Hydropower and the Environment:

Effectiveness of Mitigation Measures

IEA Technical Report

ANNEX III — SUBTASK 6

IEA Hydropower Agreement

CANADA CHINA FINLAND FRANCE JAPAN NORWAY SPAIN SWEDEN UNITED KINGDOM

OVERVIEW OF THE IEA IMPLEMENTING AGREEMENT FOR HYDROPOWER TECHNOLOGIES AND PROGRAMMES

The Hydropower Implementing Agreement is a collaborative programme among nine countries: Canada, China, Finland, France, Japan, Norway, Spain, Sweden and the United Kingdom. These countries are represented by various organizations including electric utilities, government departments and regulatory organizations, electricity research organizations, and universities. The overall objective is to improve both technical and institutional aspects of the existing hydropower industry, and to increase the future deployment of hydropower in an environmentally and socially responsible manner.

HYDROPOWER

Hydropower is the only renewable energy technology which is presently commercially viable on a large scale. It has four major advantages: it is renewable, it produces negligible amounts of greenhouse gases, it is the least costly way of storing large amounts of electricity, and it can easily adjust the amount of electricity produced to the amount demanded by consumers. Hydropower accounts for about 17% of global generating capacity, and about 20% of the energy produced each year.

ACTIVITIES

Four tasks are operational, they are: 1. upgrading of hydropower installations, 2. small scale hydropower, 3. environmental and social impacts of hydropower, and 4. training in hydropower. Most tasks have taken about five years to complete, they started in March 1994 and the results will be available in May 2000. To date, the work and publications of the Agreement have been aimed at professionals in the respective fields.

UPGRADING

The upgrading of existing hydropower installations is by far the lowest cost renewable energy available today. It can sometimes provide additional energy at less than one tenth the cost of a new project. One task force of the Agreement is studying certain technical issues related to upgrading projects.

SMALL SCALE HYDROPOWER

Advances in fully automated hydropower installations and reductions in manufacturing costs have made small scale hydropower increasingly attractive. The small scale hydropower task force will provide supporting information to facilitate the development of new projects.

ENVIRONMENTAL AND SOCIAL ISSUES

For some hydropower projects the environmental and social impacts have been the subject of vigorous debate. There is a need to communicate objective information to the public, so that countries can make good decisions with respect to hydropower projects. The environmental task force will provide such information on possible social and environmental impacts and on mitigation measures.

TRAINING

The availability of well-trained personnel is a key requirement in the hydropower sector. The training task force is concentrating on training in operations and maintenance, and planning of hydro power projects.

The International Energy Agency
Implementing Agreement for Hydropower
Technologies and Programmes

Hydropower and the Environment:

Effectiveness of Mitigation Measures

IEA Hydropower Agreement

The views presented in this report do not necessarily represent the views of the International Energy Agency, nor the governments represented therein.

April 2000

Annex III — Preface

The International Energy Agency (IEA) is an autonomous body, established in November 1974 within the framework of the Organization for Economic Co-operation and Development (OECD). The IEA carries out a comprehensive programme of energy co-operation among 24 of the OECD's 29 member countries. The basic aims of the IEA, which are stated in the *Agreement on an International Energy Programme*, are the following:

- Co-operation among IEA participating countries to reduce excessive dependence on oil through energy conservation, development of alternative energy sources, and energy research and development
- An information system on the international oil market as well as consultation with oil companies
- Co-operation with oil producing and oil consuming countries with a view to supporting stable international energy trade, as well as the rational management and use of world energy resources in the interest of all countries
- A plan to prepare participating countries against the risk of a major disruption of oil supplies and to share available oil in case of an emergency.

At its inception, the IEA concentrated on issues related to oil. Since that time the Agency has broadened its work to include all forms of energy. More than forty «Implementing Agreements» have been set up to deal with specific energy technology issues. Such Agreements comprise a number of task forces, called «Annexes», which implement specific activities such as collection of data or statistics, assessment of environmental impacts, joint development of technology etc. The work of these Annexes is directed by an «Executive Committee» consisting of representatives of the participating Governments.

In 1995, seven IEA member countries agreed to co-operate in a five-year research program focused on hydroelectric power formally called the *Implementing Agreement for Hydropower Technologies and Programmes*. Italy withdrew, but France, United Kingdom and People's Republic of China subsequently joined the remaining countries. This Agreement proposed that four distinct Task Forces («Annexes») should be set up to address the following topics:

Annex I: Upgrading of Existing Hydropower Facilities

Annex II: Small-Scale Hydropower

Annex III: Hydropower and the Environment

Annex V: Education and Training

Annex III "Hydropower and the Environment" entered into force in February 1995 with the following principal objectives:

- To arrive at a set of international recommendations for environmental impact assessment of hydropower projects, and criteria for the application of mitigation measures
- To improve the understanding of hydropower's environmental advantages and suggest ways to ameliorate its environmental drawbacks

- To forward national experiences regarding environmental effects of hydropower development at a project level and the legislation and decision making process at a national level
- To provide an environmental comparison between hydropower and other sources for electricity production

To achieve these goals the following Subtasks have been implemented:

Subtask 1 : Survey of the environmental and social impacts and the effectiveness of mitigation measures in hydropower development *(Subtask leader: NVE, Norway)*

Subtask 2 : Data base (included in Subtask 1)

Subtask 3 : Environmental comparison between hydropower and other energy sources for electricity generation *(Subtask leader: Vattenfall, Sweden)*

Subtask 4 : Survey of existing guidelines, legislative framework and standard procedures for environmental impact assessment related to hydropower development *(Subtask leader: UNESA, Spain)*

Subtask 5 : Present context and guidelines for future action *(Subtask leader: Hydro-Québec, Canada)*

Subtask 6 : Effectiveness of mitigation measures *(Subtask leader: Hydro-Québec, Canada)*

From a scientific perspective, environmental studies are complex because of the many interactions in the ecosystem. In a subject area as wide as hydropower and the environment, it has been important to maintain the scope of the work within the limits imposed by the five-year time schedule and the available financial and human resources. However, several of the topics discussed are very extensive and complex, and as such, ought to have been handled with resources equivalent to an Annex. The main Annex III challenges have been to define the context and focus on the most important environmental and social issues. Two guiding themes have been the relation to government decision-making processes, and the need to ensure the highest possible level of credibility of the work.

Annex III is based on a case study approach combined with experience from a wide range of international experts representing private companies, governmental institutions, universities, research institutions, and international organizations with relevance to the subject. In all 112 experts from 16 countries, the World Bank (WB) and the World Commission of Dams (WCD) have participated in meetings and workshops. Additionally, 29 professional papers have been presented at the meetings. The participating countries are responsible for the quality control of the information given at the national level. Reference groups have been consulted in some countries.

Like all extraction of natural resources, the harnessing of rivers affects the natural and social environment. Some of the impacts may be regarded as positive; others are negative and severe. Some impacts are immediate, whereas others are lingering, perhaps appearing after several years. The important question, however, is the severity of the negative impacts and how these can be reduced or mitigated. The aspect of ecological succession is also of great interest. Through history, the ecosystems have changed, as a result of sudden disasters or more gradual adjustments to the prevailing weather conditions. Any change in the physico-chemical conditions seems to trigger processes that establish a new ecological equilibrium that matches the new ambient situation. Under natural conditions environmental change is probably more

common than constancy. Ecological winners and losers, therefore, are found in natural systems as well as those created by man.

Even if the "fuel" of a hydropower project is water and as such renewable, the projects are often quite controversial since the construction and operation directly influences the river systems, whereby the adverse impacts become direct and visible. The benefits, like avoidance of polluting emissions that would have been the unavoidable outcome of other electricity generating options is, however, less easily observed.

Access to water and water resources management will be a very important environmental and social global challenge in the new century, because water is unevenly distributed and there are regional deficits. Dam construction, river diversions and water withdrawal are elements in most water management systems. The lessons learned from past hydropower projects may be of great value in future water resources management systems. If a regional water resources master plan or management system is available, then the development of hydropower resources could also contribute to an improved water supply for other uses.

It is necessary to underline that the Annex III reports discuss the role and effects of hydropower projects and how to improve their sustainability. They do not consider the increased energy consumption *per se* since this aspect is a national and political issue. Annex III has developed a set of international recommendations and guidelines for improving environmental practices in existing and future hydropower projects. One main conclusion is the necessity of an environmental impact assessment undertaken by competent experts and forming an integrated part of the project planning.

The Annex III reports have been accomplished based on a cost and task sharing principle. The total costs amount to USD 805 305, while the task sharing part had a budget of 93 man months. The reports which have been completed include 4 Technical reports (Subtasks 1, 3, 4, 6) with Appendices, one Synthesis report (Subtask 5) with Appendices and one Summary report presenting the recommendations and guidelines.

Annex III comprises the following countries and organizations: Canada (Ontario Hydro, 1995-98, Hydro-Québec 1995-2000), Finland (Kemijoki OY 1996-2000); Italy (ENEL 1995-98); Japan (CRIEPI 1995-2000); Norway (NVE 1995-2000); Spain (UNESA 1995-2000) and Sweden (Vattenfall AB 1995-2000).

Oslo 30 March 2000

Sverre Husebye
Operating Agent
IEA-Annex III

Annex III — Acknowledgements

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Oslo 30 March 2000

Sverre Husebye
Operating Agent
IEA-Annex III

Annex III — Organization

Operating Agent

Husebye, Sverre	1995-2000	Norwegian Water Resources and Energy Directorate (NVE), Norway

Secretary

Taasen, Jens Petter	1997-2000	Norwegian Water Resources and Energy Directorate (NVE), Norway
Fagerlund, Kirsti H.	1995-1997	Norwegian Water Resources and Energy Directorate (NVE), Norway

National representatives

Hayeur, Gaëtan	1995-1997	Hydro-Québec, Canada
Klimpt, Jean-Étienne	1997-2000	Hydro-Québec, Canada
Kaikkonen, Raimo	1996-2000	Kemijoki Oy, Finland
Aki, Shuichi	1995-2000	Central Research Institute for Electric Power Industry (CRIEPI), Japan
Husebye, Sverre	1995-2000	Norwegian Water Resources and Energy Directorate (NVE), Norway
Rivero, Cristina	1998-2000	UNESA, Spain
Svensson, Björn	1995-2000	Vattenfall Hydropower AB, Sweden
Young, Christopher	1995-1997	Ontario Hydro, Canada
Tomasino, Mario	1995-1998	ENEL, Italy
Del Corral, José	1995-1998	Hidroelectrica Catalunia, Spain

Subtask leaders

ST1
Survey of the Environmental and Social Impacts and the Effectiveness of Mitigation Measures in Hydropower Development

Fagerlund, Kirsti H.	1995-1997	Norway
Taasen, Jens Petter	1997-2000	Norway

ST2
Creation of an International Information Data Base Comprising Environmental and Social Impacts, the Effect of Mitigation Measures and the Licensing Procedures Related to World Wide Experience of Hydropower Development (Closed down in 1997, database included in ST1)

Young, Christopher	1995-1997	Canada
Yu, Margaret S.	1997	Canada

ST3
Environmental and Health Impacts of Electricity Generation

Svensson, Björn Sweden

ST4
Survey of Existing Guidelines, Legislative framework and Standard Procedures for EA of Hydropower Projects

Rivero, Cristina Spain
Del Corral, José Spain

ST5
Present Context and Guidelines for Future Action

Klimpt, Jean-Étienne Canada

ST6
Effectiveness of Mitigation Measures

Trussart, Serge Canada

Subtask 6 — Acknowledgements

The Annex III / Subtask 6 working group is composed of Serge Trussart subtask leader Hydro-Québec, Danielle Messier Hydro-Québec, Gaëtan Hayeur and his team, René Nault and his team from Del Degan Massé and Associates, Vincent Roquet and his team from Vincent Roquet and Associates.

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Other persons collaborate to this report: Mr. Roger Schetagne and Mr. Benoît Goulet Hydro-Québec, Mrs. Betty Howell for translating parts of the report and Mrs. France Ste-Marie Hydro-Québec and Mrs. Lise Blais from En Toutes Lettres for editing the report.

Montréal, 1 April 2000

Serge Trussart
Hydro-Québec
IEA - Annex III, Subtask 6 Leader

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Introduction

1. Introduction

1.1 Context

The following document aims to present a review of mitigation measures (or actions) associated with hydropower projects. The intent of the report is to provide up-to-date knowledge, guidance and references on the best available practices. For the present document (Subtask 6), available information was obtained on the basis of a review of recent literature, as well as on the basis of results from questionnaires submitted to nine international hydropower producers in OECD countries. Therefore, the information is based on actual case studies and on the experience of practitioners and environmental professionals involved in or with the hydropower industry.

In this report, the words *environment* and *environmental* have to be understood in their more general sense, which extends to biophysical, economic, social and health and safety aspects. The intended audience for this report is a range of professionals and individuals concerned by, or involved in the issues raised by hydroelectricity and the environment, whether they may be representing governments, utilities, non governmental organizations (NGOs), bilateral and multilateral organizations, academic institutions, or others.

1.2 Designing mitigation, enhancement and compensation measures

With due regard for the principles of sustainable development, the best hydroelectric project is one that satisfies development requirements while maintaining the integrity of the environment as much as possible. Integrity is taken to mean the maintenance of the environment in its natural state, as it exists before project implementation. However, the concept of integrity cannot be taken to imply a freezing of the natural environment in a fixed state. This observation can also be applied to the human environment. A changeless natural environment would be possible only in the absence of interaction between human beings and their natural environment, indeed in the absence of evolution of the natural environment itself.

