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# Anticipation, Significance and Response to Ecosystem Impacts of Large Dams


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## List of Acronyms and Abreviations

| | |
|---|---|
| EIA | Environmental impact assessment |
| ICID | International Commission on Irrigation and Drainage |
| ICOLD | International Commission on Large Dams |
| IHA | International Hydropower Association |
| OED | Operations Evaluation Department (of World Bank) |
| WCD | World Commission on Dams |

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# Anticipation, Significance and Response to Ecosystem Impacts of Large Dams

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## Abstract

*This paper provides a brief overview of the context, scope, methodology and salient findings emerging from a survey of 125 large dams in 52 countries world-wide. This global Cross-Check Survey was one of four key work programme components integral to the World Commission on Dams, initiated in Gland, Switzerland in 1997. In particular, the paper gives a brief overview of some of the key issues responsible for significant ecosystem impacts and highlights key responses practices in a variety of different regions and countries world-wide. The issues are followed by emerging findings from the Survey, reporting on the nature, frequency, significance and accuracy of prediction of generic ecosystem impacts that occurred for the dams in the Survey sample. Inferences are also drawn from an assessment of the effectiveness of mitigation measures implemented. The Survey findings largely corroborate existing literature and hypotheses regarding ecosystem impacts induced by large dams. Certain emerging findings added new and significant insights into the variability of environmental performance of large dam projects and provide strong evidence to suggest that many ecosystem impacts (both positive and negative) remain unanticipated even in recent decades. Mitigation was the most widely practised response to ecosystem impacts for the large dams in the Survey. Yet emerging findings suggest that mitigation has failed or worked only sporadically in the case of dam-induced ecosystem impacts.*



## Introduction

Rivers are an ecological continuum and a vital source of life. This fundamental characteristic makes large dam impacts unique from those of other large-scale development projects and predisposes river fauna, flora, their habitats and livelihoods of riparian communities to far reaching consequences. The effects of such ecosystem impacts can be traced not only at the inundated reservoir site but also upstream and far downstream of the dam including river deltas and ocean coastal zones. The degree to which rivers have been subject to anthropogenic influence, is best indicated by a recent estimate claiming that dams, inter-basin transfers, and water withdrawals for irrigation have fragmented 60% of the world's rivers (Revenga et al, 1998).

Ecologically, river-related ecosystems comprise a wide range of aspects (both biotic and abiotic) of the environment linked to that river, including people. This includes not only the aquatic habitats associated with water in the river channel, but all the elements of the river catchment that contribute water, nutrients and other inputs to the river. Thus the complex of ecosystems that constitute a river basin includes: the headwaters and the catchment areas; the channel to the sea; riparian areas; subterranean flow under the channel/banks and floodplains; wetlands; the estuary and the coastal zones that are dependent on freshwater inputs. Each of these elements is interconnected through various direct or indirect links with the active channel of the river. The interaction of these elements with each other determines the ecological nature of the main river channel (Petts and Amoros 1996).

Dam-induced ecosystem impacts are often the result of complex causal mechanisms manifesting themselves in first, second or third order impacts. These impacts are varied, often having adverse effects on river health. In many cases the impacts have irreversible effects on ecological pattern and process. In addition, the biochemical cycles in natural riverine systems are disrupted and altered by the ecosystem transformation, inducing changes to the quantities of organic carbon carried downstream. This change in the flow of organic carbon effects the level of emitted greenhouse gases (GHGs), increasing emissions of methane and carbon dioxide that contribute to anthropogenic climate change. Consequently, the anticipation of the nature, magnitude and significance of ecosystem change induced by the dam project poses a challenge at the pre-project feasibility and planning stage. Further to this, the consequence of a series of dams in the same basin and particularly on the main stem of the river induces additional and often complex cumulative impacts, the effects of which are often not fully understood, accurately predicted nor mitigated effectively. Based on the influences of local climate characteristics, the specific location of the dam on the river reach, the physical attributes and function of the dam, and the natural river regime, it is possible to estimate the corresponding impacts with decreasing certainty, from direct to indirect impacts. Although many ecosystem impacts remain dam-specific, the generic nature of others is generally well known and documented in numerous (and voluminous) reports world-wide (WCD Final Report, 2000).

At a time when pressures upon the diversity and productivity of the world's natural resources continue to rise, it is argued that firm action is required to prevent loss of these resources through further dam construction (McCully, 1996). In response those engaged in the planning, construction and operation of dams argue that with continuing improvements in knowledge and technology it is increasing possible to avoid, mitigate or compensate for the environmental impacts of dams, so yielding better environmental performance (ICOLD, 1997).

Yet, even when designed to minimise environmental impacts, many dams still result in significant negative impacts to a wide range of natural ecosystems and to the people that depend upon them for their livelihood despite our improved knowledge. Also many unanticipated ecological impacts continue to occur unabated. In addition, the effectiveness of mitigation, compensation and restoration measures undertaken to address ecosystem impacts of large dams has achieved limited success. This has been partly due to the paucity of reliable data leading to a limited understanding of riverine, aquatic and terrestrial ecosystems and the scope and nature of their impacts. Also limited pre-project baseline assessments, inadequate study methodologies used, ignorance of valuable local knowledge and an overriding focus on economic and financial issues during earlier decades, have hindered effective outcomes of predictions and responses to ecosystem impacts. Notwithstanding, that certain impacts are not possible to mitigate.

