen must be used in addition to standard nets in order to catch the small species and the young of larger species.

Assessment Stage. The major role of impact assessment is impact quantification and impact significance. In many cases our knowledge of cause-effect relationships is so poor that impact quantification becomes dependent on the best technical judgment of the assessment specialist. The prediction and quantification of impacts must take into consideration the complexity of inter-relationships in aquatic ecosystems. Some important considerations include: the role of riparian trees and other vegetation; the impacts of organic effluents with a high biological demand reducing the oxygen concentrations in the water below the thresholds of many species; impact assessments must be based on the river characteristics observed at the time, and on predicted potential low and high flows; the area of influence of the whole project, immediately adjacent to the project on and downstream.

Management Stage This includes the development of a plan to manage impacts, including programs for impact mitigation and monitoring. For mitigation to be fully effective, the impact assessment must be integrated into project design and feasibility studies from the very beginning. Monitoring should serve to provide a measure of the effectiveness of the management program, and early warning of unpredicted impacts. Project monitoring should be linked to the baseline aquatic inventories carried out early in the environmental assessment process, and should have a sound statistical base.

The following assessments must take place within each habitat targeted for investigation:

- structure of biological community, including riparian vegetation;
- major feeding, migratory and reproductive patterns of freshwater species;
- structure and quantity of microhabitats
- temporal and spatial variation in water flow, microhabitat availability, physical and chemical characteristics of the aquatic environment;
- degree of connectivity among different microhabitat patches across seasons.

ENGINEERING PROJECTS: ISSUES AND OPTIONS

In order to protect the goods and services provided by natural freshwater ecosystems, it is paramount to avoid all possible major negative biological impacts resulting from water development projects. *It is important to remember that it is always less expensive to incorporate mitigation measures during new construction than it is to retrofit a completed project.*

This document will address some of the most common impacts of water development projects on freshwater ecosystems and their associated biodiversity, and present some possible mitigation measures and guidelines for action in the context of some general project categories:

- Impoundments (for various purposes);
- Flood Control and Navigation Structures;
- Irrigation and Drainage;
- Aquaculture.

The majority of water development projects affect freshwater ecosystems by interfering with one or all of the basic characteristics of these ecosystems:

- Natural flow regimes;
- Connectivity;
- Suitable Water quality;
- Variety of aquatic microhabitats.

Natural Flow Regimes

The natural flow regime (movement of water and sediments) organizes and defines running water ecosystems, and can be considered a "master variable" that limits the distribution and abundance of riverine species and regulates the ecological integrity of flowing water systems. In most instances, however, the importance of natural streamflow variability in maintaining healthy aquatic ecosystems is still greatly ignored in a management context (Poff et al. 1997).

The growth and reproductive cycles of most freshwater and wetland species are synchronized with the natural seasonal hydrograph, and behaviors associated with breeding and rearing of young are triggered by rising waters at the onset of the rainy season or by receding waters at the end of it. Flooded areas with slower moving waters and plenty of organic material provide the right conditions for the breeding and rearing of many freshwater fishes. Every year, the Amazonian catfish piramutaba (*Brachyplatysoma vaillantii*) migrates up to 3,000 km inland from the Amazon estuary to reproduce, and then makes the same trip back. Another Amazonian fish, the economically important tambaqui (*Colossoma macropomum*), migrates into the flooded forest to feed on the fruits of certain trees and, when the waters recede, goes back into the main river channels where it will fast and lose weight until the next rainy season (Goulding et al., 1995).

The historical management approach to protecting river ecosystems typically emphasizes water quality and only one aspect of water quantity: minimum flow. However, many channel and floodplain features, such as river bars and riffle-pool sequences, are formed and maintained by dominant, or bankfull, discharges. The flows that build the channel may differ from those that build the floodplain (Poff et al. 1997). A river channel and its associated floodplain constitute a single, integrated ecosystem where healthy functioning of one component is intimately linked to the health of the other. Periodic floods bring new nutrients and sediments into the system, redistribute deposited materials, and move organic and inorganic materials in and out of the floodplains. Floods also perform a cleansing function as they flush away toxins that accumulate in the floodplain during the dry season.

Construction of structures that prevent inundation of the floodplain, and of artificial channels that convey water out of the floodplain faster than natural ones, result in loss of natural wetlands and the services they provide, thus seriously impairing the health and integrity of freshwater ecosystems. Dikes, levees, and channelization also cause water to move faster through freshwater ecosystems, thus reducing the opportunities for water table replenishment. During flooding, as water moves slowly or stands still over relatively flat terrains such as floodplains and marshes, more opportunity exists for infiltration into the soil and recharging of groundwater reserves.

Faster water velocities due to channelization promote channel and bank erosion, loss of riparian vegetation and their shading effect, loss of instream and riparian habitat, and increased peak floods. This results in larger than usual volumes of water and sediments reaching the estuary in distinct pulses due to decreased retention of water in the ecosystem. For a good discussion of the biological effects of sediments in streams, see Waters, 1995.

When impoundments are built in a freshwater system, the natural dynamic equilibrium between the movement of water and the movement of sediments that exists in free-flowing systems is altered drastically as upstream habitats change from flowing, shallower water into standing, deeper water, and downstream areas now experience a new flow regime determined by the operation and management of the reservoir. Dams capture all but the finest sediments moving down a river, with many severe downstream consequences such as increased bank erosion. Often, building a series of smaller dams instead of a larger one will minimize impacts on the aquatic community, but this is not true in all cases. Each situation needs to be analyzed individually.

Water development projects aimed at controlling floods or improving navigation should *always first consider non-structural solutions to the problem.* In the case of the Lower Guayas Flood Control Project in Ecuador, "the EIA only investigated alternatives with respect to the routing of by-passes in the floodplain and helped identify the less environmentally damaging... it was already decided that flood control was required and that hydraulic engineering was a prerequisite to the management of resources and improvement of living standards in the Guayas Basin... nobody will ever know if that is true because other alternatives —e.g. introduction of new agricultural methods, new flood-resistant crops, or flood adapted stock farming, etc.— were not considered (Wetten, 1995)."

Whenever possible a hands-off, live-with-floods approach should be followed. Some tools to integrate natural flood regimes into development policies include: (a) zoning of floodplains for selected activities that take place during the dry season and do not involve creation of permanent human settlements; (b) introduction or re-development of flood-dependent agriculture; (c) incentives for people to resettle out of the floodplain; and (d) where permanent resettlement is not an accepted option, construction of higher-ground flood refuge centers can be combined with the establishment of a flood warning system to avoid loss of human life during major flooding events. Economic utilization of floodplains should focus on activities that can happen during the dry season, and the establishment of permanent human settlements should be avoided in these areas as much as possible. Box 2 summarizes the case of a flood protection project that took those factors into consideration and adopted a "living with floods" approach.

A word of caution is required about alternative uses of floodplains during the dry season. In many areas, especially urban ones, flood waters may contain high levels of domestic and industrial effluents, which contaminate the floodplain with pathogenic organisms, toxic substances, garbage, etc. Under those circunstances, using floodplains both for flood control and human activities is not advisable. An urban flood control project for the city of Rio de Janeiro, Brazil, considered the possibility of diverting excess storm water into a downtown public park to improve flooding of downtown streets, but the level of contamination of such waters by domestic effluents prevented the implementation of that plan. The adopted solution consists of a storm water collector that channels and delivers floodwaters into the sea, beyond the coastal currents (Jerson Kelman, pers. Comm.)