The notion of unchanging integrity is thus incompatible with ecology, a science that studies the relationships between living entities and their environment, which are in a constant state of flux. It is nevertheless justifiable in the short and medium term to seek to preserve the integrity of the environment as far as possible. Such an approach implies, on the one hand, minimizing as far as possible the effects of any hydroelectric development on the environment, and on the other hand, taking advantage as much as possible of anticipated modifications. Accepting and implementing this approach is the only way to plan and design a project that will be acceptable to all parties concerned (stakeholders). It requires that hydroelectric project designers use all possible means to eliminate or reduce the negative effects of the project and to maximize the positive ones.

Mitigation, compensation and enhancement measures have to be understood in their most general sense as a set of technically and economically feasible actions that are carried out in respect with the principle of

sustainable development. They also have to be closely tied to all of the project phases. A first set of mitigation measures should be identified during the planning and design of the project, in order to eliminate or reduce from the onset all anticipated negative impacts. Once impact avoidance has been carried out to the utmost, mitigation actions for unavoidable impacts and compensation for unavoidable losses may be applied at a subsequent design stage. Enhancement actions may even be used to improve the state of the natural and human environment that existed before the construction of the project.

These measures can be divided into three categories:

Mitigation measures are those used to eliminate a source of impact or reduce its intensity to an optimal or acceptable extent. These measures are applied in the immediate work site area or in sectors that will directly experience the effects of hydroelectric development (e.g.: reduction of flood zones, cut off or reduced flows in rivers, loss of wildlife habitats, loss of fishing sites, removal of human settlements, reduced access to bodies of water, requirement for weirs in reduced flow river sections to maintain biological productivity, etc.).

***Compensation measures*.** Such measures seek to compensate for impacts that cannot be mitigated and for residual impacts of the project after implementation of mitigation measures.

Enhancement measures are used to improve existing environmental or social conditions which are not directly affected by the project. Such measures may be implemented outside the study area. To be efficient, these measures must be defined in cooperation with all stakeholders.

1.3 Presentation of the report

The report comprises three main sections. Chapter 2 presents 12 tables of various mitigation, compensation and enhancement measures applied or proposed as part of 130 hydropower projects examined through a literature review. Some specific examples are provided to illustrate efforts expended by producers and public agencies to preserve the environment. Unfortunately, there is a lack of actual information on any systematic evaluation of the effectiveness of the measures applied.

Chapter 3 sums up mitigation measures compiled in a database developed and analyzed by two working groups of the Annex III. Information stored in the database comes from 24 projects from Canada, Finland, Italy, Japan, Malaysia, Norway, Spain, Taiwan and Tanzania. Complete mitigation measures are given in appendices, while three tables in the chapter summarize the main type of measures.

Chapter 4 aims to review the mitigation, compensation and enhancement measures which have proven to be effective for both biophysical and socio-economics fields. It is based on the previous chapters, but completed by international experts exchanges.

As concluding remarks, steps to improve hydropower design and management are proposed. They address actual ways to integrate environment concerns in designing hydropower projects and managing their impacts. It is not surprising if the last step involves monitoring program in regard to the scarcity of information on effectiveness and efficiency of mitigation measures that were analyzed. This is certainly a challenge for present and future hydropower projects.

International experience – literature review

2 International experience – literature review

2.1 Methodology

Based on a review of the literature on various mitigation, enhancement and compensation measures applied or proposed as part of hydroelectric projects, a list of measures implemented to mitigate or fully correct impacts associated with a hydroelectric development project has been prepared. This review takes into account different climatic regions and the different components of a hydroelectric project.

The listed measures come from some 130 hydroelectric projects, broken down as follows:

- ⇨ North America: 70 projects
- ⇨ Latin America: 30 projects
- ⇨ Europe: 15 projects
- ⇨ Asia: 10 projects
- ⇨ Africa: 5 projects

We begin with a look at the general impacts generated by various impact sources and anticipated for the components of the receiving environment.

The components of the environment used are:

- Physical environment:
  - Modification of water regime and flow
  - Physico-chemical properties of water

- Biological environment:
  - Aquatic wildlife and habitats
  - Bird life, terrestrial wildlife and habitats
  - Vegetation

- Human environment:
  - Socio-economic impacts
  - Impacts on public health and safety
  - Impacts on hunting and fishing
  - Impacts on recreational uses
  - Heritage impacts
  - Impacts of rivers with a modified flow and diversion canal
  - Impacts of power lines and related structures

This presentation of the impacts makes it possible to define the environmental problems associated with a specific component of the receiving environment and at the same time to explain the application of mitigation and enhancement measures. This is followed by a review of some of the mitigation, enhancement and compensation measures identified and applied and proposed by various hydroelectricity producers on the climatic regions studied.

Examples of specific mitigation, enhancement and compensation measures are then given. These illustrate the efforts expended by hydroelectricity producers and public agencies to preserve the water resource in adequate quantity and quality to ensure, to the extent possible, the survival of various uses of the resource, according to the region where a hydroelectric development project is underway.

An evaluation of the effectiveness of certain measures applied is also provided. This evaluation was made in the light of information in the scientific literature (proceedings of congresses, scientific articles), summary or individual works published by various agencies (e.g. The World Bank, IUCN - Word Conservation Union, OECD, UNESCO, etc.) and technical reports on specific hydroelectric projects in which measures were applied or reported.

This consultation of the literature turned up a widespread shortcoming: a lack of information on any systematic evaluation of the effectiveness of mitigation, enhancement and compensation measures applied. Where the lack of information does not allow the evaluation of the effectiveness of the various measures cited, a qualitative criterion, such as frequency of application of a measure, was used to evaluate their effectiveness. In other cases, the information found on the effectiveness of certain measures is presented.

Research showed that the companies that produce hydroelectricity invest substantial sums in environmental studies and the application of mitigation, enhancement and compensation measures. Information collected on the costs of mitigation measures applied to some forty projects shows that these costs can amount to several million dollars. The sums spent were proportional to the environmental issues identified and the traditional use of the water resource in the region where the project was being carried out.

Hydro-Québec, producer of hydroelectricity in the province of Québec, Canada, has devoted more than $40 million to environmental studies and works as part of the second phase of the La Grande Complex. This was in addition to the $166 million already spent on environmental studies ($18 million), remedial measures ($97 million) and certain enhancement measures for indigenous peoples ($57 million) (Sakami Agreement, Remedial Measures Corporation) for the first phase of the Complex.

Mitigation, enhancement and compensation measures are intended to promote the integration of a project in its receiving environment. Based on the inventory of measures proposed and applied in North America, Latin America, Europe, Asia and Africa, it appears that environmental concerns related to a hydropower complex located in an isolated region are different from those for installations of the same kind located in regions where population densities are high. The climatic region where the project is built is also a factor that orients the mitigation and enhancement measures to be implemented.

The inventory of mitigation, enhancement and compensation measures demonstrates that the components of the human, physical and biological environments were taken into account in all the projects surveyed. The measures were intended to mitigate a project's impacts to the extent possible. Thus, they vary according to the nature of the project, its dimensions, the climatic region and the use of the water resource by affected populations. The measures are shown by continent and the component of the specific receiving environment.

It should be noted that most of the biophysical mitigation, enhancement and compensation measures listed are linked to actions intended to ensure that, both up and downstream of the dams, there is water of sufficient quality and quantity to maintain a degree of biological productivity and use for various purposes, depending on the climate and size of the affected population. Wildlife management activities are also a priority for developers and are intended to ensure survival of species and their use by the communities living in the region in which the hydroelectric installation is being built.

With respect to measures affecting the human environment, those intended to improve living conditions and/or maintain prior uses of the water resource before the installations were built are priorities in the forefront of the mitigation and enhancement measures surveyed.

The following tables list the various measures inventoried, according to the components of the selected environment and the climatic region where the hydroelectric project was built. The tables are built in this manner: Column A: generic impacts, Column B: the mitigation measures applicable, Column C: the type of mitigation measures (mitigation, compensation and/or enhancement), Column D: the climatic zone, Column E: the biome, Column F: a statement on the effectiveness of the mitigation measures, Column G: comments on the effectiveness, Column H: the documents where the measures were actually applied and Column I: the documents where the measures were proposed. The last two columns refer to the list of references at the end of this chapter. In some documents, mitigation measures could both have been applied or proposed.

2.2 Physical environment

2.2.1 Modification of flow and regime

Impacts

In addition to the major physical modification of the zone in which a reservoir is built by permanently flooding relatively large areas of natural habitats, a hydroelectric development project causes changes in the flows downstream of the structure. As a result, some sections of a river become dry, while others undergo flow and level fluctuations according to the production of the power station or releases from the spillway or other control structures.

The disappearance of heavy natural floods as the result of regulating watercourses alters the natural life cycle of the flood plains located downstream from the structures. The effects on modified flow environments vary, depending on specific local conditions, the organisms involved and the conditions encountered in the reservoir. The quality of the water downstream of a hydroelectric dam depends on the inflows coming from the upstream reservoir (its dissolved oxygen, temperature, turbidity, contaminants, etc.). These can be adverse for aquatic wildlife and extend downstream if the water comes from the lower layers of water in the reservoir.

Water inflows upstream of the reservoirs can also pose problems from sedimentation in the reservoirs and disrupt hydroelectric generation. Sediment inflows from the road construction, farming or varied activities conducted in the watershed cause reservoir sedimentation in some regions, while sedimentation and depositing organic materials in the reservoirs reduce the quantity of sediments transferred to downstream watercourses. Productivity can be affected positively or negatively, according to whether they are eutrophic or oligotrophic reservoirs.

Also worth noting is that the multiple uses of reservoirs (flood control, drinking water supplies, irrigation, recreation, fishing, hydroelectric production) may conflict with each other and make managing the reservoir's water and maintaining its biological integrity difficult.

Finally, water flowing in the control structures (spillway, weir) can harm fish because it is oversaturated with dissolved oxygen.

Mitigation and enhancement measures

In order to maintain the quality of the aquatic habitats both up and downstream, various mitigation measures are applied or proposed. They are intended to manage the turbined or discharged flows from the control structures, in order to maintain sufficient quantities of water downstream to ensure the survival of riparian habitats and aquatic wildlife, the quality of the water in the reservoirs and downstream rivers, control growth of aquatic vegetation and disease vectors, ensure sufficient water quality and quantity for activities by adjacent communities and protect villages and towns downstream of the structures.

Measures affecting watershed management are also applied or proposed. Increasingly, integrated water resource management is part of the decision-making process included in designing a hydroelectric project.

The measures applied or proposed are varied and planned as a function of identified environmental issues and the use and interests of communities living near reservoirs.

Measures are also applied during the construction of access roads and energy transmission lines and are intended especially to protect the watercourses crossed.

Table 2.1 shows a series of measures involving water flow conditions downstream of a hydroelectric structure and reservoir water management.

TABLE 2.1: Mitigation, enhancement and compensation measures applicable for impacts on the physical environment – Water regime

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
Reservoir, modified flow rivers and related structures								
Reservoir siltation	Maintain or promote vegetation growth on exposed banks by various means	**M**	**TR-T-C**	**F**	**LE**	Limited efficiency to prevent siltation. Can be achieved by regulating agricultural or forestry activities or by creating a natural park in the watershed.	☐ 129	☐ 129, 99
	Construction of secondary dikes, weir bilding, siltation or holding pounds in upstream reservoir.	**M**	**TR-T-C**	**M-F-S-W**	**LE**	Limited efficiency. This measure is intended to retain sediments along small tributaries to the reservoir. The use of flocculating agents seems to accelerate the silting process.	✲ 2, 142 ☐ 129	☐ 129
	Construction of bottom outlets in dam.	**M**	**TR-T-C**	**M-F-S-W**	**E**	Allows to emptying the reservoir during flood periods.	☐ 129	☐ 129
Soil erosion and sediment transportation	Control of activities promoting erosion phenomena in the watershed and reducing the storage capacity of the reservoir.	**M**	**TR**	**F**	**ND**	In addition to being reported as difficult to apply, this method has never been analyzed.	● 54, 104 ✲ 127	
Induced seismicity	Management of water masses (slowly filling the reservoir, avoid rapid drawdowns, not keeping the level of water too high for long periods.	**M**	**TR**	**M-F-W**	**ND**	Allows reducing potential earthquake risks. The efficiency of this measure has not been demonstrated.	☐ 129	☐ 129
	Do geotechnical studies prior to site selection.	**M-C**	**TR**	**M-F-W**	**E**	Do studies prior to site selection for all reservoirs with a volume in excess of 1 km^3 or depths greater than 100 m or if earthquake risks are judged significant.	☐ 129	☐ 129
Reservoir usage	Collection of woody debris in the reservoir. Cleaning of watercourses, ditches and other canals of any debris blocking the normal flow of surface waters.	M	C	F	E	Meets intended objectives. Results also depend on prior decision to clear some or most of the forested area prior to impoundment.	✲ 2, 50, 130, 131	✲ 74
	Management of reservoir levels according to user needs	**M**	**TR-T-C**	**F-S-W**	**LE**	Effective but sometimes conflicting demands. While mitigating impacts of the original project, it does not mitigate other impacts beyond the levels planned by other measures.	● 104 ◆ 8, 12, 50, 57 ✲ 2, 50 ☐ 142	◆ 11 ✲ 64 ☐ 142
Spilling of reservoir	Construction of irrigation canals to limit the rise of water levels in a body of water. Installation of pumps where necessary.	**M**	**T-C**	**F-S**	**NE**	It is vital that water levels in the irrigation canals be kept lower than the soil surface. Application of this measure doesn't have fully mitigated the impacts.	✲ 2, 130, 131	◆ 11 ✲ 64, 74
Modification of downstream water regime	Application of a minimum flow	**M**	**TR-T-C**	**F**	**E**	Preserve the habitats downstream of the dam in their original condition. Disagreement remains in the calculation of minimum flows. Flow may be seasonal or simply state an absolute minimum, year round or a combination of these	● 42, 104 ◆ 1, 2, 5, 22, 46, 50, 128, 141 ✲ 2, 16, 31, 32, 80,118, 127 ☐ 99, 129	● 26, 83, 119 ◆ 11, 110 ✲ 64 ☐ 99, 129