A further complicating issue emerges from a closer look at the 1999 International Commission on Large Dams' (ICOLD) register. Interestingly, two-thirds of the world's large dams are small – between 15 metres and 30 meters in height. This coupled with the fact that environmental transformation is often too slow to track visibly, many dam-induced ecosystem impacts go unmeasured or even unnoticed. Moreover, we are only beginning to understand the role of scale, cumulative impacts and multiplier effects today. In recent decades, however, there can be no doubt that adverse environmental and social consequences of large dams have increasingly drawn attention. A catalyst contributing to the emergence of these issues has been the growing notion of sustainability that has begun to influence conventional development paradigms.

Yet the exact magnitude and significance of dam-induced ecosystem impacts and effectiveness of responses remain contended by critics and continue to fuel controversy in the large dams' debate. It was out of this controversy that the World Commission on Dams (WCD) was borne in Gland, Switzerland in 1997.

The nature of these controversies over ecosystem impacts and responses undertaken set the context for initiation of a global survey to determine, among others, patterns and trends of ecosystem impacts and responses from a select sample of large dams. Before describing the Survey components and presenting results, it is first pertinent to outline some of the key issues regarding dam-induced ecosystem impacts and responses. Due to the complexities and the large number of environmental issues involved, this section is far from exhaustive. Rather it describes succinctly, a few strategic issues relevant to providing an understanding of particular issues applicable to the Survey indicators and findings that follow.



## Key issues: dams, ecosystems, impacts and practised responses

Ecosystems comprise a mix of interdependent biotic and abiotic factors characterised by pattern (biodiversity) and processes that maintain those patterns indefinitely. These factors consist of physical, biological or chemical components such as soils, water, plant and animal species, and nutrients. Processes among and within these components allow the ecosystem to perform certain functions such as flood control and storm protection, and generate products such as wildlife, fisheries and forest resources. There are also ecosystem scale attributes such as biological diversity and cultural uniqueness/heritage that have value either because they induce certain uses or because they are valued themselves. It is the combination of these functions, products, and attributes that make ecosystems important to society. Whether a natural or man-made ecosystem performs a certain function, yields specific products, or possesses certain attributes, is determined by the interaction between chemical and physical characteristics of the site. Characteristics vary greatly between and within each major ecosystem group. Ecosystem functions can be grouped into four categories: regulation functions, habitat functions, production functions, and information functions (WCD Thematic II.1, 2000).

The hydrological cycle provides an important linkage between the components. Another important linkage is formulated in the 'flood-pulse' concept that describes the periodic, two-way exchange of nutrients between the main river channel and riparian ecosystems (Junk et al. 1989, Bayley 1995, Sparks 1995) (see Box 2.1).

**Box 2.1 Important ecological concepts of rivers and floodplains.**

1. The "river continuum concept" encompasses the linkages upstream and downstream from a river's source to the coastal zone, including any deltas or lagoon systems. This concept includes the gradual natural changes in river flows, water quality and species, that occur along the rivers length. Nutrients and sediment generated in the headwaters are recycled downstream driving plant growth and biotic productivity. One of the most obvious characteristics of the river continuum concept is the migration of fish from the sea to spawning grounds in the headwaters. River engineering projects, such as dams, break this continuum causing radical changes in flows, water quality and stopping the movement of species.

2. The "flood pulse" concept is based on the importance of lateral connectivity between rivers and their floodplains and sees the inundation of floodplains as the main driving force behind river life, not as a problem that needs eradicating. Rivers provide the floodplain with nutrients and sediment, whilst the floodplain provides a breeding ground for river species and improves water quality through settlement of sediment and absorption and re-cycling of nutrients and pollutants.

*Source: Junk et al. 1989, Bayley 1995, Sparks 1995*



In order to understand the relationship between large dams and the river(s) on which they are built, it is essential to understand the nature and values of the different ecosystems along a river's course from its catchment to the sea. To maintain natural ecosystem goods and services it is essential to conserve and sustainably manage ecosystem pattern and process. Together they form the integrity of healthy ecosystems. For the maintenance of healthy river ecosystems, the integrated management of land and water resources is required within an entire river basin. Hence the environmental consequences of the construction of a dam should not be seen in isolation but must be considered within the context of the whole river basin, including the coastal zone. (WCD Thematic Review II.1, 2000).

In order for ecosystem impacts to be avoided, minimised or managed properly, they have to be understood and predicted. An important distinction to make here is the inaccurate perception by some that *impact* implies solely negative effects. This is not the case. Impacts can be positive.

There are different types of dams each with their own operating characteristics. Similarly, dams have been built in a wide array of conditions, from highlands to lowlands, temperate to tropical regions, fast flowing to slow flowing rivers, urban and rural areas, etc. The combination of dam types, operating systems, and the contexts where they are built, yields a multitude of conditions that are site specific and variable. Although this complexity clouds the ability to predict impacts of dams on ecosystems, as each specific context is likely to have varying significance and magnitude. However, at a certain level of generality some indications can be given of the most likely impacts and their relative order. The Cross-Check Survey results which follow provide consequential insights into these generic patterns and trends.

The generalised impacts of dams on terrestrial ecosystems and biodiversity are also well documented. However, specific aspects such as the net emissions of greenhouse gases from a particular dam site, cannot be predicted with much certainty at present with continued disagreement over the methodological approach.