Box 2 summarizes the case of a flood protection project that took those factors into consideration and adopted a "living with floods" approach.

For projects aimed at improving navigation efficiency and safety along freshwater courses, new technological advances offer many opportunities to achieve the goals through minimal structural intervention. Modern electronic signaling devices, in conjunction with satellite positioning systems and computers, can be used to guide boats safely across "tricky" channel sections and prevent collisions during day and night time.

Water abstraction from natural rivers or lakes reduces the flow of water through natural freshwater ecosystems, and drainage systems promote the drying of streams, wetlands and floodplains. Both activities have deep impacts on the hydrological cycle and on groundwater quality and quantity due to the change in system dynamics. Development projects involving irrigation and drainage schemes need to mimic as far as possible the natural hydrology, and be coupled with policies to maintain minimum instream flows. Irrigation and drainage projects have in the past been responsible for the degradation of large portions of the world's freshwater ecosystems.

If structural solutions are still deemed to be necessary after extensive consideration of all factors described above, water development projects involving the alteration of natural flow regimes should adhere to the following recommendations in order to protect or restore natural freshwater ecosystems:

1. *There should always be enough water in the river channel to sustain the original aquatic life*

C The actual amount of water needed may vary throughout the year as seasonal changes in water volume and velocity are important cues for timing life cycles and behaviors of aquatic organisms and riparian vegetation. Riparian areas downstream from a dam will be affected by the lower instream water levels, and in areas closer to the river delta reduced water flows may allow saline water to move farther inland, especially during the dry season. In naturally dry areas it may be important for some rivers to be totally dry during part of the year since the natural communities are adapted to those conditions.

C Methods to estimate environmental flow requirements for rivers focus mainly on one or a few species that live in the wetted river channel. Although this approach continues to evolve by adding biological realism to the models and by expanding the range of habitats modeled, in practice it is often only used to establish minimum flows for important (usually game) fish species (Poff et al. 1997). Unfortunately, for many projects the discussions still revolve not around *how much water* to release to downstream areas, but on whether *any* water should be released at all during times when water is not being used for the intended economic purposes of the project.

Box 2: Argentina Flood Protection Project

The Rio de la Plata system is a 100 mile-long estuary composed of the conjunction of three great rivers, Paraná, Paraguay, and Uruguay rivers, and takes in one fourth of the fresh waters of South America. Most of northeastern Argentina consists of extensive, low-sloping plains of soils that have little water retention capacity. There have been significant increases in the incidence and severity of floods within the overall La Plata Basin since the 1960s, and studies have shown that variations in precipitation explain much of the variation in streamflows and flooding.

To address this situation, the Government of Argentina has designed a new strategy to cope with Paraná River Basin flooding. The strategy calls for (a) improved management of the Basin's major natural resources through improved coordination of flood-related actions within and among the provinces; (b) structural measures consisting of well-defined, long-term investments in defending the area's most important assets, replacing present emergency reactions; and (c) nonstructural measures consisting of a combination of actions for "living-with-floods" including flood warning and civil defense measures in lesser priority areas.

The structural measures (about 75% of base cost) would include fortification of flood defenses in geographic areas with strong economic activity and greatest vulnerability to serious repeated flood damage. These investments would not attempt to control flows of the major rivers, Paraná, Paraguay and Uruguay, but would instead protect cities against floods through works that would prevent water invasions without interfering with the rivers. Works would concentrate on raising bridges, improvement of existing and construction of new drainage channels, embankments and small flood control works.

The nonstructural measures (about 24% of base cost) consist mainly of: (a) New institutional framework, including development of plans and regulations to rationalize land usage in flood-prone areas (discouraging urban expansion in high risk areas), and creation of a unit to coordinate civil defense, flood warning, maintenance of flood defense facilities, etc. The project will also provide technical assistance to the provinces to, among others, improve wetland protection and develop environmental education programs in communities benefiting from flood protection works; (b) Upgrading of flood preparedness in vulnerable areas not considered to warrant further investment in structural defenses. Actions include provision of shelters (multi-purpose installations) and improvcd housing for lower-income families in flood-prone zones. The housing component provides funding for a voluntary program of self-construction of houses by the community; c) Early flood warning system, to insure the development of a more comprehensive flood warning system linking the National Institute of Hydrological Sciences and Technology with the provincial systems. Actions include a new hydro metering system, new computational equipment and software, new communication system, the creation of local flood warning systems in each province, and training of staff on this new technology.

C It is not easy to determine the minimum flows required to maintain freshwater ecosystem function and to protect aquatic species, but several models and methodologies already exist to guide us in this quest. Models span the range of more simple ones, such as the Sag Tape Method, to the more intensive PHABSIM-IFIM model. In the Sag Tape model, the velocity and depth profiles across a section are used to estimate available habitat at various flow conditions; and various analyses can be performed with the data, including such relationships as flow vs. wetted perimeter. The Instream Flow Incremental Methodology (IFIM), developed by the Aquatic Systems Branch of the US Fish & Wildlife Service, is a concept which considers ecological demands when recommendations for the flow regimes are determined. IFIM relates changes in the extent of habitat area available to aquatic species to changes in discharge (see Box 3). The Physical Habitat Simulation Model (PHABSIM) is a suite of computer programs that focus on the characteristics of the natural physical habitat, and is used to generate habitat vs. discharge relationships for use in IFIM studies. Suggestions on where to get additional information on these and other models are included in the reference section at the end of this paper.

Box 3. Physical Habitat Modelling

The populations of many fish, invertebrates and other aquatic species are limited by the availability of suitable physical habitat, such as depth, flow velocity, substrate type and cover. River engineering and water resources projects frequently reduce the total magnitude of variability of these physical variables and thus lead to loss of biodiversity. The Instream Flow Incremental Methodology provides a framework for assessing the impact of projects or setting "ecologically acceptable flows". The locations in the water course of individuals of the target species, usually fish, are identified by snorkeling or electro-fishing, and the physical variables (depth, velocity, substrates and cover) where they are found are measured. A histogram is then produced for each physical variable defining the range of measured values, and their suitability as a habitat is defined according to the numbers of individuals occupying them - these graphs are called suitability indices.To apply the method, a map of the impacted river reach is made, depicting the distribution of meso-habitats (such as pools, riffles, glides) and from this, representative sample reaches are chosen. For each reach, cover and substrate are measured and a hydraulic model is calibrated, which predicts the distribution of water depths and velocities for any flow. Any river flow can then be scored by applying the suitability indices to depths and velocities predicted by the hydraulic model and the measured values of substrate and cover. Time series of flows can be converted to time series of available habitat using this approach. For any water resource scheme, a time series of synthetic flows (with the scheme in place) can also be converted to a time series of physical habitat. To assess the impact of the scheme, the natural or pre-scheme situation can be compared with post-scheme habitat time series using standard time series analysis methods.

C In situations where the available information on biological parameters and physical habitat is inadequate for a definitive decision on the required minimum flow, a flexible approach should be adopted which allows flows to be varied according to agreed rules as more information and better models are obtained from monitoring studies. *This adaptive management approach should be a scientific process of adapting to increased scientific understanding of the freshwater ecosystem, and not a process of adapting to changing political pressures* (Van Winkle *et al*., 1997).