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
M: mountain, **F**: forest, **S**: savannah, **W**: wetland

Effectiveness
E: effective, **LE**: limited effectiveness, **NE**: non effective, **ND**: undetermined

References as per climatic zones
☐ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ✲ (**C**) cold region

TABLE 2.1: Mitigation, enhancement and compensation measures applicable for impacts on the physical environment – Water regime (Cont'd)

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
(Cont'd)	Ecological Flow Policy (EAFR)	**M**	**TR-T-C**	**M-F-S-W**	**E**	This measure is an approach to the conservation or restoration of river ecosystems and requires consideration of the full range of flows experienced.	☐ 142	☐ 142
	Manage renewal of waters and construction of control structures to discharging phytomass generated (macrophytes) and accumulated in the reservoir	**M**	**TR**	**F**	**ND**		● 53, 104	● 26
Downstream riverbank erosion, ice jams and water flow control	Installation of weirs in reduced flow sections.	**M**	**T-C**	**F**	**E**	These weirs allow low-flow lake conditions to be maintained and reduce erosion from undermining and washouts. These structures raise water levels downstream of dam, mitigating erosion phenomena.	◆ 2, 50 ✻ 2, 50, 131 ☐ 142	✻ 64 ☐ 142
	Bank stabilization by rocks or vegetation	**M**	**C**	**F**	**LE**	Efficient but costs are high. Generate other impacts such as artificial riverbanks	✻ 2 ☐ 51	☐ 51
	Clearing of diversion zones to avoid increase in load losses and reduce quantity of woody debris, ice accumulation, erosion. Protection of resources and habitat	**M**	**C**	**M-F**	**E**	Meets intended objectives. The ice-jam floods are the principle method by which essential floodwater could replenish a vast area of this valuable ecosystem	✻ 131, 142	
	Installation of weirs downstream of the dam	M	C	F	E	Favors the formation of a stable ice cover	✻ 129	✻ 129
Modification of level and salination of ground water	Seal water leaks from beds of diversion canals.	**M**	**TR**	**F-S-W**	**E**	Meets intended objectives.		● 26

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
M: mountain, **F**: forest, **S**: savannah, **W**: wetland

Effectiveness
E: effective, **LE**: limited effectiveness, **NE**: non effective, **ND**: undetermined

References as per climatic zones
☐ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ✻ (**C**) cold region

Examples of mitigation measures

The following is a series of concrete examples, offered to provide an overview of the variety of measures that have been identified for impacts on the physical environment – Water Regime

➔ At the La Grande hydroelectric complex in the James Bay territory in northern Québec, in Canada, weirs were built on the Eastmain and Opinaca rivers where flows are reduced respectively 90% and 87%. These structures helped raise the water levels upstream of the structures, mitigate erosion phenomena and create habitats favorable to wildlife.
Source (131): Société d'énergie de la Baie James (1987).

➔ As part of the Caniapiscau-Laforge diversion at the La Grande hydroelectric complex in the James Bay territory in northern Québec, in Canada, the installation of dikes made it possible to substantially reduce the flooding of terrestrial habitats favorable to wildlife. One network of dikes reduced by 28% (area impounded 90 km²) the proposed flooding of 325 km² of land and another prevented the flooding of 350 km² (64%) of a proposed 550 km².
Source (131): Société d'énergie de la Baie James (1987).

➔ At the La Grande hydroelectric complex in the James Bay territory in northern Québec, in Canada, 1 980 ha of forest were cleared to facilitate the passage of diverted waters.
Source (131): Société d'énergie de la Baie James (1987).

➔ At the Glen Canyon Dam in the United States, water management had provided more regular flows downstream in the Colorado River during operating periods and sheltered the river from the heavy spring and early summer floods prior to dam construction. Riparian vegetation has extended beyond the zone flooded by the natural flood and the number of species present has increased.
Source (034): Calhoun C.A. (1995).

➔ In Sénégal, the Cayor Canal was sealed in order to mitigate expected impacts from the very substantial rise of the water table in certain sectors and the risks of waterlogging and salinization.
Source (026): Consortium SNC Lavalin / BCEOM (1996).

➔ In Sénégal (Manentali Dam), periodic releases of water downstream of the dam recreates the annual flooding cycle of the Sénégal River.
Source (042): Environmental Resources Ltd. (1993).

➔ In Congo, at the Inga hydroelectric structure, a surface spillway was installed to allow removal of floating orchids, which are overabundant. At Petit-Saut, the waters are quickly renewed, to limit the formation of floating beds.
Source (053): Gérard P. (1990).

➔ At the Libly Dam in Montana, USA, a minimum flow of 186 m^3/s is respected more than 95% of the time in order to preserve the habitat for aquatic wildlife.
Source (050): Gauthier & Guillemette Consultants inc. (1993).

➔ At the La Grande hydroelectric complex in the James Bay territory in northern Québec, Canada, some 417,000 m^3 of wood accumulated near the hydraulic structures, powerhouses, control structures and spillways was removed. This clean-up was intended not only to avoid damage or technical problems for the installations but also to keep large masses of floating debris from being carried downstream into the rivers below the structures. Floating debris was burned in a floating incinerator, while wood washed up on the banks was burned on the shore.
Source (131): Société d'énergie de la Baie James (1987).

➔ At the Fortuna Dam in Panama, protection of the lands in the upper part of the watershed helped reduce sediment deposition in the reservoir.
Source (109): Liebenthal A. (1997).

2.2.2 Physico-chemical properties of the water

Impacts

Creation of reservoirs and diversion lakes is the major physical transformation experienced by the hydrographic network in the region where construction takes place. This transformation has implications of various kinds, depending on the region. The water resource of the newly created lakes is used for various purposes besides hydroelectric generation, but whether for subsistence activities, commercial (fishing, aquaculture), recreation or farming, the communities located on the periphery of reservoirs often use these bodies of water as a source of supply and potential for use, especially in arid countries where drought creates problems (famine, reduced economic development).

The creation of reservoirs leads to flooding and the decomposition of biomass. The most commonly observed problem associated with a reservoir is the reduction of the oxygen rate, threatening the survival of aquatic organisms, especially in tropical countries. The recirculation of contaminants, proliferation of pathogenic organisms, mollusks, mosquitoes that are disease vectors, production of

methyl mercury, particularly in tropical countries where reservoir waters are often stagnant, are other problems.

Mitigation and enhancement measures

Measures have been studied and are generally proposed and applied by hydroelectricity producers to improve the physico-chemical quality of water from reservoirs or circulating in diverted rivers or diversion canals. These measures differ according to the climatic regions and the size of the reservoirs created. Table 2.2 shows various mitigation measures for the protection and conservation of physico-chemical properties of water applied as part of the development of various components of a hydroelectric complex (reservoir, power lines and transformer stations, diversion of watercourses, etc.).

TABLE 2.2: Mitigation, enhancement and compensation measures applicable for impacts on the physical environment – Water quality

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
Reservoir and rivers with a modified flow and diversion canal								
Decrease in water quality	Spillway design causing sufficient turbulence downstream to promote gas exchange at the outlet of the turbines and the elimination of methane and organic matter.	M	TR-T	F	E-LE	This structure promotes better reoxygenation downstream of the dam. This allows a rate of dissolved oxygen that satisfies the aquatic fauna support criteria. However, the absence of mitigation or enhancement measures dealing with the problems of habitat losses can limit recolonization by zooplankton and the food chain depending on it. This type of installation is thus not in itself sufficient to restore the conditions observed before the hydroelectric development.	● 53 ◆ 1	
	Installation of a desanding basin at the entrance to the intake diversion canal to capture coarse particles and mollusks that are disease vectors	M	TR	F-S-W	ND			● 26
	Construction of a weir in the diversion canal to maintain water levels, reduce rates of suspended matter (turbidity) due to runoff and favor sediment capture.	M	T-C	F	E	Meets intended objectives.	◆ 2 ✲ 2	✲ 64
	Construction of diversion walls upstream of filtration wells and reduction of problems associated with sedimentation in the river with a modified flow.	M	TR	F-S-W	ND	Resulting increase in current speed reduces the scope of sedimentation phenomena on wells and their gravel beds.		● 26
	Application of measures to prohibit and control organic, agricultural, industrial and domestic pollution in the reservoir and construction of urban and industrial effluent treatment systems to control and limit organic matter inflows.	M	TR-T	F	E	The effectiveness of this measure is generally recognized. However, its application encounters obstacles in the costs it generates and access to existing technologies. In the cases described, this measure was applied during operations in response to the unexpected appearance of this impact. The importance of good planning and its inclusion in the earliest steps of construction is stressed. No residual impact was reported.	● 53, 104 ◆ 46, 128	● 26, ◆ 11
	Prohibition and control of solid or liquid waste dumping in diversion canal.	M	TR	F-S-W	ND			● 26
	Maintaining work areas and mechanical activities within a strip of less than 20 m of diversion canal	M	TR	F-S-W	ND			● 26
	Protection the diversion canal against silting and erosion.	M	TR	F-S-W	E	Meets intended objectives.	✲ 2	● 26

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
M: mountain, **F**: forest, **S**: savannah, **W**: wetland

Effectiveness
E: effective, **LE**: limited effectiveness, **NE**: non effective, **ND**: undetermined

References as per climatic zones
□ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ✲ (**C**) cold region

TABLE 2.2: Mitigation, enhancement and compensation measures applicable for impacts on the physical environment – Water quality (Cont'd)

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
(Cont'd)	Management of water intake openings as a function of the turbidity of the reservoir.	M	TR-T	F	E-LE	Depending on the intensity of the phenomenon causing the turbidity of the water entering the reservoir, this method may entirely or partially mitigate downstream impacts. If a large mass of turbid water reaches the reservoir (from intense rains, for example) over a long period, the manager must combine actions and limit the passage of turbid waters downstream.	● 104 ◆ 128	◆ 11
	Management of discharges to avoid periods of stagnation and improve general water quality of the reservoir.	M	TR-T-C	F	E	Method with good results if compatible with the operations of the control structures and powerhouse. It conflicts with measure to increase retention time during intense rainy seasons.	● 42, 53 ◆ 128 ✻ 2	● 26
	Permanent flow in diversion canal to avoid periods of stagnation.	M	TR	F-S-W	ND			● 26
	Constant physico-chemical monitoring of reservoir water quality.	M	TR-T-C	F-S-W	E-LE	This measure, once applied, only provides the manager with the tools necessary to develop a future action plan. In itself, it provides no mitigation without being accompanied by subsequent measures affecting water quality control.	● 53, 104, ✻21, 101, 131, ☐ 129	✻ 69, 70, 74, 78 ☐ 129
	Periodic dredging of accumulated sediments, in combination with a policy promoting the treatment of industrial effluents located upstream of the reservoir and periodic flushing of sediments by opening gates.	M	T	F	ND			◆ 11
	Filtration of reservoir water	M	T	S	E-LE	This measure can be effective in small reservoirs but is expensive for large ones. This measure is often applied in combination, increasing the effect of synergy. Experiments have been used to develop mathematical models to predict the amplitude of the discussed impacts and thus propose a combination of methods.	◆ 128	

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
M: mountain, **F**: forest, **S**: savannah, **W**: wetland

Effectiveness
E: effective, **LE**: limited effectiveness, **NE**: non effective, **ND**: undetermined

References as per climatic zones
☐ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ✻ (**C**) cold region

TABLE 2.2: Mitigation, enhancement and compensation measures applicable for impacts on the physical environment – Water quality (Cont'd)