Downstream impacts on aquatic ecosystems and biodiversity and on floodplain ecosystems represent the sum of many complex interactions and thus are inherently difficult to predict where baseline data are absent or unreliable. However, the overall direction of the impacts is generally negative. For the case of floodplain effects, the impact of large dams on these ecosystems varies. With regard to fisheries, while it appears that the effect on species composition is generally negative at all levels (upstream, reservoir and downstream), downstream losses in productivity may be accompanied by increases in reservoir fishery production (WCD Thematic II.1, 2000). However, it is not meaningful to adopt a balance sheet approach to offsetting these issues as they remain independently significant regardless of the net effect.

Multiple dams on a river significantly intensify the impact on ecosystems. Sediment entrapment can reach 99% if a cascade of dams is developed. Fish migration is affected even by a single dam and multiple dams worsen risk of species loss dramatically. In the Northern hemisphere 77% of the largest rivers are affected by dams and on many rivers natural or *intact* reaches are restricted to catchment areas. Further, the global impacts of dams on the global water cycle are increasingly recognised (WCD Thematic II.1, 2000).

In summary, past anticipation and prediction of ecosystem impacts was limited, in part due to a lack of reliable baseline data, scientific uncertainty regarding the nature of the interactions, inadequate attention paid to these issues and a correspondingly limited ability to model these complex systems. While improvements in measurement, scientific understanding and modelling capability have been made, many ecosystem impacts remain site-specific. Their exact nature cannot be predicted in the absence of appropriate field studies of individual river systems.



Regarding responses to ecosystem impacts of large dams, supporting literature revealed that efforts to avoid or minimise impacts through alternative designs or projects were more effective than reactive responses post dam design. Avoidance and minimisation of impacts, by their very nature, reduce ecosystem impacts on the site concerned. But where alternative sites or designs have been chosen, the net consequences for ecosystems have rarely been recorded. Project planners and proponents have employed five principal measures to respond to ecosystem impacts:

- measures that avoid the anticipated adverse effects of a large dam through the selection of alternative projects;
- minimisation of impacts by modifying project design features;
- mitigation measures that are incorporated into a new or existing dam design or operating regime in order to reduce ecosystem impacts to acceptable levels[1];
- compensation for unavoidable residual effects by enhancing ecosystem attributes in watersheds above dams or at other sites; and
- ecosystem restoration (WCD Final Report, 2000).

[1] The term mitigation is used to describe the reduction of potentially significant adverse

The primary option for avoiding ecosystem impacts from large dams has been to not build the dams in the first place. This is given a legal basis in several countries where legislature protects particular river segments or basins from re-regulation or development (WCD Thematic II.1, 2000). Efforts to minimise the impacts of changes in flow regime have relied on measures to restore the streamflow regime through carefully derived environmental flow releases (EFR) (see Box 1).

**Box 1 Environmental flow requirements**

At least twenty-nine countries seek to minimise ecosystem impacts from large dams by using an EFR to meet predetermined ecosystem maintenance objectives. The practice of EFRs began as a commitment to ensuring a 'minimum flow' in the river (often arbitrarily fixed at 10% of mean annual runoff). It has since grown to include a definition of ecosystem requirements and a planned flow release programme, which may vary annually or seasonally, to meet downstream needs for both the environment and people. The level of EFR required is determined by the need to maintain particular ecosystem components downstream, often with reference to national legislation. The countries that use this method have recognised that a short-term reduction in financial returns from a project often leads to improved long-term sustainability and attainment of broader societal objectives for a healthier environment. Still, this represents a re-distribution of the benefits of a dam project and thus existing beneficiaries such as irrigators and operators of hydropower facilities may resist EFRs.

*Sources: Brown et al, 1999, Contributing paper for WCD Thematic Review II.1 Ecosystems; Tharme, 2000.*



An increasing number of countries are using environmental flow requirements to minimise downstream impacts sometimes in the form of managed floods. Good site selection, such as not building large dams on the main stem of a river system, and better dam design also played significant roles in avoiding or minimising impacts (WCD Thematic II.1, 2000).

A key issue that has been the centre of much controversy is the impacts that dams have had on migratory fish. Whilst attempts have been made to mitigate these impacts through response such as fish passes, diversion channels, and other mechanisms, the ability to accommodate species sensitivities have posed a formidable challenge (see Box 2).

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environmental impacts to acceptable levels.

**Box 2 Mitigation measures practised with respect to impedance of migratory fish**

Fish passes are often used as an engineered mitigation measure for reducing impacts on fish. However, very few of the over 400 large dams in Australia have fish passes of any description, only 16 had been constructed on the 450 large dams in South Africa by 1994, and only 9.5% of 1 825 hydropower dams in the United States have an upstream fish pass facility. An example is Idaho Power Company which built fish passes into each of its dams in the Hells Canyon Complex. However, all were unsuccessful and salmon no longer migrate above Hells Canyon Dam. Even when fish passes have been installed successfully, migrations can be delayed by the absence of navigational cues, such as strong currents. This causes stress on the energy reserves of the fish, as anadromous fish (fish that spawn upstream in rivers) such as salmon do not feed during migration. Recent research in Australia, the United States, and Japan has shown that fish passes need to be modified to meet the needs of each species and the particular situation at each dam. They cannot simply be considered an easily transferable technology, as shown by the Pak Mun dam in Thailand where the fish pass, which used a design appropriate for leaping trout and salmon in mountain streams, was ineffective for species living in the slower-flowing Mekong.