- Re-regulation weirs and reservoirs can be placed at several points below a hydropower dam to temporarily store some of the water released during operation of the turbines, especially for hydroprojects operated on a peaking basis. This water can continue to be released after the turbines stop working, thus ensuring that water never stops flowing in the channel downstream from the dam. As a result of the Yacyretá II Hydropower Dam, and in the absence of appropriate mitigation measures, the Aña Cua Branch of the Paraná River (22 km long and 2 km wide) would be virtually dry for about 9 months each year after the installation of turbine no. 14. To prevent potentially serious environmental problems, three small dams are planned to maintain adequate water levels in that river section. Until these small dams are built, a minimum flow of 1,500 m^3/sec will be released throughout the year to ensure adequate water levels in the Aña Cua Branch.

- Turbine pulsing techniques and/or installation of small hydroturbines that work constantly are two ways to ensure constant release of water to downstream areas.

- Impoundments built for irrigation or multipurpose use should include design features that allow for the release of water necessary to maintain natural ecosystem function in areas below the dam. Ecological use of the impounded water needs to be considered as an integral part of the project, and not viewed as "wasted water."

Box 4 offers an example on an irrigation project that tries to address the needs of freshwater organisms.

2. Enough sediments should move across the structures to sustain natural channel morphology

- Sediments which usually move downstream with the flow will tend to settle at the bottom of reservoirs due to the lower water velocities. This affects habitats downstream because a regular influx of sediments is needed to maintain shallow areas such as sand bars, and balance erosion of river banks. The river tries to compensate for the lower sediment influx by increasing its capacity for erosion, thus damaging existing banks and scouring the channel bed. Several techniques exist for moving sediments across a reservoir and into the downstream areas, and they vary in cost and effectiveness depending on the characteristics of each particular reservoir. Sediment management techniques usually follow one of three general approaches: mechanical removal, sediment routing, or sediment flushing.

- Sediments can be dredged and transported by trucks to a downstream area, but this is usually an expensive proposition. Where possible, the difference in height between the reservoir bottom and the river bed below the dam can be used to remove fine sediments through hydrosuction/siphoning, which transports the suspended mud over the wall through flexible pipes. This solution is usually cheap and ecologically sound because the downstream river bed is constantly replenished with sediments. Another mechanical solution for sediment management is building a bypass channel which directs sediment-rich waters, usually during heavy storms, around the reservoir and directly into the downstream area.

Box 4. Orissa (India) Water Resources Consolidation Project: Naraj Barrage

In the past the Mahanadi River, along with its six-branch delta and extensive floodplains, contained rich fisheries resources supported by tidal estuaries with seasonal fresh- and salt water conditions and extensive spawning grounds for freshwater prawns and fish. Due to conversion of the delta into irrigated land and interventions in the hydrology of the river, such as the 1958 construction of the Hirakud dam some 250 km upstream of the delta, many aquatic species have virtually disappeared.

The indian carps (*Catla catla, Labeo rahita, L. calbasu and Cirrhina mrigala*) live in the Mahanadi delta and are totally dependent on monsoon floods for spawning, especially during early monsoon between mid-June until the end of July. The more intense the flood, the more fry will be produced. The Mahanadi branch is the most important for these species and, due to the Hirakud dam and the use of water for irrigation, spawning is virtually absent during years of low rainfall when floods are very limited. Artificial floods during early monsoon might partially solve this problem. Also, freshwater prawns of the genus *Macrobrachium* reproduce in the brackish water zone of the delta, but the hatched juveniles migrate upstream into freshwater areas during a three month post-monsoon period. Maintenance of post-monsoon discharge towards the Kathjori river is essential for continuation of this event.

The Naraj Barrage, below the Hirakud Dam, replaces the deteriorating Naraj Weir. The Naraj Weir diverts water from the Kathjori branch into the Mahanadi and Birupa branches of the Mahanadi delta, and its collapse will render the irrigation in the extensive Delta Stage I irrigation scheme impossible. The new barrage will be provided with gates for flow regulation which opens the possibility to manage to a certain extent the fresh water and sediment inflow into the different branches of the Mahanadi delta. A fish pass of 2 m width is included. Apart from its irrigation function, the new Naraj Barrage will be useful to increase early monsoon floods in the Mahanadi branch to enhance fish spawning in the river, and to maintain certain minimum flows in the Kathjori branch the first three months after the monsoon in view of upstream prawn migration.

The initial operational rules for the Naraj Barrage determine that, after the primary irrigation conditions are fulfilled, the first monsoon floods should be as high as possible to enhance spawning of Indian carps, and a continuous flow through the barrage is required during three months after the monsoon to enhance upstream migration of prawns. The minimum required flows for optimal prawn migration will be determined after monitoring by the Fisheries Department yields more data on the relation between water flow and prawn collections below the barrage. Management of the Naraj Barrage should be adjusted according to the advice of the Fisheries Department, within limits set by Stage I irrigation demands.

- Sediment routing involves moving sediment-rich waters through the reservoir and into the downstream area *before* the sediments have a chance to deposit. Sediment-rich waters have high density and tend to move in currents near the deepest areas of the reservoir. Hydrological modeling of water currents in the reservoir can predict where those currents will be located, and gates can be placed at the appropriate points in the wall to let that sediment-rich water out into the downstream area.

- Flushing involves periodically remobilizing deposited sediments and flushing them out through gates built at the lowest point of the dam wall. This solution involves the used of large amounts of water to resuspend the sediments and is not cost-effective for areas where water abundance is an issue. Also, this design is not as effective in reservoirs with very gentle bottom slopes.

Flushing is usually done every few years in the rainy season and can involve partial or total drawdown of the reservoir. Although this solution provides the downstream areas with periodic replenishment of sediments, downstream aquatic communities can suffer from the violent scouring caused by waters heavily laden with suspended sediments.

3. Natural flood cycles should be maintained as much as possible, including periodic inundation at the required times

- Current understanding of river ecology clearly indicates that fish and other aquatic organisms require habitat features that cannot be maintained by minimum flows alone. A range of flows is needed to scour and revitalize gravel beds, to import wood and organic matter from the floodplain, and to provide access to productive riparian wetlands (Poff *et al*. 1997).

- Natural intra- and inter-seasonal variation in water flow will be altered by impoundment of a river. This may have a substantial effect on freshwater organisms because for many of them, including some species of riparian vegetation, this variation works as a cue to trigger migratory movements and reproductive events.

- The natural riparian vegetation upstream from a dam will be permanently eliminated due to flooding in the reservoir area. Diminished flows will subject downstream riparian vegetation to increased bank erosion, and will severely impact the integrity of natural floodplains which depend on natural flooding patterns for their existence.

The initial project design should incorporate features that allow for the production of artificial floods of magnitudes that satisfy the needs of the natural aquatic community, at the appropriate times. Although this proposition seems to contradict the very purpose of having a project, i.e. storage of water and reduction of natural flow variation throughout the year, the artificial floods would probably have lower magnitude and/or frequency than the natural flow cycle. Controlled releases of water from reservoirs during wet seasons can ensure the conservation of healthy downstream freshwater ecosystems and associated riparian and floodplain areas. These controlled releases can also discourage the establishment of permanent human settlements in floodplains where occupation used to be limited by the ocurrence of natural floods. Box 5 presents a project which attempts to incorporate a "natural" flood regime into its operational strategy.