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
(Cont'd)	Oxygenation of the water of a reservoir or downstream of a river with a reduced flow. Variable water intake In turbine air drive	M	TR-T-C	M-F	E-LE	Forced aeration has had very good results in small reservoirs. It becomes very difficult to apply in large reservoirs, given the cost of the equipment required. Moreover, aeration facilitates the growth of plankton and bacteria. This can cause sedimentation problems in the long term, as in aerated ponds (domestic water treatment). Favor the precipitation of hydrogen sulfate, iron and manganese in the reservoir from the chemical action of the oxygen.	● 53 ◆ 1,2, 5, 12, 57, 95, 128, ✻ 2	● 26
Eutrophization of reservoir	Mechanical removal of macrophytes and phytoplankton on the reservoir surface to limit eutrophication of the reservoir	M	TR-T	F-S-W	LE	Measure that is simple to apply but requires on-going follow-up. Alone, it is not sufficient to achieve the objectives of limiting the eutrophication of the reservoir. Must be applied in combination with other measures, such as forced aeration, discharge measurement, etc.	● 42, 104 ◆ 128	● 26
Mercury methylation	Removal and controlled burning of vegetation before impounding.	M	TR-T-C	M-F	E-LE	This measure seems to effectively reduce the decomposition of organic matter that results in organic enrichment of reservoir waters. On the other hand, it is often very expensive and its secondary impacts on fishing are not negligible. Moreover, in tropical regions, cleared zones are recolonized at a very high rate, often recreating bushes that is similar to that cut before impounding.	● 42, 53 ◆ 133 ✻ 2, 21, 101, 130, 131 ☐ 129	☐ 129
Gas saturation	Modification of the exit of the tailrace canal to avoid oversaturation of water with gases	M	T	C	E	Meets intended objectives.	◆12 ✻ 2, 16	
Thermal shock	Installation of water intakes at various levels in the reservoir to mitigate the impact of thermal shock downstream of the reservoir.	M	T	C	E	Simple mitigation measure that is easy to apply. It completely mitigates the impact of thermal shock downstream of the dam. Should be planned as part of project planning.	◆ 128 ✻ 2 ☐ 129	☐ 129
	Management of releases to reduce salinity of waters feeding the diversion canal.	M	TR	W	ND			● 26
Saline intrusion	Construction of protective dikes in the diversion canal to control inflows of salt water in an estuary.	M	TR	W	NE	This measure seems inadequate on its own.	● 38	
	Sealing the diversion canal walls to reduce rise of water table and risks of waterlogging and salinization of surrounding land.	M	TR	S-W	ND			● 26

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
M: mountain, **F**: forest, **S**: savannah, **W**: wetland

Effectiveness
E: effective, **LE**: limited effectiveness, **NE**: non effective, **ND**: undetermined

References as per climatic zones
☐ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ✻ (**C**) cold region

TABLE 2.2: Mitigation, enhancement and compensation measures applicable for impacts on the physical environment – Water quality (Cont'd)

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
Transmission lines and energy transformation substations and refurbishing power stations								
Protection of sensitive areas (erosion and water temperature)	Respect a protection perimeter in areas with steep slopes, watercourses, important wildlife habitats, peat bogs and marshes.	M	TR-**C**	F	E	Meets intended objectives.	● 42 ✲ 77	● 26 ✲ 68, 77
	Piling wood waste at least 25 m from watercourses	M	C	F	E	Meets intended objectives.	✲77	✲ 68
	Designation of a site distant from bodies of water (60 m) for maintaining and refueling motors and vehicles.	M	C	F	E	Meets intended objectives.	✲77	✲ 81, 82
	Arrange a site distant from all water sources for washing concrete mixers and equipment	M	C	F	E	Meets intended objectives.	✲77	✲ 81, 82
	Disposal of waste in an authorized disposal site.	M	C	F	E	Meets intended objectives.	✲77	✲ 81, 82
	Install a settling basin and use of booms to retain muddy waters.	M	C	F	E	Meets intended objectives.	✲77	✲ 81, 82
	Operational areas of quarries and borrow pits located at a safe distance from wells, springs or other water intakes used for supplying a water distribution system	M	TR	F	E	Meets intended objectives. Avoid lowering of water table.	● 28	
Soil and water contamination	Collect runoff from a substation site or construction site for electrical installations at a point where it can be treated.	M	C	F	E	Meets intended objectives.	✲77	✲ 68
	Supervision during handling of fuels, oil and contaminants and availability of emergency treatment materials in case of accidental spills	M	C	F	E	Meets intended objectives.	✲77	✲ 81, 82
	Treatment of residual waters and discharges from construction sites and housing	M	TR-C	F	E	Meets intended objectives.	● 53 ✲77, 131	● 26 ✲ 74
	Preparation and application of an emergency plan for accidental spills of contaminants.	M	C	F	E	Meets intended objectives.	✲77	✲ 68
Decrease in water quality	Reuse of coarse and clean materials from an old structure when building cofferdams	M	C	F	E	Meets intended objectives.	✲ 77	✲ 81, 82

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
M: mountain, **F**: forest, **S**: savannah, **W**: wetland

Effectiveness
E: effective, **LE**: limited effectiveness, **NE**: non effective, **ND**: undetermined

References as per climatic zones
☐ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ✲ (**C**) cold region

Examples of mitigation measures

Below are concrete examples of applications, offered of mitigation measures. They are intended to show that efforts are made to protect and improve the quality of the water used in hydroelectric generation. The examples selected refer to projects carried out in warm regions, where water quality problems following the construction of a reservoir are greater than in temperate climates.

➔ To stabilize fill and protect against silting, salanes, trees and bushes were suggested as part of the landscaping of the Cayor Canal in Sénégal. Three types of windbreaks proposed:

- A central windbreak, consisting of four successive rows of trees, arranged in the following order: Prosopis juliflora, Eucalyptus camaldulensis, Eucalyptus canaldulensis - Prosopis juliflora;
- A lateral windbreak, on the canal side, consisting of two successive rows of trees in the following order: Acacia mellifera - Parinsonia aculeata (spaced 2 m x 2 m on the line and between the lines, in a honeycomb arrangement);
- A lateral windbreak, on the outside of the fill, which has the same configuration as on the canal side.

Source (026): Consortium SNC Lavalin / BCEOM (1996).

➔ To protect the water quality of the Cayor Canal, releases from Lac de Guiers into the lower Ferlo valley were suggested to reduce the salinity of the water that directly supplies the canal. Permanent flow in the canal is provided as a function of demand and to avoid periods of stagnation. When required, releases are performed to maintain water quality.

Source (026): Consortium SNC Lavalin / BCEOM (1996).

➔ For the Saltinho hydroelectric project in Guinea-Bissau, appropriate treatment is provided for residual waters from the construction site and housing as well as water from watercourses contaminated by suspended solids, associated with earthworks and by oils.

Source (024): COBA (1993).

➔ For the Petit-Saut project in French Guyana, water is occasionally released during highwater periods, to improve water quality.

Source (053): Gérard P. (1990).

➔ In Japan, as part of the planning of the construction of a hydroelectric power station, the water intake canals are located at different levels in the reservoir, to manage water discharges that completely eliminate the impact of thermal shock and manage turbid waters to assure adequate water quality downstream of the structure.
Source (128): Aki S. (1997).

➔ In Japan, the reservoirs of certain hydroelectric structures receive filtration and forced aeration. These methods give excellent results in small volume reservoirs. For large reservoirs, the method is too expensive to apply.
Source (128): Aki S. (1997).

➔ In Latin America, to improve the quality of reservoir water affected by the reduction of oxygen, organic pollution and frequent stagnant periods, water is now treated. The effectiveness of the treatment is recognized but the high cost and technologies required are common obstacles. Water treatment infrastructures should be planned from the start of the project.
Source (104): Ledec G. et al. (1997).

➔ In Latin America, selective cutting is carried out in zones to be flooded in order to mitigate the reduction of oxygen and organic pollution of reservoir waters. This measure appears to effectively reduce decomposition of organic matter in the reservoir water but its cost is very high and the zones are quickly recolonized, often creating bush flora similar to that cut before impounding.
Source (053): Gérard P. (1990).

2.3 Biological environment

2.3.1 Aquatic fauna

Impacts

Hydroelectric reservoirs can promote aquatic fauna by increasing the water area and favoring productivity. However, in some cases, construction of a dam can be seen to block the migration of fish species, with fish injured and dying from passage through turbines or spillways and some aquatic species from lotic habitats cannot survive in reservoir lakes. Deterioration of the water, especially in eutrophic reservoirs in tropical zones, can create adverse conditions for aquatic organisms.

Benthic organisms are often more seriously affected than the fish, who are more mobile. However, when the support offered by flooded vegetation is substantial, the number of macroinvertebrates can be greater than that encountered under natural conditions. In tropical regions, shallow zones of reservoirs may create habitats favorable to organisms that are disease vectors.

Multiple uses of reservoirs may result in conflicts between the generation of hydroelectricity and the conservation of fish populations, which are subject to commercial or subsistence exploitation in most regions.

Downstream of the structures, aquatic habitats are governed by inflows and the quality of released waters. Changes in the structures of fish communities, reduction of aquatic productivity affecting fish populations, artificial fluctuations in the flow of watercourses that affect the quality and quantity of aquatic habitats are the main impacts noted on fish life in the lower reaches of the body of water used for the hydroelectric complex.

Flow conditions and water quality downstream of generating and control structures play a dominant role on benthic fauna.

Mitigation and enhancement measures

Table 2.3 shows the mitigation measures applied or proposed as part of hydroelectric projects that favor the maintenance and development of aquatic fauna.

TABLE 2.3: Mitigation, enhancement and compensation measures applicable for impacts on the biological environment – Aquatic fauna

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
Reservoirs and rivers with a modified flow								
Loss of habitat and resources	Site selection and proper design.	**M**	**TR-T-C**	**F**	**E**	Meets intended purposes but may result in important loss of revenues. Best mitigation measure, may avoid impacts at the source, by modify project design.	● 104 ◆ 2 ∗ 2, 131	∗ 70, 74 □ 99
	Reservoir filling procedures. (outside the reproduction period, slowly reservoir filling, winter reservoir filling..)	**M**	**T-C**	**F**	**E**	Meets intended objectives.	◆ 2 ∗ 2	
	Installation of infrastructures for crossing watercourses to avoiding changing their flow conditions.	**M**	**C**	**F**	**E**	Meets intended objectives.	∗ 2, 17, 67, 77	
	Monetary compensation for loss of habitat	**C**	**T-C**	**F**	**ND**	May be good if the money is used to create the new habitat or ameliorate the existent habitat	◆ 133 ∗ 15, 16, 65	
	Maintaining a guaranteed minimum flow.	**M**	**T-C**	**F**	**ND**	It seems that controlled flow is not sufficient in itself to maintain the quality of gravel beds and preserve fish growing habitats. To be effective, this measure must reproduce the original conditions, in harmony with the production needs of the powerhouses involved. This combination of constraints often makes application of this measure complicated.	◆ 1, 5, 22, 46, 117, 120, 128, 141 ∗ 2, 14, 31, 32, 65, 80, 118, 127	◆ 11, 110, ∗ 64 □ 99
	Management of reservoir water levels (access to spawning areas, prevention of freezing and drying of eggs).	**M**	**T-C**	**F**	**E**	Clearly favors aquatic fauna to the detriment of energy production.	◆ 117 ∗ 2	◆ 110
	Inducing artificial floods in downstream to create spawning areas, clean spawning ground substrates, promote the return of species to the disturbed sites, nature -oriented river works, substrate improvement.	**M**	**T-C**	**M-F-W**	**E**	Artificial floods from by the periodic opening of control structures has helped increase the flooded surface over larger periods. The data strongly suggest that restoring ecosystems, regulation of sedimentation and rehabilitation of wetlands respect the needs of the target species. This measure could have significant effects on macroinvertebrate fauna of rapids Artificial areas of rocks and stones in the rivers provide improved conditions for fish, by creating greater diversity in substrate, flow conditions and water depth. Utilization of natural materials such as creates good conditions for fish	◆ 115, 141 ∗ 14, 142 □ 99	

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
M: mountain, **F**: forest, **S**: savannah, **W**: wetland

Effectiveness
E: effective, **LE**: limited effectiveness, **NE**: non effective, **ND**: undetermined

References as per climatic zones
□ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ∗ (**C**) cold region

TABLE 2.3: Mitigation, enhancement and compensation measures applicable for impacts on the biological environment – Aquatic fauna (Cont'd)

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
(Cont'd)	Management of flows released at the structures and reservoir water levels to recreate natural conditions favoring spawning.	**M**	**TR-T-C**	**F**	**E**	Meets intended objectives.	● 35, 42, 104, 117 ◆ 12, 14, 128 ✳ 2	● 119
	Creation of spawning areas in the tributaries Improvement of access conditions at mouths of tributaries favorable for spawning and fry rearing.	**M-E-C**	**T-C**	**F**	**E**	This measure consists of installing spawning areas with weirs in combination with submerged shelters and deflectors. It allows adequate access for fish breeding in tributaries. This measure has good mitigation results for lost breeding habitats at a reasonable cost. Success depends on accessibility of selected sites for target species.	◆ 12, 22, 133, 138 ✳ 2, 15, 16, 17, 32, 48, 59, 96, 130, 131	✳ 64, 74
	Create spawning area in reservoir by remaniement of the granular material in the carriers of quarries with be drown	**M**	**C**	**F**	**E**	Create the news habitats	✳ 130	
	Dredging work in the diversion canal and depositing of dredged materials outside of optimum breeding periods.	**MM**	**TR**	**F**	**E**	Meets intended objectives.		● 26
	Dredging the residual bed of river with a modified flow to ensure maximum flow over natural spawning areas and creation of pools and deflectors with rocks downstream of the dam.	**M**	**T-C**	**F**	**E**	This measure has restored the diversity of fish habitats. Increased use of the area is noted.	◆ 22 ✳ 32, 48	✳ 64
	Deposit of rock in the bed of the excavated diversion canal to maximize the number of rest shelters.	**M**	**C**	**F**	**E**	In combination with the creation of a shallow berm-type zone in the downstream section of the diversion canal, this measure makes it possible for walleyes to swim up the canal and use natural or artificial habitats on either side of the river. Rest shelters do not reduce the speed of the current but are used by fish to enter the most difficult portion of the canal and move towards habitats that strong currents keep them from.	✳ 14, 48	
	Diking of bays and wetland at the reservoir periphery	**M**	**C**	**F**	**LE**	Expensive measure to implement	◆ 2 ✳ 2,131	
	Creation of artificial meanders in river arms.	**M-E-C**	**T-C**	**F**	**ND**	Expensive measure to implement	◆ 2 ✳ 2	
	Aquatic fauna management plan	**M**	**T-C**	**F**	**E**	Meets intended objectives but sometimes difficult to implement.	◆ 23 ✳ 2, 15, 16, 17, 96	