*Sources: Australia: Blackmore, per comm 2000; South Africa: Benade, per comm 1999; USA: Francfort et al, 1994;Collier et al, 1996, p22; Larinier, 2000, Contributing paper for WCD Thematic Review II.1 Ecosystems.*



In response, a recent paper by the International Energy Agency, *Hydropower and Environment*, formulated policies to support better initiatives for avoiding, minimising and responding to the adverse ecosystem impacts induced by hydropower dams. These include:

- integrating the preservation of biodiversity and productivity in project designs;
- optimising flow regimes downstream of a reservoir;
- improving fish passages for valuable migratory species at dam sites;
- improving sedimentation management in reservoirs;
- limiting water quality problems through good site selection; managing reservoir eutrophication and contamination problems during operation (IEA, 2000).

These policies provide a way forward for dam operators and new development projects in the pipeline. But evidence to suggest whether many of these efforts will take effect is to be highlighted in the Survey findings further in this paper.

## Survey Overview: Scope, Sampling Technique and Methodology

The global Cross-Check Survey formed one of four key work programme components of the WCD. A pilot study using trial questionnaires was conducted on the Orange River Basin in South Africa to assess the effectiveness of questionnaire design and degree of response. The revised Survey questionnaire was subsequently disseminated globally for reporting. The specific objectives of the Survey with regard to ecosystem issues were to determine:

- generic trends and patterns of the nature, frequency, significance and accuracy of predictions for dam-induced ecosystem impacts that occurred
- to investigate the nature and effectiveness of responses to ecosystem impacts

While the Survey does not claim to be statistically representative, the findings provide generic entry points to better inform the dams debate and further studies than has been achieved previously. The Survey findings are indicative of the larger population currently in the order of 45 000 large dams (ICOLD, 1998). In addition, the Survey did not assess individual projects.

A variety of large dams of different types (e.g. storage, run-of-river), ages (e.g. dams from the 1930's through the 1990's), functions (e.g. water supply, irrigation, hydropower, flood control, multi-purpose and other), heights, areas, ownership (e.g. public, state and private), and regional locations were included. Each dam questionnaire provided date records with time series dimensions where feasible. Analysis was performed on the full set and on sub-sets of dams in the sample. Large dams were added from previous studies or surveys but new data for these was collected. The Cross-Check analysed several different sub-samples that were selected to reflect the greater regional populations (Cross-Check Survey, 2000).

A select number of case study dams investigated in-depth by the WCD and a selection of particular dams from river basin formed the first two sub-samples. Inevitably, the selection of these two sub-samples involved an element of bias due to the criteria used in selecting them. The remainder of the sample aimed to eliminate many aspects of this selection bias – that is, to correct for the over-representation of specific attributes such as size, location, purpose and age. The third sub-sample aimed to build on dams from existing surveys by selecting a sub-sample of the dams examined in the 1996 World Bank Operations Evaluation Department (OED) desk study of 50 large dams. Specifically, dams were chosen to represent regions, countries and purposes not reflected in the first two sub-samples. Representations of dams from additional countries were introduced by incorporating dams from WCD country studies of India, China and the Russian Federation into the fourth sub-sample (Cross-Check Survey, 2000).

A random sampling technique was adopted for the fifth and final sub-sample in the sampling process. This was done in order to preclude the possibility that some dams and issues might be overlooked or insufficiently studied by the use of selection criteria applied to the first four sub-samples. Random schemes eliminate many aspects of selection bias. To meet this requirement, the WCD used the 1998 ICOLD World Register of Large Dams to select a sub-set of complementary dams. This was the best available information on the current global population of large dams, but excluded a significant number of large dams in China, the consequence of which should not be discredited. More dams were selected from countries with larger numbers of dams, but with some attempt to achieve a balance of dams of height greater than 15 metres, across dam age, size and purpose (WCD Cross-Check Survey, 2000).

The diversity of large dams that made up the Cross-Check Survey sample can be summarised to comprise dams:

- from different regional locations;
- of differing ages – dating from the 1930s through to the1990s;
- with a range of different heights and sizes; and
- with different purposes such as water supply, irrigation, flood management, power and recreation.

After rigorous analysis of the data with regard to various cross-classifications made, conditional inferences were drawn. Statistical significances were largely omitted due to a relatively small sample size compared to the current global population of large dams. Descriptive and informational objectives were chosen as a higher priority, by the WCD. The performance measures of the Cross-Check findings were limited to predicted versus actual nature and therefore did not capture the performance of the dams relative to pre-project conditions. Although this is a limitation of the Survey, in most cases reliable pre-project data records capturing the required levels of detail simply do not exist (WCD Cross-Check Survey, 2000).

## Survey Contributors and Data Collection Procedure

Data for the WCD dams was collected in conjunction with the execution of the in-depth case studies, while information for dams drawn from other databases underwent supplementation and verification. The data for the complementary subset of large dams was collected by commissioned contributors and/or submitted by parties with access to the required information. The approach for developing the data records for the dams in the Survey included research of published reports, secondary data sources available in the public domain and data records sought through contact with a variety of organisations from dam operators and utilities, key government departments and river basin authorities, to local research institutions/universities, professional international bodies and NGO networks (WCD Cross-Check Survey, 2000).