4. Maintain water table recharge function and water quality

- Flood control structures could be used to move water faster through the system in highly populated areas, but wetlands and other known groundwater recharge areas should be allowed to flood on a regular basis along rivers and streams. This can be achieved through a series of interruptions along levees and dikes, and where necessary land should be bought for the sole purpose of insuring inundation of floodplains that, besides contributing to flood control, provide important habitats for the aquatic community and/or have a major role in groundwater recharge (see figure 1).

Box 5.Regional Hydropower Development Project: Manantali Dam

Most of the population in the Senegal River Valley has traditionally depended on the annual flooding of the river for their livelihood. The natural yearly flooding supported flood recession agriculture, livestock grazing, fisheries, and fostered the replenishment of shallow aquifers used for village water supply and the regeneration of vegetative cover. Originally, the main objective of the Manantali Dam, completed in 1988, was to respond to the drought and famine of the 1970s and 80s by providing a steady supply of water for agriculture. The construction and management of the Manantali Dam combined with changing rainfall patterns, has resulted in the curtailment of this flood and diminished or threatened the aquatic and floodplain production systems.

The Manantali Energy Project is an example of an infrastructure project that attempts to address ecosystem function issues by restoring some of the original characteristics of the natural ecosystem. The project finances the installation of a 200MW hydropower facility at the Manantali Dam, in Mali, and a transmission system to distribute power to Mali, Senegal and Mauritania. The project includes assistance with the implementation of an environmental mitigation and monitoring plan along with studies aimed at the optimization of reservoir management and mitigation measures for environment, traditional agriculture and health.

The Manantali Reservoir will be operated as a multi-purpose reservoir in agreement with a Reservoir Management Manual, under preparation as a result of the Reservoir Management Optimization Plan. As part of this plan, artificial flooding is proposed to enhance aquatic and floodplain habitats, and increase overall production. The artificial flood, except in the driest years, will reestablish many of the traditional floodplain functions impacted by the Manantali Dam, such as considerable increases in flood recession agriculture, dry season pastures and crop residues, an increase in fish production (related to the area covered by the flood and its duration), and possible regeneration of forest resources (also strongly dependent on improved management). Recharge of nearby shallow aquifers is also hoped for. To monitor the impacts of the artificial floods, a comprehensive monitoring system will be put in place including field evaluation to assess negative and positive trends.

5. *Enough freshwater must reach the delta to maintain the estuary in its natural condition*

- Diminished discharge of freshwater to estuarine areas often results in upstream intrusion of saline waters that transform previously freshwater habitats into brackish ones. Freshwater ecosystem services are affected through the loss of salt-intolerant species and the invasion of others typical of brackish conditions.

  Mangrove communities, typical of estuarine areas, are adapted to the local conditions of water salinity and influx of sediments and nutrients. Disruption of these daily and seasonal patterns, caused by reduced freshwater inflows, affect the normal functioning of the local mangrove ecosystem and their role in maintaining healthy coastal and marine fisheries.

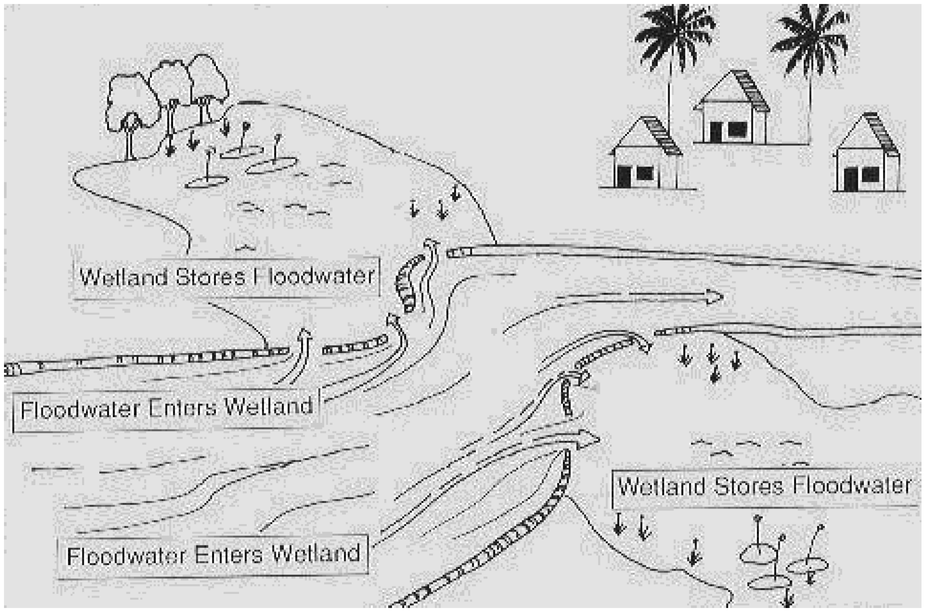


Figure 1: Wetlands control floods while contributing to the recharge of the groundwater table (Source: Davies and Claridge, 1993).

Connectivity

The over-riding attribute of freshwater ecological systems is one of connectivity. Rivers form a linkage between the uppermost parts of the catchment, from headwater streams, to meandering rivers through the floodplains into estuarine and coastal marine systems. The river network carries water along its length back into the ocean from whence it originated in the hydrological cycle. In the process there is a loss of kinetic energy, in the form of heat, from the headwaters to sea level (which hydro-electric engineers harvest and exploit).

The energy of flowing water transports materials downstream. Particles brought into suspension from the catchment soils by erosion are carried down on the currents to areas of deposition. The cycle of erosion and deposition of particles is repeated many, many times along the river system. The Inner Niger

Delta in Mali is an example of an inland area of deposition; but normally, the ultimate destination of sediment burdens is the sea (even if over geological time-spans). At the interface between river and ocean, marine delta systems are created and a rich alluvium is deposited on the deltaic land. An equilibrium between deposition and erosion is established at the leading edge of the delta such that deltaic areas advance and retreat in response to climatic and coastal hydraulic processes.

Leachates from run-off and discharges in the catchment are washed into streams and rivers, the ions and salts being cycled through biological and/or chemical cycles, and perhaps being deposited and re-solubilized along the way. Washed into the rivers too are allochthonous organic materials providing energy inputs to food webs in the system. From the headwater streams down the river system to the ocean, a tendency towards an increase in total dissolved salt concentrations is usually accompanied by higher total production, increase in numbers and diversity of habitats and the development of more intricate food webs. When nutrient enrichment becomes excessive and eutrophication reaches pollution proportions, total numbers of individuals may increase dramatically with a sudden decline in biological diversity (algal blooms are an example of this phenomenon).

The connectivity of the system discussed so far, has been uni-directional; from headwater streams to the sea, or, if one thinks in terms of kinetic energy transformation and of water and nutrient flow, from source to sink. But connectivity is multi-directional, forming a network of links for the ecological stability of catchment. The connectivity of river systems provides a mechanism for the longitudinal movement of organisms both up and down stream. Migrations of fishes up rivers to spawn is a regular phenomenon. The River Corridor is a mechanism for the migration and interaction of species along the length of the river system and all links within, between and through adjourning ecosystems. Rivers cut their way through biogeographical barriers and inter-connect otherwise isolated biomes (for example, through mountain ranges and across deserts) so gene flow and the gene pool may be sustained and genetic diversity, retained. The river corridor, (i.e., whole ecological system of the river: river banks, levees, wetlands and associated habitats), allows for an intricate network of interactions between, plants, animals, micro-organisms, genetic material and their natural environment.