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
M: mountain, **F**: forest, **S**: savannah, **W**: wetland

Effectiveness
E: effective, **LE**: limited effectiveness, **NE**: non effective, **ND**: undetermined

References as per climatic zones
□ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ✳ (**C**) cold region

TABLE 2.3: Mitigation, enhancement and compensation measures applicable for impacts on the biological environment – Aquatic fauna (Cont'd)

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
Use of resources, destruction of habitat and species, drop population	Installation of fish hatcheries (aquaculture integrated in reservoir).	**M-E-C**	**TR-T-C**	**F-W**	**E**	This method allows maintaining fish populations that can live but not breed in reservoirs (lake conditions). It requires constant follow-up of the expansion of the target species. Ineffective without fishing control measures.	● 53, 104 ◆ 23 ✻ 2, 15, 16, 96	
	Fish stocking	**M**	**TR-T-C**	**F-W**	**LE**	Following the initial disappearance of salmonidae, stocking has concretely relaunched migrations or allowed populations to be maintained. In other cases, this measure has not been adequate without measures to control fishing at sea, addition of migration aids or other. Danger inherent in the spread of fish deseases the mixing of genetically.	● 104 ◆ 45, 46, 138 ✻ 2, 10, 14, 15, 16, 17, 31, 32, 65, 100, 107, 140, 142	☐ 99
Loss of aquatic productivity within fish population, deterioration habitat	Construction of weirs and basins in certain reaches of the river; installation of obstacles to the current to create calm zones, migration barriers,	**M**	**C**	**F**	**E**	By preserving lacustrine zones, the weirs preserve original habitats for the species present before diversion. Increase in aquatic fauna production. Prevents undesirable species to access certain areas. Maintain fish population	✻ 2, 14, 32, 59, 130, 131	✻ 64
	Construction of a fish trap upstream of the control structures, with fish collected during the day and transported downstream of the dam at night.	**M**	**T**	**F**	**E**	The trap is entered by fish who are trucked downstream over short distances. Mortalities during transport are very rare and injuries from crushing in the turbines clearly reduced. However, the accumulation of young fish in the trap and at the upstream entrance of the structures attracts predators (birds, mammals and fish-eating fish). Predation pressure is such that may cancel cancels the effects of reducing turbine mortality.	◆ 45, 51	

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
M: mountain, **F**: forest, **S**: savannah, **W**: wetland

Effectiveness
E: effective, **LE**: limited effectiveness, **NE**: non effective, **ND**: undetermined

References as per climatic zones
☐ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ✻ (**C**) cold region

TABLE 2.3: Mitigation, enhancement and compensation measures applicable for impacts on the biological environment – Aquatic fauna (Cont'd)

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
(Cont'd)	Annual addition of nitrogen and phosphorus at the mouth of tributaries, addition of fish food (plankton, small fish) to the rivers to increase the growth of fishes.	**M-E**	**C**	**F**	**E**	This measure has helped increase the biomass of phytoplankton by a factor of 2 and primary production per chlorophyll unit doubled starting the first year. The zooplankton and benthic fauna biomass increased by 5 in the second year after application of the measure. Average weight of brown trout and arctic char individuals increased much faster than in natural conditions after fertilization began. The measure thus had very satisfactory results. However, it is limited to small and medium sized lakes for various reasons, including the cost of the substances being added, which increase exponentially with the lake area. The enhanced lake production has increased growth and survival juveniles Sockeye salmon.	✳ 2, 17, 31, 142	
	Capture and transfer of trapped fish upstream of temporary structures.	**M**	**T-C**	**F**	**E**	Meets intended objectives.	◆ 45 ✳ 130	
	Anti-downstream migration grills at the entrance to the tail race canal, installation of exclusion barriers with a 200 mm mesh in the pump entry zone, installation of a channel promoting the passage of fish and reducing fish mortality from passing through the turbines.	**M**	**T-C**	**F**	**E**	Fish larger than 350 mm do not approach the openings. There was a 75% reduction in individuals of all species longer than 165 mm and 92% of bass near the pumping installations. Moreover, there was no significant loss of pumping efficiency. This measure reduced the speed and strength of the current downstream, allowing fish to enter the canal and travel upstream to spawning sites.	◆ 12, 116 ✳ 2, 46	
Injuries and death within fish population	Optimization of the physical configuration of the generating and control structures to minimize the risks of fish injury or mortality.	**M**	**T-C**	**F**	**E**	Meets intended objectives most of the time.	◆ 12 ✳ 2, 15, 16, 131	✳ 70, 74
	Use of dissuasive methods to prevent fish from using potentially dangerous sectors (strobe lights, sound waves, electric shocks).	**M**	**T**	**F**	**E**	The fish were relocated in sites where lights were installed. They completely avoid the turbulence caused by pumping. Sound reduced fish in front of the pump opening by 56%.	◆ 116	
	Elimination of all-day pumping	**M**	**T**	**F**	**E**	Reduction of fish trapped by more than 90%. Management of the powerhouse is just as efficient with night pumping only.	◆ 116	
	Dispersion of fish before blasting.	**M**	**T-C**	**F**	**E**	Meets intended objectives.	✳ 14, 16, 77	✳ 74
Protection of resources and habitat	Establishment of a protection perimeter around areas with steep slopes, watercourses and major wildlife habitats. Construction work outside of spawning period	**M**	**C**	**F**	**E**	Meets intended objectives.	✳ 2, 15, 16, 67, 77, 131	✳ 74, 75, 78, 81, 82

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
M: mountain, **F**: forest, **S**: savannah, **W**: wetland

Effectiveness
E: effective, **LE**: limited effectiveness, **NE**: non effective, **ND**: undetermined

References as per climatic zones
□ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ✳ (**C**) cold region

TABLE 2.3: Mitigation, enhancement and compensation measures applicable for impacts on the biological environment – Aquatic fauna (Cont'd)

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
Obstacles to migration and access to proper habitat	Construction of fishways or fish ladders, bypass tunnels, fishways channels, construction of locks and fish elevators, installation of submerged deflectors upstream of the water intake to promote discharges of the surface layers of the reservoir	**M**	**TR-T-C**	**F-W**	**E-LE**	This measure has been mainly applied where there are important species for fisheries or sports or subsistence fishing. Effective in most cases in Latin America but often faces problems of selectivity by the species targeted during migration periods. During downstream migration, some fish do not recognize the entry to these structures and instead enter the turbine intake canals. Success depends on use potential of target species.	● 53, 104 ◆ 8, 12, 103, 115, 128, 138 ✳ 2, 10, 15, 16, 59, 65, 100, 130, 142	◆ 11, 110
	Control of predating and competing species (use of chemicals, lowering of water levels, construction of sills)	**M**	**C**	**F**	**E**	These techniques are still under development and are often controversial.	✳ 2, 142	✳ 64
Competition between species and colonization by undesirable species	Reduction of fish biomass of undesirable species.	**M**	**C**	**F**	**ND**	Effects difficult to evaluate because the data before and after are not known	✳ 2	

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
M: mountain, **F**: forest, **S**: savannah, **W**: wetland

Effectiveness
E: effective, **LE**: limited effectiveness, **NE**: non effective, **ND**: undetermined

References as per climatic zones
□ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ✳ (**C**) cold region

Examples of mitigation and enhancement measures

The following are concrete examples of mitigation measures applied, offered to improve or preserve fish quality and biomass, both upstream and downstream of the structures. These examples show the concern of producers of hydroelectricity for preserving and maintaining fish resources.

➔ At the Outardes-2 reservoir, in Québec, Canada, Hydro-Québec stocked more than 600,000 landlocked salmon redd and parr, in 1980, to introduce a population. A fish pass allows breeders to reach additional spawning areas.
Source (107): Lessard M. (1995).

➔ In the United States, Duke Power manages the levels of six of its largest reservoirs to optimize the breeding of large mouth bass.
Source (117): Olmsted and Bolin (1996) in (051) GDG (1998).

➔ In the Susquehanna River basin, in the United States, four hydroelectricity companies have built fish elevators and traps to transport shad upstream of dams. When the crossing structures are completed (year 2000), shad will be able to reach breeding areas located over more than 300 km. This measure has allowed a population of 3,000 specimens in 1980 to increase to 100,000 shad in 1990.
Sources (117): Olmsted and Bolin (1996)
(120): PP&L Resources (1995) in (051) GDG (1998).

➔ Stocking between 1990 and 1992 in the Peace-Wilbistau Reservoir in British Columbia, Canada, of 1,100,000 Kokani salmon, 350,000 rainbow trout and 100,000 brook trout.
Source (015): Read D.J. (1991).

➔ At Toben Lake, created on the Saskatchewan River in Saskatchewan, Canada, water levels are controlled during the six-week spawning period of the walleye and pike in the spring. These same species are also stocked.
Source (002): Acres Consulting Services Ltd. (1984).

➔ At the Mactaquac Reservoir on the St. John River in New Brunswick, Canada, the public utility which generates hydroelectricity, has trapped more than 6 million alewives to reduce their overabundance. This operation is conducted every year, and the catch is sold to a cat food processor.
Source (002): Acres Consulting Services Ltd. (1984).

➔ In Newfoundland, Canada, Newfoundland & Labrador Hydro has installed a water regulation structure on the Upper Salmon River to maintain minimum flow and assuring spawning and alevin habitats for salmonidae.
Source (002): Acres Consulting Services Ltd. (1984).

➔ In the United States, at the Still River hydroelectric power station in Connecticut, regulated flow of 0.3 m^3/s (19% of the release) is applied, to preserve the salmon habitat.
Source (110): Mackowiak R.G. (1992).

➔ At the Sisson, Trousers and Lac Lang reservoirs in New Brunswick, and Wreck Cove Reservoir in Nova Scotia, Canada, minimum flows in the order of 0.85 m^3/s to 3.40 m^3/s are maintained downstream to protect fish species.
Source (002): Acres Consulting Services Ltd. (1984).

➔ As part of the project to partially divert the Sault aux Cochons and Portneuf Rivers in Québec, Canada, uncrossable obstacles are planned. Installation of these infrastructures will make it possible to keep breeders from abandoning a brook trout spawning area and prevent the introduction of undesirable species which would compete for the habitat and sports fishing.
Source (064): Hydro-Québec (1999).

2.3.2 Bird life, terrestrial wildlife and habitats

Impacts

Creation of a reservoir sometimes requires the flooding of large land areas and, as a result, of wildlife habitats. The scale of the impacts on fauna will vary, depending on the climatic zones, size of the area affected, diversity of the substitute habitats available and the species present. Flooding land areas also has impacts on the use of breeding, rearing and feeding areas and the migratory routes of the species involved.

While a reservoir is being impounded, the fauna will have to move away. Intra and interspecies relations may increase.

Creation of a reservoir may also make new animal habitats available that are favorable for maintaining animal populations. For example, a bank morphology favorable to he development of littoral or wetland zones, the presence of half-submerged tree trunks and the development of macrophytes may promote the use of a reservoir by bird life.

Downstream of the structures, flow reductions and periodic flooding may result in impoverishment of the riparian vegetation of rivers, wetlands and deltas. This modification may have repercussions for the specific composition, diversity and abundance of bird species that were present before the development works. On the other hand, permanent, controlled discharges may have positive effects for the colonization of downstream vegetation by birds.

Installation of a power line corridor causes a loss of wildlife habitats. However, this impact is usually short-term, given the regrowth in the rights-of-way which creates new habitat conditions that may satisfy the biological needs of species in the region where the work is being done.

The presence of energy transmission lines can result in fatal collision for birds. The presence of lines in bird flyways increases the risk of collisions.