The Survey process ensured that all submissions were contained data accessed from at *least two* independent source documents. Contributors were requested to invite participation and cite any divergent perspectives from stakeholders where possible. The 125 large dam projects analysed span more than 50 countries in six major regions of the world. Submissions were received from:

- over 70 contributors, consisting of 40% government departments/utilities, 40% private consultants/companies and 20% NGO/academic/research institutions;
- an additional 30 contributors that reviewed a select sample of 17 randomly chosen and 18 controversial projects for independent data verification. The reviewers were predominantly local NGOs who provided a check to the government and private contributions.

To enhance credibility and confidence in results, extensive safety nets for data verification and refinement were implemented. Not only was it imperative to create a balanced multi-stakeholder input but it was necessary to accommodate a series of iterative steps to enhance both the quality and quantity of submitted data. The collective 'checks' of these safety nets were designed to optimise the integrity of data analysed and the revisions and iterations of questionnaires received yielded improvements in almost all cases (WCD Cross-Check Survey, 2000).

## Use of Indicators and Analytical Approach

Whilst drawn directly from the data fields of the Survey questionnaire, care was taken to harmonise the indicators with internationally acceptable measures for similar aspects of large dam and other large-scale development projects. Subsequently, quantitative and qualitative indicators were derived for all 125 dams in the final verified sample across three primary categories: performance; social and environmental impacts; and decision-making. For the purposes of this paper, only the analytical approach for the derivation of environmental impact indicators is presented and discussed (WCD Cross-Check Survey, 2000).



The examination of the trends and patterns relating to the Survey dams was structured around indicators responding to questions such as:

- What were the frequencies of anticipated to unanticipated impacts, and the degree to which these are positive or negative?
- What were the most significant environmental impacts and how effectively were they mitigated?
- What the accuracy of prediction of compensation costs paid for loss of fisheries and other ecosystem resources?

Interpretations of the Cross-Check indicators were accomplished through a combination of data manipulations deterministic in nature, but supplemented by accompanying narratives provided by many contributors. The latter provided contextual orientation for certain figures to avoid misrepresentation. The analysis performed to derive environmental impacts consisted predominantly of determining specified activities reported in the questionnaires. Frequency histograms and cross-tab counts of binary information ("yes" or "no" data fields) across the various classifications were performed. The interpretations were mostly inferred from graphs in conjunction with basic statistics. All data was represented at the case (dam) level but findings were inferred from the aggregate or collective results of all dams in the sample (WCD Cross-Check Survey, 2000).

Box 3 details the indicators and specific related question(s) to be answered for determining the change in predictions, frequency, significance and assessment of mitigation effectiveness.

Patterns and trends were inferred from the prepared graphs in the Cross-Check Report. Where possible, appropriate scientific or other explanations were given to justify emergence of particular trends or patterns.

**Box 3 Cross-Check Survey Environmental Indicators**

**Anticipated & Unanticipated Ecosystem Impacts:**

a) What was the % anticipated to unanticipated impacts experienced by the ecosystem components and functions?
b) What was the % of anticipated to unanticipated impacts having a positive / negative affect on the ecosystem components and functions?
c) What is the frequency of unanticipated ecosystem impacts per ecosystem component?

**TOP 5 Ranked Ecosystem Impacts:**

What were the top 5 ecosystem impacts ranked in order from most significant to least significant?

**Planned Mitigation Measures:**

a) What % of mitigation measures implemented were planned?
b) What % of design & operation measures implemented had mitigation planned?

**Effectiveness of Mitigation Measures:**

What are the proportional %'s for three degrees of mitigation effectiveness: (1) very effective; (2) moderately effective; (3) not at all effective

**Actual to Planned Compensation Costs paid:**

What were the actual compensation costs paid for loss of environmental goods and services to planned?

*Source: WCD Cross-Check Survey, 2000*

## Key findings and discussion of the Survey results

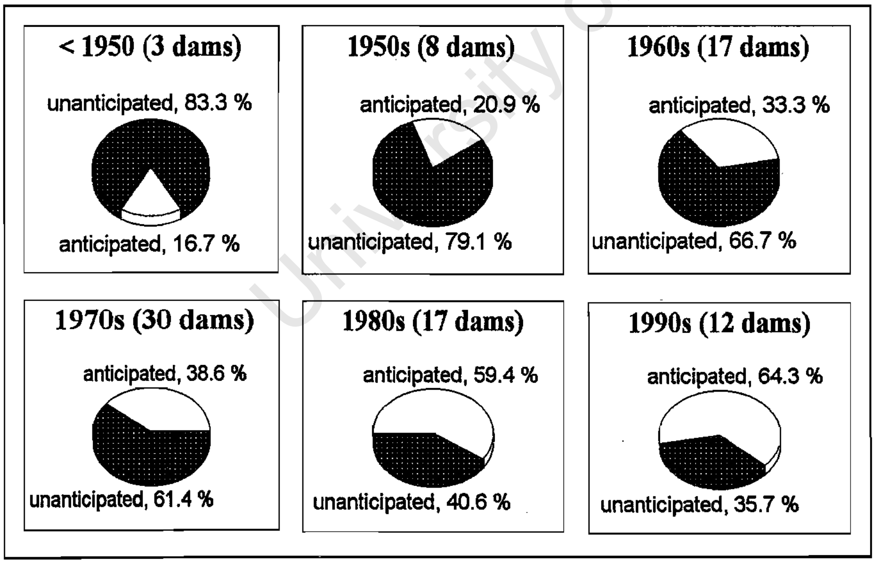
The Cross-Check Survey produced significant evidence to suggest that with respect to large dam-induced ecosystem impacts, most are unanticipated and negative but have been increasingly anticipated over time. The detailed results are presented and discussed below.