Just as important as longitudinal connectivity are lateral connections within and between ecological systems. River floodplains and wetlands, which are ecotones, are good examples. The wetland ecotone links aquatic and terrestrial habitats through a water depth gradient. River floodplains are wetlands with distinct seasonal variation in water levels linked to flooding regimes. The natural flood regimes allows lateral movement of species, inter-connecting riverine species with species in adjourning water bodies. Nutrients from the river also flood into the lagoons and recharge the nutrient budget. Rivers and river corridors are essential media for migration, cross-breeding, gene flow and maintenance of biological diversity.

Finally, consider the water cycle within the catchment. Water from evapotranspiration in the river floodplains and wetlands rises and condenses in the cooler, upper catchment. Morning mists are normal. Where days are hot and dry, morning moisture condensation and increased humidity may be sufficient to support permanent vegetation cover without which soil erosion would proliferate. With a change in the lake, river, wetland and river floodplain systems, the hydrologic cycle would be altered, with a concomitant change in landscape and biological diversity.

Water development projects can interrupt the natural connectivity of freshwater ecosystems in many different ways. The process can occur over a relatively short period of time when a continuous habitat is divided in two portions, upstream and downstream, by the construction of a dam. The natural movement of water is affected, as well as movement of aquatic organisms. Migratory species are now denied access to the habitats needed for their reproduction and growth. The loss in connectivity can also take place gradually as a result of increasing water abstraction from a system, which results in diminished frequency and magnitude of flooding events that connect the floodplain and oxbow lakes to the rest of the freshwater ecosystem.

Levees and dikes also prevent water from entering the floodplain, destroying the natural connectivity and resulting in the fragmentation of floodplain habitats. When levees break or when flood levels go beyond the levee's height, sudden and violent flooding occurs in the landward side of the levee, scouring and destroying natural habitats and their associated organisms.

Water development projects with a potential for fragmenting the connectivity of a freshwater ecosystem must ensure that:

1. Migrations of aquatic organisms, especially fish, should not be so impeded as to harm populations

- Creation of a reservoir is an unavoidable consequence of impounding running waters, and this can be addressed through mechanisms that provide currents in certain areas of the reservoir to guide aquatic organisms in their migration. The problem of allowing organisms to move over the impoundment wall can be minimized through thoughtful design and management plans.

- The first fish ladders to be developed were designed and built to address the needs of salmonids (salmon and trout), most of which are capable of jumping out of the water and swimming against fast currents for extended periods of time. Replication of this same ladder design in all situations has proven to be disastrous as most species of fish do not have the same abilities.

- New management techniques and fish-pass designs have been developed that allow fish of various swimming abilities and migratory requirements to overcome barriers such as the wall of a dam or a levee, and others are presently in trial stages. Some examples of upstream fish passage facilities are: vertical slot fish ladders; fish elevators; Denil fish ladders; fish locks; weir and orifice ladders; and fish diversion weirs. Some structures that provide safe downstream passage for migratory fish are: moving screens; fixed screens; floating screens; inclined plane screens; and diversion weirs. A "fish-friendly" turbine which allows fish of certain sizes to go through the turbine unharmed is currently being tested. Box 6 describes two examples of fish elevators already in use, and figures 2 and 3 show the cross sections of some upstream fish passage facilities.

- The key to providing successful upstream and downstream passage for fish is having good quality data on the migratory behavior of target migratory species present in the river or stream. In order to choose the appropriate passage structure, and to know where to place the entrance to the structure, information is needed on whether the fish swim near the surface or close to the bottom, along a margin or closer to the center of the channel, and on the swimming and jumping abilities of the migrating species. Clay (1995) addresses all topics regarding fishways and fish migrations; provides the background for decision making regarding the design, operation, and type of facility needed; and describes the main types of fishways and facilities used worldwide to assist the passage of fish over dams and other migration obstructions.

Box 6. Migratory Fish at Yacyretá II Hydropower Project

The Yaciretá Hydropower Project, on the Paraná River between Argentina and Paraguay, converts some 57,000 ha of existing river and stream area into a reservoir lake habitat covering about 165,000 ha. Although some native fish species were expected to disappear from the inundated sections of the river and streams, recent monitoring data has shown that there has been no decline in fish species diversity, probably due to the fact that Yacyretá is operated mostly as a run-of-river reservoir and this has preserved enough riverine conditions in parts of the reservoir to maintain populations of riverine species.

However, the Yacyretá Dam poses a significant barrier to fish migrations. In an experimental attempt to facilitate passage of migratory fish upriver, the dam design includes two fish transfer stations, each with two elevators to lift migratory species, including those that lack the jumping ability to utilize a fish ladder. Two elevators are already installed and functioning properly, and fish survival within the elevators exceeds 99 percent, but monitoring indicates that only about 7 percent of the fish seeking to move upstream succeed in finding the elevators and using them. While the elevators cannot help restore pre-dam dish migration patterns, they are nonetheless useful for ensuring that the Yaciretá reservoir and upstream river areas have a genetically diverse breeding stock of native fish. A significant source of fish mortality is the presence of large-scale commercial fishing below the dam, where migratory species are highly concentrated. Enforcement by the Paraguayan authorities of the ban on fishing in a 3 km stretch below the dam is extremely weak.

Migratory american shad at Conowingo Dam

The Conowingo Dam, built in 1928 across the Susquehanna River, Maryland, was believed to constitute an insurmountable barrier that would forever block the migratory route of the american shad towards their breeding grounds in the upper Susquehanna watershed. By 1984, only 167 fish were recorded attempting to go by the dam. However, some 103,945 fish have passed through the dam in 1997 thanks to an elaborate system of fish elevators, lifts, hoppers and traps, installed about seven years ago at a cost of US$ 12 million (Dybas, 1998). This cost reflects the additional effort involved in retrofitting an existing dam, and a similar system would probably cost much less if designed and installed as part of the original dam building.

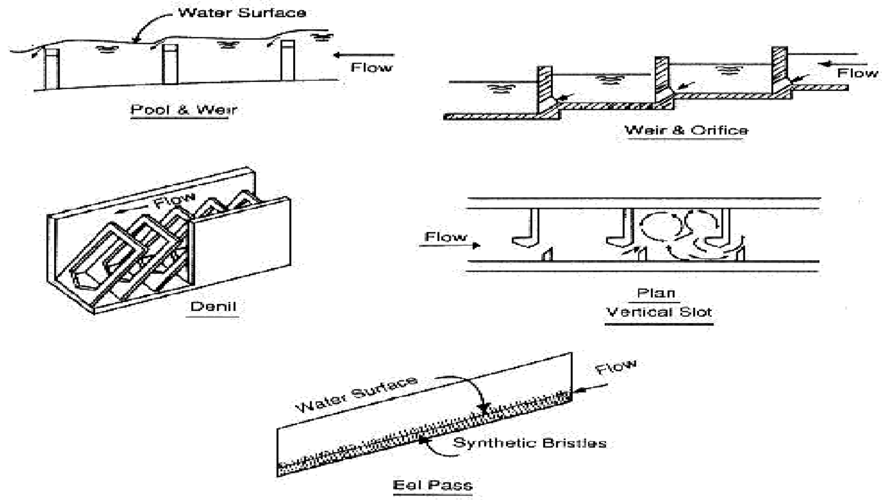


Figure 2: Cross sections of some fishways that facilitate upstream passage of fish over dams (Source: Clay, 1995).