Mitigation and enhancement measures

Table 2.4 shows mitigation measures applied, offered as part of hydroelectric projects that are favorable for maintaining or developing bird life or terrestrial wildlife

TABLE 2.4: Mitigation, enhancement and compensation measures applicable for impacts on the biological environment – Bird, terrestrial fauna and habitat

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
Reservoir and Modified Flow Rivers								
Habitat destruction, loss of resources disturbance of population, loss in productivity and recruitment	Selection of a project site and implementation approach that has less impact on fauna.	**M**	**TR-C**	**F**	**E**	When applied during planning, this measure is definitively most effective. Prevention at source of impacts generally avoids the need for expensive and complex mitigation methods. This also makes it possible to forecast and limit secondary and residual impacts. However, the objectives and physical constraints of a project make this preventive measure inapplicable in many cases. Often results in compromises.	●104 ∗ 2, 131 ☐ 51	∗ 117 ☐ 51, 99
	Wildlife management plan based on a complete fauna inventory, promoting non-forced migrations.	**M**	**TR-T-C**	**F**	**E**	This measure is possible in conditions where there is no obstacle to animal migration to other sites. Captures and transfers are rare or nonexistent, except in specific cases.	● 54 ∗ 2, 17	
	Stabilization of the level variation and construction of a protective dike at the entry of tributaries to counteract the impoverishment or elimination of sites for nesting and raising young for a number of migratory birds.	**M**	**C**	**F**	**E**	Immediate increase, from the first breeding season, in the number of species and number of individuals of each species on the reservoir. This measure allows exploiting zones otherwise inadequate as habitats for water fowl.	∗32 ☐51	☐51
	Installation of weirs in the low flow zones with seeding and selective cleaning of definitively exposed zones.	**M**	**C**	**F**	**E**	Preservation of a habitat appropriate for waterfowl.	∗ 59, 130, 131, 142	∗ 69
	Reduction of construction activities during calving, nesting or migration periods.	**M**	**C**	**F-S-W**	**E**	Meets intended objectives.	∗ 2, 67	∗ 74
	Management of reservoir levels and releases downstream in order to recreate the natural flooding cycle and promote the development of vegetation suitable for maintaining bird populations.	**M**	**T-C**	**F**	**E**	Meets intended objectives.	● 42 ◆57 ∗ 2 ☐ 51	☐ 51
	Selective clearing of bush stands and mature arborescent species to increase the ability of the habitat to support moose, hare and ptarmigan.	**M**	**C**	**F**	**E**	Selective cutting increases the support capacity of the habitats for moose, hare and ptarmigan by promoting larger production of available browse.	∗ 17, 59, 65, 130, 131	∗69 , 74
	Creation of new habitats for migratory birds in the reservoir. (e.g. creation of small islands on the reservoir, with semi-aquatics and willows planted in combination with grass and legume seeds).	**M-C**	**TR-T-C**	**F**	**E**	This measure must be harmonized with vegetation control and rehabilitation measures on the reservoir, in combination with the wildlife management plan. Although mitigating the impacts measured or anticipated on migratory birds and their resting places, this measure is a compensation measure, profiting from new zones created by the reservoir.	● 54, 60, ◆ 57, 139 ∗ 2, 130, 131 ☐ 51	◆ 11 ☐ 51

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
M: mountain, **F**: forest, **S**: savannah, **W**: wetland

Effectiveness
E: effective, **LE**: limited effectiveness, **NE**: non effective, **ND**: undetermined

References as per climatic zones
☐ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ∗ (**C**) cold region

TABLE 2.4: Mitigation, enhancement and compensation measures applicable for impacts on the biological environment – Bird, terrestrial fauna and habitat (Cont'd)

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
(Cont'd)	Diking of bays (creation of bays adjacent to the reservoir to create a habitat for fauna). Creation of ponds by protection dikes.	**M-C**	**C**	**M-F**	**LE**	The need for maintenance and control of levels makes their use only for preserving habitats not very cost-effective. Mixed success. This measure allows maintaining habitats in their original condition but offers no advantage for breeding. Success depends on accessibility and maintenance. More favorable to removal than breeding.	∗59, 130, 131, 142	
	Intensive trapping, relocation of individuals of ecologically, socially and economically important species to new habitats.	**M-E-C**	**TR-C**	**M-F**	**NE**	This measure requires extensive characterization of the relocation sites. Consultation of users is essential. Follow-up of displaced populations is also important. The advantage of this measure is small, given the mortality caused by weakening of individuals from transportation, predation at the relocation sites and the questionable quality of the sites. Should be applied in combination with enhancement measures, such as creating relocation sites offering adequate support capacity.	● 53, 54, 104, 111 ∗ 59, 131 □ 51	□ 51
Loss of faunic heritage and biodiversity	Integral legal protection of species considered rare, vulnerable or endangered.	**M**	**TR-T-C**	**F**	**E**	Meets intended objectives.	● 51, 54 ◆ 51, 57 ∗ 51	
	Land acquisition for creation of new reserves, conservation units in areas adjacent to the reservoir.	**E-C**	**TR-T-C**	**F**	**E**	Meets intended objectives.	● 54, 104 ◆ 2, 22, 23, 138, 139 ∗ 2, 130, 133 □ 51	□ 51
	Full taxonomic inventory of the flooded region.	**M**	**TR-C**	**F**	**E**	This measure is applied to provide a baseline for the application of subsequent measures, without which it would not work. It is a necessary part of the planning of every project.	● 54 ∗ 131	∗ 74
	Creation of a fund for protection and conservation of fauna.	**M-E-C**	**T**	**F**	**ND**	Meets intended objectives.	◆138	
	Breeding in captivity and release into the natural habitat.	**M-E-C**	**TR**	**F**	**ND**		□ 51	□ 51
Death or injuries to large mammals	Construction of a pedestrian-type walkway to facilitate movement by wild animals from one side to the other of a diversion path.	**M**	**TR**	**F-S-W**	**ND**		◆ 2 ∗ 2	● 26
	Installation of a system for collecting surface debris in reservoirs at crossings for large mammals.	**M**	**C**	**F**	**ND**		∗ 17	

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
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Effectiveness
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References as per climatic zones
□ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ∗ (**C**) cold region

TABLE 2.4: Mitigation, enhancement and compensation measures applicable for impacts on the biological environment – Bird, terrestrial fauna and habitat (Cont'd)

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
Transmission lines and energy transformation substations and refurbishing power stations								
Loss of habitat, ecological heritage, biodiversity disturbance of individuals.	Energy transmission line route planning to reflect preservation of existing parks and reserves.	**M-C**	**TR-T-C**	**F**	**E**	The parks and reserves are protected by law so application of this law is mandatory. No residual impact is noted on protected, unique or exceptional habitats.	● 42, 54, 104 ∗131 ☐ 51, 66	∗ 68 ☐ 51, 66
Loss of habitat, disturbance of population, loss in productivity and recruitment	Respect a protection perimeter around major animal habitats, peat bogs and marshlands for work areas, installing access roads, etc.	**M**	**C**	**F**	**E**	Meets intended objectives.	∗65, 67, 77	∗ 74
	Reduction of construction activities during calving, nesting or migration periods.	**M**	**TR-T-C**	**F-S-W**	**ND**		∗ 2, 67	
	Recycling of materials by creating a marshy zone in the reservoir favorable for Canada goose, small plant-eating wildlife and predators (planting of semi-aquatic plants, seeding of grasses and legumes).	**M**	**C**	**F**	**E**	Meets intended objectives.	∗ 130	
	Planting and seeding of unused borrow pits to create habitats for water fowl.	**M-C**	**C**	**F**	**E**	Several borrow pits were treated, creating water fowl habitats. This measure made it possible to create several hectares of habitats favorable to bird life, as well as providing sites suitable for hunting by indigenous people.	∗ 2, 59, 67, 130, 131 ☐ 51	∗74 ☐ 51
Death or injuries to birds	Marking of power lines or guard wires, installation of anti-roosting devices or platforms to persuade birds to roost or nest at the safest locations. Integration of insulated perches in the design of power line towers (reduce bird electrocutions)	**M**	**TR-T-C**	**F**	**E**	Meets intended objectives.	● 18, 42, 105 ◆ 13, 98 ☐ 51, 66	☐ 51, 66
	Installation of high platforms for nesting by osprey and other infrastructures for birds of prey.	**M-E-C**	**TR-T-C**	**F**	**E**	This measure helps maintain conditions favorable to nesting near feeding areas. In spite of habitat losses, it is possible to maintain biodiversity with this simple method. It should be applied on a broader scale and to several species.	● 42, 51 ◆ 51 ∗ 2, 51, 130, 133	∗ 69
(Cont'd)	Use of plant or other screens near energy transmission lines to force the birds to increase their flying altitude.	**M**	**TR-T-C**	**F**	**ND**		● 42 ☐ 51, 66	☐ 51, 66
	Modification or creation of habitats near power line rights of way to promote bird travel on the same side of the line.	**M-E**	**TR-T-C**	**F**	**ND**		● 42 ☐ 66	☐ 66
Death or injuries to caribou	Selective clearing to facilitate crossing of access roads by caribou.	**M**	**C**	**F**	**ND**		∗ 2	

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
M: mountain, **F**: forest, **S**: savannah, **W**: wetland

Effectiveness
E: effective, **LE**: limited effectiveness, **NE**: non effective, **ND**: undetermined

References as per climatic zones
☐ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ∗ (**C**) cold region

Examples of mitigation and enhancement measures

The following are concrete examples of mitigation measures applied, offered to improve or preserve birds or mammals population and their habitat. These examples show the concern of producers of hydroelectricity for preserving and maintaining terrestrial fauna.

➔ At the La Grande Complex at James Bay in northern Québec, Canada, selection cutting of willows contributed to a 2.5 to 3 times increase in the quantity of phytomass (dry weight) available to fauna. Follow-up of selection cutting performed in stands of quaking aspen showed that growth available for fauna had increased by a factor of 10 in a period of 8 years.
Source (131): Société d'énergie de la Baie James (1987).

➔ As part of the Itaipu project, on the Itaipu River, whose reservoir is shared between Brazil and Paraguay, more than 30,000 animals have been captured since 1982 (year of impounding). Captured animals are relocated in the two reserves and five refuges created after the hydroelectric project. The total conservation area represents nearly 995 km^2, of which more than half serves as a protective belt around the reservoir. Moreover, a centre for breeding in captivity protects rare or endangered species by reintroducing them in their natural habitat.
Sources (092): Itaipu Binaciaonal (1997)
(009): The World Bank (1998)
(097): Kohlhepp G. (1987) in (051) GDG (1998).

➔ At the La Grande Complex (1988-1993) at James Bay in northern Québec, Canada, more than 75 sites representing 295 ha. of forests and bushes were the subject of selection cutting, whose goal was the creation of substitute wildlife habitats of good quality for wildlife. Follow-up of these facilities showed that wildlife used these sites in the first year of cutting and the phytomass produced was better than in prior conditions.
Source (131): Société d'énergie de la Baie James (1994).

➔ In Sénégal, the high level of the Diana reservoir creates the effects of flood in the upstream section of the watershed. The conditions created by the inflow of water allowed 12,000 great flamingos and thousands of cormorants, terns and small flamingos to find breeding zones on islands and in flooded forests. The region has become exceptionally important for wildlife conservation.
Source (044): Van Lavieren B. and Van Wetten J. (1990) in (051) GDG (1998).

➔ In the United States, a management plan for releases in the Colorado River has enabled peregrine falcons to find abundant prey from the increase in primary productivity and greater diversity of plants and aquatic organisms. At this time, the population of peregrine falcons nesting in the Grand Canyon is the largest in North America.
Source: Wieringa and Morton (1996) in (051) GDG (1998).

➔ At Colorado at United State, perches installed on the top of electric 12,5 kV pole to incite birds to perch there where electrocution risks are weak.
Source (013): Bridges and Lopez (1995) in (051) GDG (1998).

2.3.3 Vegetation

Impacts

The impact on vegetation of the construction of a hydroelectric project is loss of vegetation, caused mainly by flooding and, to a lesser extent, by clearing work areas for related infrastructures (energy transmission lines, access roads, camp sites, dumping and borrow areas). In some cases, parts of the future reservoir are cleared. The area to be flooded, climate, soils and vegetation type and state (burned, regenerating, mature) are all factors that influence the scale of the impact on this resource.

It is relatively difficult to develop riparian habitats on the banks of a reservoir in temperate zones but it is possible when the reservoir's morphology allows to create zones where water levels experience only little variation. In arid regions, the creation of reservoirs is favorable to the development of riparian vegetation and in tropical regions, aquatic vegetation can proliferate and become an operating constraint.

Industrial, urban and farming activities conducted on the periphery or in the watershed of a reservoir can contribute to enriching the water and lead to the quick development of substantial aquatic vegetation. This phenomenon is often observed in tropical countries.

Downstream from structures, in habitats with modified flow, the arrangement of natural basins alters the natural flooding cycle and can contribute to the modification of riparian ecosystems. This phenomenon is more perceptible in tropical and arid regions. In tropical regions, the development of significant aquatic vegetation may become a problem.

Control of vegetation in energy transmission line rights-of-way can become a factor of expanded environmental aggression if adequate measures are not applied when using and applying herbicides, controlled burning and mechanical cutting.

Mitigation and enhancement measures

To mitigate, correct or enhance these impacts on vegetation, electricity producers applied different measures. Table 2.5 shows mitigation measures for vegetation applied, offered as part of hydroelectric projects.