### Anticipation and prediction of ecosystem impacts

The Cross-Check Survey found that for the 87 projects that provided data on ecosystem impacts, almost 60% of the impacts identified were unanticipated prior to project construction, largely due to inadequate studies. While the sample size is small for some time periods, the Cross-Check also suggests that over time the trend is increasingly to anticipate impacts (see Figure 1). This confirms the expectation that the trend towards the use of environmental impact assessments (EIA) would result in improved identification of potential impacts (WCD Cross-Check Survey, 2000).



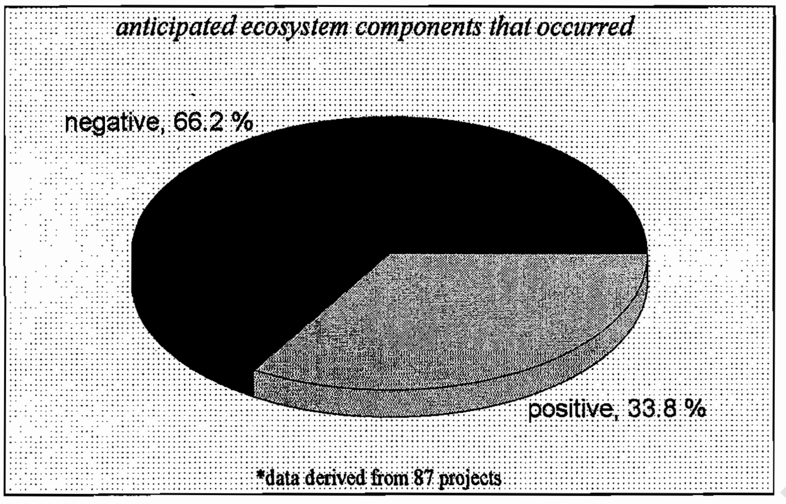
**Figure 1 Anticipated and unanticipated ecosystem impacts**




*Source: WCD Cross-Check Survey, 2000*

Anticipating an impact is, however, not synonymous with accurately predicting the nature, magnitude or significance of its effect on ecosystems and biodiversity. Nor is it a guarantee of understanding the further impact on livelihoods and economic welfare. Beyond the apparent tendency to anticipate the majority of ecosystem impacts, the Survey further found that for 87 projects that contributed to the ecosystem data, two-thirds of the ecosystem impacts occurring had negative consequences (see Figure 2) (WCD Cross-Check Survey, 2000).

**Figure 2 Anticipated ecosystem impacts having positive or negative consequences**

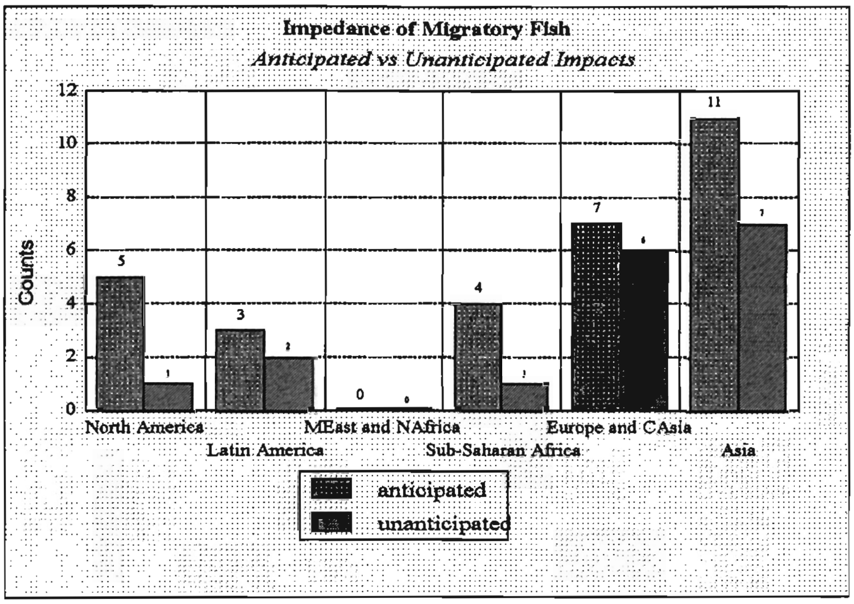



*Source: WCD Cross-Check Survey, 2000*

## Significance of Ecosystem Impacts

Arising from the frequency of negative impacts on ecosystems discussed previously, it is understandable that the impact of large dams on freshwater species is significant. The Cross-Check Survey found that impeding the passage of migratory fish species was the most frequently observed ecosystem impact, recorded at over 60% of the projects for which responses on environmental issues were given. In 36% of these cases, the impact of the large dam on migratory fish was not anticipated prior to the project. Within regions, the predictions for anticipating these negative impacts on migratory fish too have varied (see Figure 3) (WCD Cross-Check Survey, 2000).