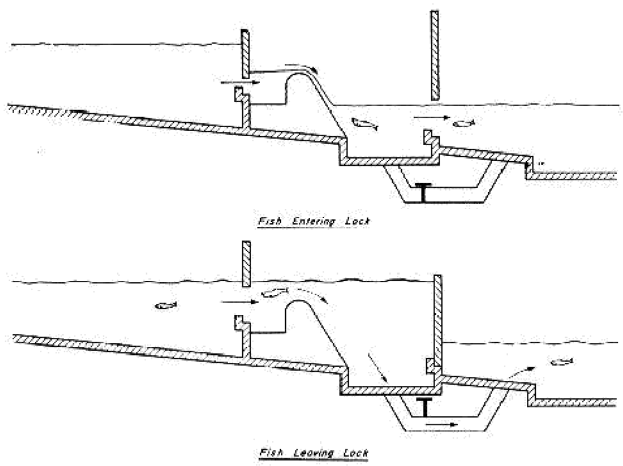


Figure 3: Schematic operation of a fish lock (Source: Clay, 1995).

2. *Maintain habitat connectivity as much as possible*

C Aquatic organisms must have access to all different habitats required for their normal growth and reproduction. Where construction of levees and dikes is unavoidable, fish passages geared to the migratory needs of the local freshwater community must be installed in the appropriate places and in sufficient numbers to insure the healthy functioning and the integrity of the affected freshwater ecosystem (see Box 7).

C When construction of levees are absolutely required, preference should be given to set-back levees which allow the river to occupy some of its natural floodplain (see Figure 4). Also, as shown in figure 1 on page 26, levees can be interrupted for short lengths along their extension to allow water to flow into natural wetlands which can absorb some of the flood waters.

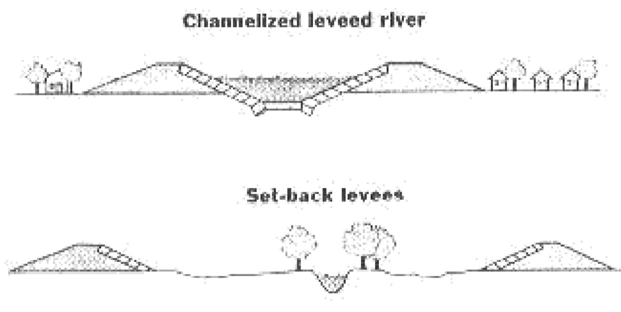


Figure 4: New Approach to Managing a River (Source: The New York Times, 02/4/97)

Water Quality

Impoundments usually affect water quality in both the inundated areas and downstream from the impoundment; post-impoundment conditions may differ considerably from the conditions prior to impoundment. Usually, the most significant changes in water quality involve changes in levels of dissolved oxygen, nutrients, suspended solids, and temperature.

Deterioration of water quality can be a serious problem when converted/irrigated land is used for agriculture. Drainage water can be higher in salinity, polluted by chemicals such as nutrients and pesticides, and drainage return flows will have secondary impacts especially near wetland areas. Also, the quality of the river water in an estuary and flowing into the marine environment has a direct bearing upon the productivity and biological diversity of the coastal marine ecosystems. These are some of the most fragile biologicalsystems. High sediment loads settle and stifle delicate coral ecosystems while suspended particles reduce light penetration through seawater so photosynthesis by marine plants, such as sea grasses and seaweeds, becomes limiting. If the river water contains high concentrations of nutrient ions, then plant growth is encouraged and phytoplankton blooms, periphytic coverings and excessive growth of macro-algae ensues. Biodiversity is reduced accordingly, with aggressive species out-competing diverse populations of sensitive species.

As a general guideline, saline drainage with salinity levels below 2000 mg/l usually do not pose a threat to freshwater biodiversity, but this may not apply to systems where some species have a low tolerance to increased salt concentrations. Madramootoo et al. (FAO, 1997) provide a more detailed discussion of water quality issues related to agricultural drainage.

Water development projects should include measures to ensure that water of appropriate quality will be available for ecosystem uses even after the project is operating:

1. The chemical and physical characteristics of the water should be of suitable quality

- In many instances the water released from the reservoir will have lower concentrations of dissolved oxygen, at times totally devoid of it, causing mortality of aquatic organisms in downstream reaches. Super saturation of nitrogen can cause serious problems in fish (gas bubble 'disease') when bubbles of nitrogen gas are released in the blood after supersaturation caused by water falling from high above into the plunge pool at the base of the dam. Water discharged from the reservoir is usually colder than the water the channel, but water temperature in the channel downstream may increase in the summer and decrease in winter at times of low discharge volumes.

Box 7
Fishpass Pilot Project in Bangladesh

The *Fishpass Pilot Project* constructed a vertical slot fishpass across a flood control embankment in northeast Bangladesh at Kashimpur, to re-open a fish migration route between river and floodplain. The impact of the fishpass was comprehensively monitored for three years, and compared to a three-year project baseline. Over 80 fish species were able to negotiate the fishpass. Significant increases in fish biodiversity and fish catch were recorded on the floodplain and could be attributed to the fishpass. The application differs from conventional applications at dams and weirs, and includes flow reversal during the late monsoon due to floodplain drainage, and continuous two way fish traffic inside the structure (NERP,1998).

- The placement of tailgates at various heights on a dam wall allows for controlled release of water from different reservoir depths, and provides reservoir management with the ability to release water of suitable quality and temperature for the downstream aquatic communities. In the United States, this technique is already in use at three hydropower dams —Hungry Horse and Libby dams in Montana, and Shasta dam in California— with very positive results.

- For hydropower dams, several proven techniques already exist that ensure appropriate levels of dissolved oxygen in tailwaters: induced air turbine injection; forced air turbine injection; forebay oxygen injection; penstock air/oxygen injection; surface water pumps; aeration weirs; and auto venting-turbines.

2. Natural riparian vegetation must be maintained

- Natural riparian trees and other vegetation provide shade and lower water temperature, hold bank soil and prevent erosion, and reduce water turbidity by stopping most incoming sediments at the margin.

- Any natural riparian vegetation destroyed during construction should be replaced as soon as possible. Here again the project could be used as a cost-effective opportunity to restore previously degraded riparian vegetation.

Natural Freshwater Habitats

Within the larger freshwater habitats (rivers, lakes, floodplains, etc.) we find a variety of "meso-habitats" such as waterfalls, rapids, slow backwaters, riffles, pools, etc. Within each one of these, a range of substrates such as boulders, cobble, and sand, as well as wood, twigs and accumulations of leaves, provide additional "microhabitats" resulting from the different water velocity and turbulence conditions associated with the different substrates. In order to conserve the whole of the freshwater community at a given site, this natural variety in habitats must be understood and preserved.