TABLE 2.5: Mitigation and enhancement measures applicable for vegetation

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
Reservoirs and reduced flow rivers								
Loss of forest resources and terrestrial habitat	Project optimization to minimize vegetation losses and preserve forest.	**M**	**TR-C**	**F**	**E**	When applied during planning, this measure is definitively most effective. Prevention at source of impacts generally avoids the need for expensive and complex mitigation methods. This also makes it possible to forecast and limit secondary and residual impacts. However, the objectives and physical constraints of a project make this preventive measure inapplicable in many cases. Often results in compromises.	● 104 ◆ ✲ 2 ☐ 51	✲ 74 ☐ 99
	Clearing and removal of vegetation before the reservoir is impounded.	**M**	**TR-T-C**	**F**	**LE**	Very expensive. In the tropics, vegetation growth is too fast and fills in the cleared sectors even before reservoir clearing is completed. Water quality is more disturbed, given the abundance of new phytomass generated. Reduction of nutrient to prevent aquatic vegetation growth.	● 35, 42, 53, 104, 113 ◆ 2, 46, 126 ✲ 2, 16, 63, 130, 131 ☐ 51	● 26 ☐ 51
	Management of reservoir levels and flow releases according to the natural regimes in order to promote regrowth and maintain adequate riparian vegetation.	**M**	**TR-T-C**	**M-T-W**	**E**	Growth of grasses and bushes promotes the capture of sediments and contributes to degradation of aquatic habitat. Contribute of shoreline stabilization In subarctic, subtropical and equatorial regions, under stabilized low flows, an increased growth of aquatic macrophytes is noted. A substantial reduction in water flow downstream of large dams may cause a decline of floodplain forests. Changing the water level schedule of reservoir will contribute in the recolonization of macrophytes within the formerly barren littoral zone.	● 88, 121, 134 ◆ 5, 28, 34, 50, 57 ✲ 127 ☐ 51, 142	☐ 51, 142
	Selection of borrow sites in areas where flooding will cover the destroyed habitats.	**M**	**TR-C**	**F**	**E**	When properly applied, this measure allows reducing habitat losses (principle of necessary losses) by combining the sites used with the flooded zones.	● 104 ◆ ✲ 131 ☐ 51	✲ 74 ☐ 51
	Planting and seeding affected sites, borrow pits, camp sites, dumps, industrial sites	**M**	**TR-T-C**	**F**	**LE**	Natural regrowth is just as fast as the application of this measure. The use of indigenous species must be promoted. Very sensitive to floods. This measure is compulsory in Quebec, Canada.	● 104 ◆ 2, 46 ✲ 2, 16, 17, 21, 51, 65, 67, 77, 130, 131 ☐ 51	● 26 ✲ 73, 81 ☐ 51

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
M: mountain, **F**: forest, **S**: savannah, **W**: wetland

Effectiveness
E: effective, **LE**: limited effectiveness, **NE**: non effective, **ND**: undetermined

References as per climatic zones
☐ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ✲ (**C**) cold region

TABLE 2.5: Mitigation and enhancement measures applicable for vegetation (Cont'd)

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
(Cont'd)	Reforestation by planting around the reservoir. (forest or riparian resources)	**M-E-C**	**TR-T-C**	**F-S**	**E**	This measure mitigates the impact of the loss of wooded habitats up to a point. However, the major part of the planting zone is in regions not directly affected by the reservoir. This is mainly an enhancement measure for the forest resource.	● 35, 104, 111, 113 ◆ 57 ✻ 2, 21, 29, 30, 31, 59, 101, 130, 131 ☐ 51	● 26 ◆11 ✻ 64, 68, 75, 78, 81 ☐ 51
	Installation of a lacustrine outlet in order to allow free flow of waters and avoid the periodic flooding of the riparian strip.	**M**	**C**	**F**	**E**	Meets intended objectives.	✻ 64, 119, 130	✻ 64, 119
Loss of biological production	Maintain a woodland or riparian vegetation along watercourses	**M-C**	**C**	**M-F**	**E**	Maintain of corridors of woodland and riparian vegetation along watercourses is of major importance for biological production in rivers and stream, as well as being of vital importance for birds and games.	✻ 142	
Loss agricultural production	Water level schedule of reservoir	**M-C**	**T**	**M-T-V**	**E**	Changing the surface-water intake systems is the most effective solutions. In Japan, cold water causes poor growth of rice plants	◆115	
Loss of biodiversity or of floristic heritage	Conservation, legal protection of rare, vulnerable or endangered species.	**M-C**	**C**	**F**	**E**	Meets intended objectives.	✻ 102 ☐ 51	☐ 51
	Creation of conservation zones.	**M-E-C**	**TR-T**	**F**	**E**	Meets intended objectives. Coordination with governmental agencies, sufficient financing, collectivity agreement	● 35, 104, 113 ◆ 133 ✻ ☐ 51	☐ 51
	Collect and preserve seeds for conservation purposes and transplantation to other sites. Creation of forest arboretums for in-site preservation of the genetic heritage.	**M-E-C**	**TR**	**F-S**	**E**	This measure was employed successfully but is very expensive. It is very important to carefully characterize the transplantation sites to ensure compatibility with plant needs.	● 111 ◆ ✻ ☐ 51	☐ 51
Loss of biomass for human uses	Harvesting and use of macrophytes and algae (compost, fodder, fuel, biogas production)	**M**	**TR**	**F-W**	**E**	Meets intended objectives.	● 51	☐ 99
Protection of equipment, aesthetics, navigation, eutrophisation of reservoirs or diversion canal, changes in hydraulic conditions	Clearing of reservoir debris surface near the water intake. (Physical removing of floating aquatic plants).	**M**	**TR-C**	**F**	**E**	Meets intended objectives but very expensive.	● 35, 113 ◆ 2 ✻ 2, 4, 50, 59, 65, 130, 131	● 26

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
M: mountain, **F**: forest, **S**: savannah, **W**: wetland

Effectiveness
E: effective, **LE**: limited effectiveness, **NE**: non effective, **ND**: undetermined

References as per climatic zones
☐ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ✻ (**C**) cold region

TABLE 2.5: Mitigation and enhancement measures applicable for vegetation (Cont'd)

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
(Cont'd)	Control of agricultural, urban or industrial activities and treatment of tributaries to reduce the load of nutrients that promote growth by macrophytes. Selective cutting in zones to be flooded.	**M**	**TR**	**F**	**ND**	Difficult to implement.	● 53	
	Control and destruction of aquatic vegetation using periodic releases of surface water from the control structures, lowering of reservoir, sediments dredging, use of booms.	**M**	**TR**	**F**	**E**	This measure allows eliminating a large portion of the floating plants. However, it encounters obstacles associated with the generating objectives of the power stations	● 53, 104	● 26
	Local use of selective herbicides to control aquatic plants. Biological control of aquatic plants with natural predators.	**M**	**TR**	**F**	**E**	Simple but effective method. Must however be applied continuously. Its simplicity allows its application by the local communities, thereby reducing costs and promoting involvement by local residents. Effective but can become expensive when repeated applications are required to control large-sized plants.	● 53, 104	● 26
Energy transmission lines and other infrastructures								
Protection of sensitive environments, contamination of terrestrial or aquatic environments	Protection of sensitive or exceptional floristic environments while building a transmission line or access roads.	**M**	**TR-C**	**F**	**E**	Meets intended objectives.	● 42, 104 ◆ ✻ 2, 16, 17, 66, 67, 77, 131	
	Vegetation control done by mechanical, manual or biological means. Control vegetation while integrating management concepts.	**M**	**T-C**	**F**	**E**	Meets intended objectives.	✻ 66, 67, 77 ☐ 51	☐ 51

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
M: mountain, **F**: forest, **S**: savannah, **W**: wetland

Effectiveness
E: effective, **LE**: limited effectiveness, **NE**: non effective, **ND**: undetermined

References as per climatic zones
☐ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ✻ (**C**) cold region

Examples of mitigation and enhancement measures

➔ For the Cayor Canal in Sénégal, recovery by local residents of wood cut in the work zones helped reduce illegal pressure on existing forests for domestic use.
Source (026): Consortium SNC Lavalin / BCEOM (1996).

➔ In the Cayor Canal in Sénégal, booms were installed upstream of the gates to control the formation of aquatic vegetation (rafts of cattails, water lettuce, water hyacinth, etc.) that can affect the output of the structures.
Source (026): Consortium SNC Lavalin / BCEOM (1996).

➔ The Cayor Canal project in Sénégal has promoted the return of biodiversity, triggered by the installation of wooded strips on either side of the canal. Before the project, the Forest of Thiès had little hope of a return of natural formations due to overgrazing.
Source (026): Consortium SNC Lavalin / BCEOM (1996).

➔ In the Pensacola project in Oklahoma, United States, management of the reservoir level allowed recreation of fluctuations recorded in natural conditions and, combined with a program to replant the shores, helped the development of riparian habitats.
Source (057): Grand River Dam Authority (1992).

➔ In Laos, as part of the project to build the Nam Theun Two dam on the Theun River, timber was recovered and phytomass removed from the reservoir. As an enhancement measures, they prepared to create a 3,710 km^2 conservation unit in the Theun River watershed.
Sources (035): Dorcey et al. (1997)
(113): Monbiot (1997) in (051) GDG (1998).

➔ As part of phase 1 of the La Grande project (1978-1986), nearly 11 millions seedlings (green alder, speckled alder, jack pine, willows, scrub birch, balsam poplar, bog myrtle) were introduced over 6,000 ha. From 1986 to 1996, more than 5 million seedlings were planted in 1,150 ha. in zones affected by construction activities for phase II of the La Grande hydroelectric complex at James Bay in Québec, Canada.
Source (131): Société d'énergie de la Baie -James (1987).

➔ At the Aswan Dam in Egypt, the Nasser Reservoir promoted heavy growth by riparian vegetation in the periphery of the reservoir, following periodic floods in desert lands of the Wadi Allaqi.

Sources (121): Pulford et al. (1992)
(134): Springuel et al. (1989) in (051) GDG (1998).

2.4 Human environment

Involuntary population displacement is the source of the most significant socio-economic impacts associated with hydropower projects, particularly in less economically advanced countries. This is especially true when forced resettlement involves aboriginal or rural indigenous populations, who most often are profoundly attached to their land. In addition to populations removed from the flood zone, such ancillary facilities as roads, power transmission lines, borrow pits, campsites, etc. also may cause populations to be displaced.

Even when residents are not physically displaced by a hydropower project, they may still lose their livelihoods through the loss of fishing and hunting grounds, farmlands and pastures, as well as other valued natural resources such as forests, sources of drinking water and raw materials (e.g.: riverside clay used in making bricks, tiles or pottery). These economic losses may result either from the impoundment of the reservoir, or from the use of borrow pits, the construction of new access roads, etc. The loss of archaeological, historical, cultural or religious resources may also have a substantial impact upon aboriginal or rural indigenous communities.

➔ There are no simple ways to prevent the temporary increase of mercury in fish in large reservoirs. Mercury and other contaminants must be monitored in fish harvested from the reservoir to comply with national marketing standards. Moreover, a risk management program should be set up to encourage locally affected communities to avoid consumption of contaminated species of reservoir fish, without abandoning their traditional lifestyles. Such a program has proven to be successful for aboriginal communities in Northern Québec (Canada).

Sources (145): Lucotte et al. (1999)
(146): Chevalier et al. (1997)
(147): Dumont et al. (1998).

Introducing new infrastructures (roads, power lines, campsites for workers, etc.) into an isolated environment may be the source of potentially major changes in the daily lives of aboriginal or rural indigenous peoples. Such populations may come into contact for the first time with workers from outside and immigrants attracted by new access to the territory or other facilities associated with the project (related developments). Indigenous, highly traditional populations are particularly vulnerable to new sources of social conflict, crime, prostitution and the loss of traditional customs and beliefs.

Accordingly, to minimise or mitigate the socio-economic impacts of hydropower projects, projects should be planned and implemented according to the following principles:

- Avoid or minimize resettlement.
- Improve or restore livelihoods.
- Allocate resources and share benefits, move people in groups.
- Promote participation.
- Rebuild communities and consider hosts' needs.
- Protect indigenous peoples.

Mitigation, enhancement or compensation measures

Table 2.6 to table 2.12 summarize a series of mitigation and enhancement measures which may be applied to the human environment in the context of hydroelectric projects.

TABLE 2.6: Mitigation, enhancement and compensation measures applicable for impacts on to the human environment – Socio-economic impacts

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
Reservoir and related structures								
Involuntary population displacement and loss of livelihoods in traditional, rural communities	Resettlement and rehabilitation (R&R) of displaced populations by providing new homes, agricultural land, community facilities and services, as well as assistance or training in order to restore and improve people's livelihoods.	M-E-C	TR-T-C	F-W	E	Resettlement and rehabilitation (R&R) programs require considerable political goodwill and financial and technical resources to be successful. Involuntary displacement of large numbers of people should be avoided as much as possible. Design and implementation of an R&R program should aim to improve people's livelihoods through the development of comprehensive community development schemes. People should be moved in groups. R&R must be based upon an open, inclusive and transparent participatory process.	● 7, 38, 54, 60, 90, 104, 111, 137 ∗ 15, 16, 131 □ 33, 50	□ 33, 50
						Significant social and political tensions may appear even in the best planned and implemented R&R programs. Very few cases of successful R&R stand out. The R&R program put into place in the tropical highlands of Costa Rica is considered as a success and as an example to follow. Population regained their initial standard of living five years after the transfer.		
						Resettlement programs aim to ensure the improvement of the lives of displaced people and host communities. A good example of an income restoration program is the Kariba Lake fisheries development program in Zambia. To be successful, R&R programs require the development of appropriate regulatory frameworks. They also require the building of local institutional capabilities.		
Downstream economic impacts	Management of reservoir levels and periodic releases in order to maintain pre-existing conditions downstream of the hydropower dam, and thereby ensure the availability of timely water requirements for irrigation, flood recession farming, fishing, or other economic uses of the water resource.	M	TR-T-C	F-W	E	The case of the Manantali dam on the Senegal River is a much studied example where alternate water management techniques could prove to be feasible and offer significant socio-economic benefits.	● 42, 104 ∗ 2, 32, 50	◆ 11

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
M: mountain, **F**: forest, **S**: savannah, **W**: wetland

Effectiveness
E: effective, **LE**: limited effectiveness, **NE**: non effective, **ND**: undetermined

References as per climatic zones
□ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ∗ (**C**) cold region

TABLE 2.6: Mitigation, enhancement and compensation measures applicable for impacts on to the human environment – Socio-economic impacts (Cont'd)