**Figure 3 Regional counts of prediction regarding impedance of migratory fish**




*Source: WCD Cross-Check Survey, 2000.*Note: the data for this graph is not normalised across regions - i.e.. the data does not account for the different number of dams in each region. Therefore, comparison across regions in this instance is inconsequential.*

Of those ecosystem impacts ranked most significant, more than one-quarter of the dams marked impedance of migratory fish as the overriding negative impact. After impedance of migratory fish species, the next five ecosystem impacts occurred within three percent of each other in the sample. The top six ecosystem impacts ranked by significance (in descending order) are listed in Table 1.

**Table 1 Ranked ecosystem impacts by significance**

| Rank | Ecosystem Impact |
|---|---|
| 1st | impedance of migratory fish |
| 2nd | reduced water quality |
| 3rd | bioproductivity at the reservoir$^{\phi}$ |
| 4th | geomorphological change along the river |
| 5th | bioproductivity downstream of the reservoir |
| 6th | flooding of the downstream floodplain |

*Source: WCD Cross-Check Survey, 2000*

It is important to clarify that the impacts for bioproductivity at the reservoir and flooding of downstream floodplains were both positive and negative in the majority of cases reported. An example of the former impact might be the immediate benefit to communities of enhanced fish yield as a result of the reservoir in juxtaposition to the change in the evolution of all biotic species including fish and the corresponding unknown longer-term effects on biodiversity. However, in order to determine the overall effect of the ecosystem impacts discussed in this section, the magnitude of each must be taken into account with its corresponding significance. The magnitudes of impacts remain site specific, unpredictable and require extensive pre-project baseline studies to better predict the scale and reversibility through avoidance, minimisation and effective mitigation techniques. Interestingly, the six ecosystem impacts listed were also the most frequently occurring for the dams in the Survey sample (WCD Cross-Check Survey, 2000).



## Avoidance, minimisation, mitigation and ecosystem compensation

Mitigation was the most widely practised response to ecosystem impacts for the large dams in the Survey. Mitigation has failed or worked only sporadically in the case of fish passes. Of 87 projects for which ecosystem impacts were recorded, mitigation was undertaken for less than one-quarter of the anticipated ecosystem impacts – i.e. in 10% of all ecosystem impacts that occurred (see Figure 4 a). Of these projects, 47 also recorded the effectiveness of mitigation measures implemented. Respondents stated that about 20% worked very well, 40% did not mitigate the impact, and 40% were average (moderately effective) (see Figure 4 b).

Thus, only a small percentage (less than five percent) of ecosystem impacts that occurred across the sample of dams, were actually mitigated effectively. Notwithstanding the facts that some ecosystem impacts are not mitigable and that certain ecosystem impacts are irreversible (WCD Cross-Check Survey, 2000).

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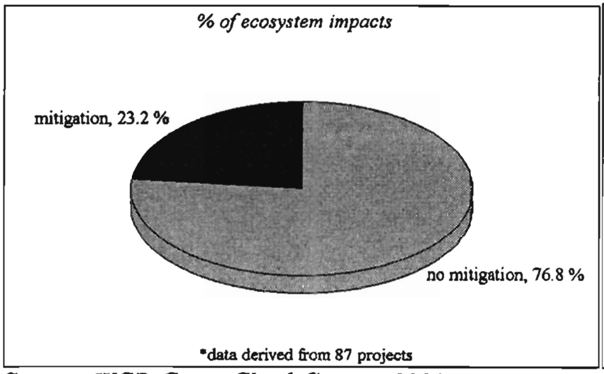
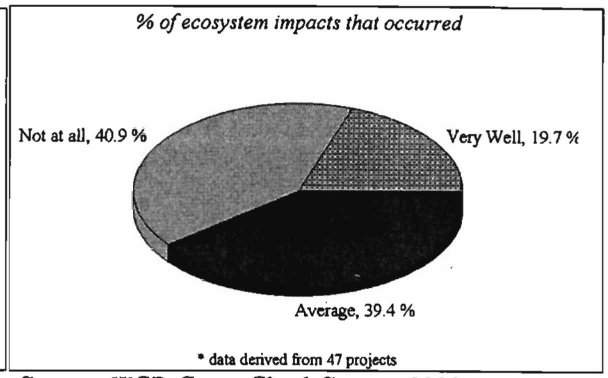
$^{\phi}$ bioproductivity refers to the production of biotic species at the reservoir site and downstream of the dam, but with particular regard to fish species.

**Figure 4 a&b Degree of planned mitigation and effectiveness of measures implemented to minimise and restore ecosystem impacts**




*Source: WCD Cross-Check Survey, 2000*




*Source: WCD Cross-Check Survey, 2000*

It was suggested in a review response to the Survey submitted by the International Rivers Network (IRN) that the categories for measuring mitigation should preferably be 'enhanced, maintained or declined' (IRN, 2000). Arguably, this may present a more accurate categorisation of mitigation effectiveness. However, scepticism regarding the accuracy of measurement of such categorisations due to the paucity of mitigation assessment data still experienced, were the overriding motivations for adopting a simpler classification (WCD Cross-Check Survey, 2000).

For the 13 dams, analysis of compensation costs shows an average tendency to under-compensate when compared to planned targets. The average actual compensation costs for these dams was 90% of predicted targets. The extreme variability indicates that each dam is its own unique case with overestimates in one case of fivefold as compared to a 100% overrun from targeted planned compensation cost. The compensation cost underruns could be the result of several factors.