1. The natural distribution of physical habitats in the river channel and riparian zones will be maintained

- In many instances the water released from the reservoir will have lower concentrations of dissolved oxygen, at times totally devoid of it, causing mortality of aquatic organisms in downstream reaches. Super saturation of nitrogen can cause serious problems in fish (gas bubble 'disease') when bubbles of nitrogen gas are released in the blood after supersaturation caused by water falling from high above into the plunge pool at the base of the dam. Water discharged from the reservoir is usually colder than the water in the channel, but water temperature in the channel downstream may increase in the summer and decrease in winter at times of low discharge volumes.

- The development and distribution of morphological features in running waters, such as sand bars, are the result of energy dissipation processes. Channel structures such as riffle-pool systems and patches of rooted aquatic plants tend to slow down the materials transported downstream, thus helping to reduce losses of organic matter and nutrients from the landscape (Ripl *et al*., 1995). The river/stream channel after the project should have the same basic physical habitat characteristics as the natural freshwater habitat before the project.

- There are no clear formulas to determine the optimal dimensions of vegetated buffer zones or strips along water bodies. The results of some studies indicate that benefits to the stream ecosystem increase exponentially from no buffer strip to a width of 20 meters, and continue to increase less rapidly for strips wider than that. Recommended widths usually lie between 5 and 50 meters. Wider buffer strips should be used where the catchment area has been heavily modified by human activity.

- Composition of plant species in the buffer strip should replicate as much as possible that of natural riparian zones in the area. Where the water course comes near fields with intensive agricultural activity, a buffer strip with plants highly effective at removing nutrients, such as grasses, should be placed between the field and the natural riparian area closer to the wa-ter. Periodically, this grass strip can be cut and fed to livestock.

2. Refuge areas for aquatic species, especially breeding and young individuals, must be maintained

- The natural habitats and substrate diversity required for the breeding and rearing of young in the affected freshwater community must be available in the system during and after project completion. As examples, these may include slow and shallow waters, channel bends, sand bars, submerged vegetation, and natural benthic substrate such as fallen trees, debris dams, and coarse or fine sand. For a hydropower dam under planning in Nepal, agreement on minimum downstream flows is currently a problem since engineers do not favor release of more than one cumec during the dry winter (usually one month/year). That is certainly not enough to maintain fish communities in the channel, and an alternative solution has been suggested: dredge a path in the river bed of about 40 cm deep, to allow about 32 cm depth of water during the low flow for maintaining habitat for the fish. Otherwise, the little water released spread over the wide river bed would not provide enough depth for the fish (Parvaiz Naim, per. comm).

- In areas where the remaining water flow is not enough to produce the turbulent conditions required by some fish, control structures placed in the channel might be used to induce turbulence and changes in water velocity that could aid fish movement. For example, a pair of concrete cylinders placed at the edges of the main channel in a reservoir might induce vortices sufficient to accelerate fish movements in the channel. If such cylinders were placed at intervals along the channel, water velocities conducive to fish migration might be maintained for the necessary distance (The Independent Scientific Group, 1996).

- Where disturbance during project construction is unavoidable, the natural features of the habitat must be restored as soon as possible after the activities are completed. Large sediments such as cobble and boulders can be placed in the downstream area to insure availability of diverse habitats for downstream aquatic communities. In areas where the natural physical aquatic habitat was already degraded before project inception, it is probably cost-effective to restore some of the natural missing features in conjunction with construction activities.

Aquaculture

Aquaculture projects will be addressed as a separate category since they have some specific effects on aquatic ecosystems. The success of most aquaculture operations is highly dependent on a reliable supply of water of suitable quality. Aquaculture projects need different amounts of suitable water at specific stages of operation, and project design must insure that water will be available when needed, in sufficient amounts and with the required quality. Water needs vary greatly with the aquaculture system being used; recirculating systems require less water than ponds or raceway cultures. Therefore, *in selecting the site and design for aquaculture operations, the water supply must be thoroughly investigated and possible environmental impacts, both positive and negative, need to be thoroughly addressed in all phases of aquaculture project development and implementation.*

Traditional extensive aquaculture systems tend to have little adverse environmental impact, provided they are not taking the place of existing wild habitats, especially mangrove forests. Many modern aquaculture schemes, however, utilize methods involving high stocking and feeding rates, and those tend to be more unfriendly to the surrounding environment. The article by Anne Platt McGinn (1998) presents an excellent review of the promises and pitfalls of fish farming, and includes the list on what is necessary described in page 32 to make fish farming sustainable.

The most pressing environmental issues that should be addressed in all aquaculture projects are:

- *Use of native vs. exotic species* —most aquaculture projects, through the production of seed and marketable fish, might have a slight positive influence on the environment by decreasing the fishing pressure on wild fish stocks. One must be careful, however, when exotic species are used; if animals are allowed to escape from aquaculture ponds into the surrounding environment, they generally present a threat to populations of native aquatic life through competition for food and habitat, and in many instances in the past have greatly reduced or totally eliminated native species from the habitat.

- *Destruction of habitat and ecosystem function when mangroves, wetlands or other natural areas are replaced by aquaculture farms* —when aquaculture schemes replace wild areas, there is an instant loss of the habitat available to native animal and plant species, often with deleterious effect to the function of the overall ecosystem. This situation is even more serious when mangrove areas are destroyed because they are known to be highly productive areas offering major breeding and feeding grounds for several commercially important freshwater, marine and estuarine species. In the past, some projects were claimed to be environmentally neutral because the sites selected for fish ponds would be swamps, marshes, or low-lying poorly drained crop lands which are marginally productive. It is important to note that many of these habitats, although marginally productive from a narrow agricultural point of view, could provide essential ecosystem services and habitat for several types of terrestrial and aquatic life.

- *Effluent discharge into the surrounding environment* —the quality of water discharged from aquaculture ponds depends on the intensity of culture and the treatment the water receives during and after use. Typically, discharge waters are commonly eutrophic with high biological oxygen demand, resulting in low levels of dissolved oxygen; some effluents may also contain substances such as chlorine, antibiotics and hormones (used in intensive aquaculture schemes) which may affect the organisms in the natural aquatic ecosystem. Aquaculture effluents can have severe impacts on the quality of receiving waters, and should be analyzed as any other point source of pollution. *All effluents should be analyzed and treated, as necessary, before discharge into streams, rivers, and other bodies of water to prevent adverse effects upon the aquatic community and downstream users.* In many typical aquaculture operations the effluent should be used for irrigation where its load of organic matter can act as plant fertilizer.

- *Impact on local and global biodiversity* —aquaculture projects may affect natural aquatic biodiversity in a number of different ways:

  (a) direct impacts on native species through water pollution, habitat alteration, and competition from introduced species;

  (b) excessive harvest of wild young to be used as seed in commercial operations. A study supported by the multinational Bay of Bengal Program has established that only 2% of a seed fisherman's catch is composed of the desired tiger prawns (*Penaeus monodon*) post-larvae, the other 98% consisting of the "non-desirable" crustaceans and finfish that are usually thrown on the shore to die for lack of any perceived value. The total harvest of wild prawn seed in the West Bengal area is estimated at 400 million units per year, which results in the destruction of nearly 20 billion fry or juvenile stages of other species;

(c) indirect impacts when non-commercial aquatic life is harvested to be used by the fish feed industry, or when disease agents or antibiotics introduced into the environment interfere with the health of the natural system.

What is Necessary to Make Fish Farming Sustainable	...And How it Can be Done
1. Stop the Decimation of Sensitive Ecosystems	Restrict locations of fish farms to assure no net loss of mangrove forests or other threatened environments. Use biofiltration to degrade fish waste. Maintain buffers between ponds, water sources, and filtration systems.
2. Protect Local People's Traditional livelihoods	Locate farms so there is no displacing of local fishing and spawning grounds. Guarantee local people access rights to fishing grounds, forests, and agricultural land.
3. Reverse Net Protein Loss	Raise fish that require little or no fish-meal in their diets. Promote consumption of herbivorous species such as catfish, crayfish, tilapia, carp, and mollushs.
4. Stop Escapes	Ban net-cages from coastal waters. Monitor farms for escape routes, and keep cages and holding facilities in good conditions. Raise native strains rather than introduced species. Employ conventional breeding programs rather than transgenic technologies.
5. Halt Pond Abandonment	Reduce stocking rates of fish. Restrict inputs of chemicals, antibiotics, and pesticides. Allow ponds to lie fallow. Remove wastes regularly. Provide regular maintenance. Require monocultures to pay for equivalent area of land rehabilitation. Rotate crop production and maintain a variety of species.
6. Recirculate Water	Charge fish farms for water use and develop market incentives for recirculating technologies. Invest in R&D to improve recirculating technologies.
7.Integrate with Other Industries	Use household wastewater to feed fish. Use locally available ingredients to make feed. Raise hydroponic vegetables with fish. Apply fish-farm manure to agricultural land. Reuse water from fish farms for other industries. Provide tax incentives for closed-loop production and resource effciciency. Certify and label aquaculture products produced sustainably.

It is important to remember that all aquaculture schemes depend on the existence of good environmental conditions since they make use of the water and local food webs to rear their stock. For these reasons, environmental issues should receive careful consideration during all stages of the project cycle, including those issues related to the institutional arrangement responsible for monitoring and enforcing water quality standards, habitat destruction, and conservation of native biodiversity.

CONCLUSION

There are no definitive conclusions or magic formulas that tell us how to effectively integrate freshwater ecosystem function and services with water development projects. However, if we follow the basic principles described below, combined with a good dose of common sense and the available scientific knowledge on the ecology of freshwater ecosystems, we will surely get closer to achieving the ultimate goal of long-term sustainable use of the world's freshwater and aquatic resources:

- Incorporate biodiversity concerns and issues during the earliest stages of project identification, planning and design, and allow enough time for the necessary empirical studies. It is always less expensive to apply mitigation measures during construction of a project than to retrofit at a later date;
- Ensure that freshwater biodiversity is addressed through comprehensive examination of all freshwater habitats, and their biological components, in and around the project area. This assessment should consider the function of those freshwater habitats, as well as their temporal and spatial characteristics;
- Assess the current ability to determine all possible project impacts, and frame a strategy to determine any necessary additional information/study;
- Hire a competent team with proven and appropriate biological expertise;
- Ensure that data are collected in all seasons and over more than one year;
- Provide a locational context —how unusual/common is the system about to be changed;
- Ensure that a monitoring program is designed and implemented to test the predicted impacts and to provide guidance for future management;
- Adopt adaptive management strategies at all stages of the project cycle;
- Publish and disseminate the findings, thereby contributing to improving the management of freshwater biodiversity elsewhere.

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Because environmental, social and hydrological conditions vary throughout the Asia and Pacific region, this book attempts to provide a wide range of examples to allow the user to compare and contrast their own situation with documented examples. Part I of the book focuses on the functions and values of wetlands and their relationship to river basin management. It also demonstrates how they can be integrated into sustainable river basin management programs. Part II contains three detailed case studies from the Asia and Pacific region, highlighting issues relevant to Part I.

Federal Interagency Floodplain Management Task Force, US Government. Two publications address the change in US policy from one of "controlling the floods" to one of integrated flood management and hazard mitigation. Both available from the Federal Emergency Management Agency (FEMA), Washington, D.C.
a) A Unified National Program for Flooplain Management, 1994. 43 pp. In contrast to prior reports, which emphasized voluntary coordination of authorities, this Unified National Program document focuses on achieving national floodplain management goals that are both measurable and specific, and discusses the economic, environmental, and social trends affecting decisions that determine floodplain use, as well as the successes and deficiencies in the country's approaches to floodplain management.
b) Protecting Floodplain Resources: A Guidebook for Communities. 1995. 41 pp. This guidebook provides relevant information for local officials, citizens, landowners, and groups interested in protecting and restoring the natural resources and functions of floodplains. It focuses on "grass roots" efforts needed to effectively manage and protect the resources of the floodplain environment including wetlands, riparian habitats, historic sites, and aesthetic amenities. Many useful pictures and diagrams.

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The purpose of this study is to demonstrate a methodology that incorporates biological and GIS techniques to quantify fisheries habitat in the wet season in Bangladesh. The study identifies fish preference for specific depth classes of a floodplain. The study also illustrates how to measure

fisheries biodiversity, and how to relate that biodiversity to subsistence fishing activity. The methodology demonstrated in this study is *habitat-based* and is unique for Bangladesh fisheries investigations since most fisheries evaluations in Bangladesh have focused on fish catch (production as kg/ha).

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These two technical volumes contain a vast number of papers on the current knowledge about the relationship between hydraulics and freshwater habitats, and address the following broad categories:
Volume A: Direct and remote effects of civil works; Coastal-estuarian-fluvial interactions; Land uses impacts; Role of abiotic variables; Geomorphology and habitats; Ecohydrology; Fish overwintering; Impacts of logging operations; Conservation of wetlands and shore habitats; Minimum flow and adapted hydrological regime; Habitats and comprehensive management; Peak flow management; Impact mitigation measures; Water quality and habitats; Interdisciplinary approaches - partnerships.
Volume B: Instream flow needs methodology; Habitat modeling; Validation strategies of habitat models; Alternate modeling approaches; Habitat creation and restoration; Bioengineering for shore protection; Fishways and by-pass structures.

Instream Habitat Modelling: Several simulations models have been developed based on the IFIM/PHABSIM methodologies. Two sources of additional information on this topic are (a) Dr. Mike Acreman, Flow Regimes & Environmental Management Section, Institute of Hydrology, U.K. fax +44 491-832256; (b) SINTEF - The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology, fax +47 73 59 23 76.

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National Park Service. 1996. Floods, Floodplains and Folks: A Casebook in Managing Rivers for Multiple Uses. 88 pp. Contact: NPS - Rivers, Trails and Conservation Assistance Program, (202) 343-3780. This casebook illustrates projects all over the US where the project leaders used creativity, innovation, and risk-taking to achieve objectives well beyond those in the original project. Examples include: a project that originally was to be a concrete holding tank, transformed by the engineer into a contoured, vegetated detention basin with a dry-phase soccer field; in a place where rip-rap was to be used, soil engineering techniques were now employed; at public request, wildlife habitat and the preservation of an historic train depot were added to the objectives of a single-purpose floodway project. Many diagrams illustrate the case studies.

S.O.Conte Anadromous Fish Research Center. A research laboratory with large experience in designing fish ladders and fishpasses. They have experience with fish migration in several tropical countries, typically involving fish that are not as good jumpers as the salmonids. Contact: Dr. Mufeed Odeh (hydraulic engineer). One Migratory Way, Turner Falls, Massachusetts 01376. (413) 863-8994, ext 43, or ODEHM@external.umass.edu