## Implications for new and existing dams, and further studies

It is clear from the findings of the Cross-Check Survey that even with improved knowledge currently available, a significant proportion of ecosystem impacts induce by large dams remain unanticipated. The implications of this have had far-reaching consequences on river health and require focused attention when assessing dams as the preferred development option. In addition, extensive ecosystem baseline studies are required as early in the project phase as possible and should take particular cognisance of the value that local knowledge can add. These baseline studies should account for the most significant emerging impact – that being on migratory fish – as recorded by the Survey.

Efforts to minimise, reduce and rectify ecosystem impacts have on the whole been moderately effective to ineffective. However, there is case-specific evidence of effective mitigation undertaken for particular impacts that occur. This success is nevertheless conditional upon restrictive conditions of:

- reliable information and professional capacity to assess the complexities required to inform decision-makers;
- adequate legal frameworks and compliance mechanisms;
- collaboration between designers and stakeholders and iterative opportunities for informing the planning and design phase of the project;
- effective monitoring through appropriate methodologies and measurement to evaluate effectiveness of mitigation; and
- adequate financial resources and institutional capacities (WCD Thematic II.1, 2000).

Absence of any of these conditions is likely to render mitigation attempts unsuccessful. Mitigation, though often possible in principle, can present many uncertainties *in situ* and is therefore at present not a credible option in all cases and all circumstances. In addition, the constraints and limitations of EIAs conducted for many projects reduce the possibilities of positive outcomes (WCD Thematic V.2, 2000). The implications are that the use of alternative strategies rather than simply one of mitigation need to be considered. An additional point worth noting is that no experience exists with minimising, mitigating, or compensating GHG impacts. Pre-inundation removal of vegetation is one alternative, but the net effects of such an activity are not well established. The outcome of global negotiations on climate change may bear on future penalties and incentives for net GHG emissions from dams (WCD Final Report, 2000).

Further, it may be probable that the dams in the Survey sample under-compensated due to the tendency of most of the projects to incur capital cost overruns, compensation budgets come under pressure and are adjusted accordingly. This is an area that requires further research in order to establish the validity of this presumed correlation.

Projects 'in the pipeline' and new projects to be built should undertake comprehensive reviews of potential avoidance and minimisation options, as early in the project planning cycle as possible, in order to enhance environmental performance. In addition that avoidance of impacts should take precedence over mitigation or minimisation responses and enhancement programmes should be implemented where the health of the affected rivers are declining. Furthermore, management systems and action plans for monitoring ecosystem impacts including those downstream of large dams should be given due attention. To achieve these goals, decision-making aspects require refocusing to place ecosystem aspects at least on par with technical and financial issues that still dominate the direction of decisions made over large dam projects today.

The technical and operational limits of large dams should accommodate adaptive operational procedures catering for minimisation, compensation and mitigation of impacts. Non-conformance to threshold criteria set for EFRs and managed floods should influence decision-makers to seriously consider more sustainable and environmentally benign project alternatives that will meet the same development goals. Importantly, the findings and existing literature show poor prediction of generic ecosystem impacts suggesting that environmental goods and services provided by the ecological continuum of a river remain undervalued.



## References

Acreman M, Farquharson F, McCartney M, Sullivan C, Campbell K, Hodgson N, Morton J, Smith D, Birley M, Lazenby J, Wingfield R, Berbier E, (2000) *Managed Flood Releases from Reservoirs: Issues and Guidance*, Contributing paper to WCD Thematic Review IV.4 Flood Control, Report to DFID and the World Commission on Dams, Wallingford, UK.

Benade, per comm (1999) South Africa.

Blackmore, per comm (2000) Australia.

Brown et al, (1999) Contributing paper for WCD Thematic Review II.1 Ecosystems.

Collier M, Webb RH, Schmidt JC, (1996) Dams *and Rivers: A Primer on the Downstream Effects of Dams*, US Geological Survey Circular 1126.

IEA, (2000) *Implementing Agreement for Hydropower Technologies and Programmes. Annex III Hydropower and the Environment: Present Context and Guidelines for Future Action*, International Energy Agency.

International Rivers Network (IRN), (2000) *Comments from IRN on the WCD Cross-Check Sheets*, August.

ICOLD, (1997) *ICOLD Position Paper on Dams and the Environment*, Paris, International Commission on Large Dams.

ICOLD, (1998) *ICOLD World Register of Dams*, Computer Database, Paris, International Commission on Large Dams.

Larinier, (2000) Contributing paper for WCD Thematic Review II.1 Ecosystems. World Commission on Dams.

McCully, P. (1996) *Silenced Rivers: the ecology and politics of large dams*. Zed Books, London.

Petts, G.E. (1984) *Impounded rivers*, Chichester, UK, John Wiley & Sons Ltd. Publishers.

Revenga CS, Murray J, Abramowitz, Hammond A, (1998) *Watersheds of the World: Ecological Value and Vulnerability*, The World Resources Institute and Worldwatch Institute.

WCD Cross-Check Survey, (2000) *Cross-Check Survey Final Report*: A report for the World Commission on Dams.

WCD Thematic Review (2000) *II.1 Dams, Ecosystem Functions and Environmental Restoration*, pp. xii, section 4.2.1., section 6.2., pp.14. World Commission on Dams.

WCD Thematic Review (2000) *V.2 Environmental and Social Assessment*, section 2.5. World Commission on Dams.

WCD, (2000) Draft Report of the World Commission on Dams, September.