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
Loss of economically valued land uses in recreational and agricultural areas	Replacement of valued resources flooded in the impoundment zone (fishing grounds, farmlands, pastures) where feasible.	M-C	TR-C	F-S-W	E	This measure, even when carefully planned and implemented, may run afoul of many obstacles that could compromise its success: inadequate monetary compensation, higher cost of living in the receiving environment, more complex agriculture in the new sites, etc. On the other hand, the quality of transportation, communications or other facilities may be better in the receiving environment.	● 53 ∗2, 15, 16, 65, 131, 133 ☐ 33, 50	☐ 33, 50
Loss of economically valued hunting and fishing grounds in aboriginal or indigenous communities	Income Security Program to support traditional hunting and fishing activities in aboriginal or indigenous communities	C	C	F	E	In Northern Canada, the James Bay and Northern Québec Agreement guaranteed exclusive hunting, trapping and fishing rights to local Cree and Inuit indigenous communities. It also enabled them to benefit from a government funded Income Security Program (ISP). It has enabled these communities to maintain their traditional ways-of-life, or at least slow the decline in the practice of such activities that had been observed the project, when compared to other indigenous communities that have not benefited from the ISP.	∗ 131	
Flooding of the reservoir hinders the development of future land uses and activities	Clearing of the whole reservoir area prior to impoundment in order to improve overall conditions for reservoir use (access, navigation, docking, fishing), to protect future structures and to improve the quality of the landscape.	M	C	F	E	Meets intended objectives.	∗ 2, 17, 21, 29, 30, 59, 65, 101, 126, 130, 131 ☐ 33, 50	∗ 65 ☐ 33, 50
Absence of appropriate planning hinders future development of land uses and activities	Establishment of a comprehensive master plan to control and manage future land uses around the reservoir.	M-E-C	TR-T-C	F	ND	This measure aims at creating favorable conditions for future economic development around the reservoir.	● 42 ∗ 15, 16, ☐ 33, 50	☐ 33, 50
Absence of appropriate planning hinders future subsistence fishing	Establishment of a commercial fisheries management plan to control and manage fishing on the reservoir.	M-C	TR	F-W	E	This measure aims at creating favorable conditions for fish farming within the reservoir.	☐ 33	☐ 33
Silting-up of the reservoir and reduced possibilities for commercial navigation	Construction of locks for navigation and dredging.	M-E-C	TR-T-C	F-S	E	This measure aims to facilitate commercial navigation on the river.	☐ 33	☐ 33

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
M: mountain, **F**: forest, **S**: savannah, **W**: wetland

Effectiveness
E: effective, **LE**: limited effectiveness, **NE**: non effective, **ND**: undetermined

References as per climatic zones
☐ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ∗ (**C**) cold region

TABLE 2.6: Mitigation, enhancement and compensation measures applicable for impacts on to the human environment – Socio-economic impacts (Cont'd)

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
Social impacts in affected communities	Financial support for the development of community services (health, education, housing, social services) in affected communities	C	TR-T-C	F-W	E	Compensation for social impacts in affected communities can be achieved to a certain extent through improved housing, education, social services and health care. However, such forms of compensation may not be sufficient, particularly in the case of vulnerable indigenous or ethic minority groups that are largely dependent on locally available natural resources.	☐ 33	☐ 33
	Community involvement in project planning	M-C	TR-T-C	F	ND	It is difficult to completely mitigate or compensate for the social impacts of hydropower development in affected communities. Such communities must be treated as partners in the project and be given sufficient time to properly understand the issues and be able to propose solutions that may enable them to be properly compensated. In the case of the Sainte-Marguerite 3 hydropower project in the Province of Quebec, an agreement was recently negotiated with an aboriginal community whereby they would receive substantial funding over a 50 year period to support their economic development and to maintain their traditional way of life.	☐ 33	☐ 33
Loss of farming and logging area in the impoundment zone	Optimization or intensification of farming or forest operations in land already devoted to these activities. Construction of irrigation canals, controlled flow to offset loss of arable land from drying.	M-E-C	TR	F-S-W	E	Meets intended objectives.	● 38, 42, ☐ 33	☐ 33
Loss of valuable economic resources	Recovery of timber and mineral resources before flooding of the impoundment zone.	M	TR-C	F	E	Resources must be rescued sufficiently in advance before impounding. This measure does not allow for full preservation of resources.	● 104 ☐ 33	☐ 33
Insufficiently protected farmland and arable soils	Establishment of a policy regarding the implementation of soil conservation methods and the development of sustainable farming methods	M-C	TR	F-W	E	This measure has shown mixed effectiveness. It requires substantial financial resources.	● 38 ☐ 33	☐ 33
Absence of appropriate planning hinders future farmland productivity downstream of the dam	Establishment of an agriculture management plan downstream of the dam	M-E-C	TR	F-S-W	E	By ensuring the proper supply of irrigation, this measure allows an increase in crop productivity.	● 38 ☐ 33	☐ 33

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
M: mountain, **F**: forest, **S**: savannah, **W**: wetland

Effectiveness
E: effective, **LE**: limited effectiveness, **NE**: non effective, **ND**: undetermined

References as per climatic zones
☐ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ∗ (**C**) cold region

TABLE 2.6: Mitigation, enhancement and compensation measures applicable for impacts on to the human environment – Socio-economic impacts (Cont'd)

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
Workforce lacks proper training and opportunities to adapt to new conditions in the impoundment zone	Promote the retraining of surplus labor and develop farming, animal raising, forestry, fishing and handicrafts in the region.	M-C	TR	F-W	ND		● 53, 54 □ 33	□ 33
Insufficient economic benefits for local communities	Promote the hiring of local manpower and the granting of contracts to local and regional companies Assistance or training to obtain new jobs, employment equity programs	M-E-C	TR-T-C	F-S-W	E	Such measures are generally acknowledged to have good results without benefiting all of the affected population. Allows an increase in the percentage of benefits to the communities living around the reservoir. Also allows the stabilization of the workforce and a reduction in labor costs.	● 42, 53, 54 ∗ 17, 65 130, 131 □ 33	∗ 74 □ 33
	Prolong project construction schedules to facilitate the hiring of local labor	M-E-C	TR	F	E	Reduces the peak demand for migrant laborers, but may increase project costs and be in conflict with other priorities.	□ 33	□ 33
Work site conflicts because of insufficient cultural awareness	Information programs for workers concerning aboriginal communities	M	C	F	E	Meets intended objectives.	∗ 17, 65, 131	
Conflicts over land use, ethnic conflicts, preservation of traditional activities	Restrict access of non-residents to the territory, prohibition of contacts between various ethnic groups, management of conflicts between workers and residents.	M	TR-C	F	E	This measure produced the expected effects in the short term. In the medium and long term, recreational use of traditional hunting and fishing grounds by non-residents increased noticeably. Very difficult measure to apply. It may involve for instance the construction of separate recreational facilities for workers or of separate foodstuff depots for aboriginal groups	● 104 ∗ 65, 131 □ 33	□ 33
Ethnic conflicts, threats to traditional activities and ways-of-life.	Adapt to existing social relationships between local and migrant worker populations during construction.	M	TR	F	E	Meets intended objectives.	● 53	
Threats to quality of drinking water supply	Adapt to existing social relationships between local and migrant worker populations during construction.	M-C	TR-T-C	F-W	E	Meets intended objectives.	● 104 ∗ 65, 130 □ 33	● 26 □ 33
Insufficient community infrastructures for existing population and future residents	Design the new infrastructures associated with the project to serve the resident population as well as the population attracted by the project	M-C	TR-T-C	F-S-W	E	Meets intended needs. In certain cases, the presence of the new road has helped to improve local communications and access to regional markets and services, but the beneficial effects are offset by impacts on the fauna of the watershed. Moreover, the lack of financial means has led to the deterioration of the road.	● 38, 104 ◆ 22, 133 ∗ 50, 130, 131 □ 33	∗ 50 □ 33

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
M: mountain, **F**: forest, **S**: savannah, **W**: wetland

Effectiveness
E: effective, **LE**: limited effectiveness, **NE**: non effective, **ND**: undetermined

References as per climatic zones
□ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ∗ (**C**) cold region

TABLE 2.7: Mitigation, enhancement and compensation measures applicable for impacts on to the human environment – Impacts on public health and safety

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
Reservoir and related structures								
Public health impacts in the impoundment zone during the transitional period	Provide means of subsistence to affected populations during the transitional period between resettlement and rehabilitation	M-C	TR	F	ND		● 53 ☐ 33	● 53 ☐ 33
Public health impacts in the impoundment zone during the transitional period between resettlement and rehabilitation	Implementation of public health measures, including prevention, education and follow-up programs, as well as clinical treatment Cooperation with existing community health prevention programs Screening for diseases likely to develop and treatment of existing illnesses. Systematic monitoring of the health of migrant laborers on the work site	M-C	TR-C	F	E	Extensive educational and social programs are required when social and cultural differences are significant. However the education of the community on hygiene and the proper use of water is considered on the long term as the most efficient measure if applied to the whole population through public education. Prevention at the source reduces the chances of epidemic outbreaks and the appearance of unexpected secondary effects. On the other hand, community prevention programs may face cultural resistance, thus complicating the implementation of such a measure.	● 53, 54, 104, 111 ∗ 131 ☐ 33	☐ 33
Public health impacts in the impoundment zone	Treatment of domestic and industrial waste waters and control of air pollution around the reservoir.	M	TR	F-W	E	Meets intended objectives and helps to solve health problems for populations residing near the reservoir.	☐ 33	☐ 33
Public health impacts in the impoundment zone and threats to quality of drinking water supply	Treatment and abundant supply of drinking water	M	TR	F	E	Meets intended objectives but requires important investments.	● 38, 53, 111 ☐ 33	☐ 33
Public health impacts in the impoundment zone	Setting up of control programs and easily accessible clinics	M	TR	F-W	E	This measure concerns both setting up community health centers in the affected communities and in densely populated and developing areas, as well as hiring and training of personnel and setting up structures to acquire the proper medication supply for disease control.	☐ 33	☐ 33
Public health impacts in the impoundment zone	Design and implementation of an epidemiological monitoring program	M-C	TR	F-W	E	This measure aims to detect changes in public health conditions for local and regional populations	☐ 33	☐ 33
Public health impacts in the impoundment zone	Design and implementation of public health education programs	M-C	TR	F-W	E	This measure is mainly for the affected population	☐ 33	☐ 33
Public health impacts in the impoundment zone	Control of the movements of migrant worker populations and of influxes of neighboring populations	M	TR	F-W	E	This measure aims to control health effects resulting from rapid population growth around the reservoir. A land use master plan must be put in place by the government	☐ 33	☐ 33
Public health impacts in the impoundment zone	Setting up of disease vector control programs	M	TR	F-W	E	This measure aims at eliminating disease vectors and controlling still waters	☐ 33	☐ 33

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
M: mountain, **F**: forest, **S**: savannah, **W**: wetland

Effectiveness
E: effective, **LE**: limited effectiveness, **NE**: non effective, **ND**: undetermined

References as per climatic zones
☐ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ∗ (**C**) cold region

TABLE 2.7: Mitigation, enhancement and compensation measures applicable for impacts on to the human environment – Impacts on public health and safety (Cont'd)

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
(Cont'd)	Monitoring of mercury levels in various fish species in reservoirs and adjacent lakes	M	C	F	E	This measure aims to identify which species present a risk for human health and to reorient fishing efforts toward species less at risk. However, some low risk species may not necessarily be popular with users	∗ 65, 101, 126, 131 ☐ 33	∗ 74 ☐ 33
	Application of insecticides and/or biologic controls of mosquitoes, mollusks, etc. Installation of camp sites on highlands well drained zones equipped with screens, sanitary facilities and waste and effluent treatment systems Periodic monitoring of the colonization of plants and adjacent waters by mosquitoes and mollusks Avoid formation of wetlands (marshes, puddles) in the reservoir drawdown zone near inhabited areas, by draining and filling.	M	TR	F	E	Meets intended objectives	● 42, 53, 104 ☐ 33	☐ 33
	Establish a family and community fishing program in adjacent lakes to reduce health risks associated with consumption of reservoir fish that may have accumulated methyl mercury. Support efforts by local residents to pursue their traditional activities and respect their way of life. Establish a program to persuade local residents to hunt and fish in other bodies of water than the hydroelectric reservoir or to diversify their diet by consuming products with low mercury contents	M-C	C	F	E	Overall, this type of measure succeeds in offsetting the loss of interest in fishing for species whose mercury levels have increased following reservoir impoundment. It must be adapted to existing values and perceptions within the concerned communities.. The measure may become a source of financial revenue for users, a benefit that is not to be overlooked. However it requires the rigorous monitoring and follow-up of fish species taken to prevent over-fishing.	∗101, 126	
	Develop commercial fishing of potentially marketable non predator fish species (e.g. locate sturgeon populations and market them) or provide alternative fish foods for local communities	M-E-C	C	F	E	Meets intended objectives	∗101, 126	
Public health impacts in the impoundment zone and local development benefits	Introduction of commercial reservoir fish farming	M-E-C	TR-T-C	F-W	E	This measure was the subject of a pilot project to assess its feasibility. The results seem positive. The most attractive short-term impact was the training of aboriginal participants in techniques for raising aquatic species.	● 53, 104 ◆ 50 ∗ 2, 50, 101, 126 ☐ 33, 51	◆ 50 ☐ 33, 51
Access to reservoir and nautical safety	Clear navigation channels and prepare navigation charts. Install markers for navigable zones and create navigation channels	M	C	F	E	Accessibility and safety assured. Effect appreciated in the short-term. Temporary benefit	∗65, 130	

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
M: mountain, **F**: forest, **S**: savannah, **W**: wetland

Effectiveness
E: effective, **LE**: limited effectiveness, **NE**: non effective, **ND**: undetermined

References as per climatic zones
☐ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ∗ (**C**) cold region

TABLE 2.7: Mitigation, enhancement and compensation measures applicable for impacts on to the human environment – Impacts on public health and safety (Cont'd)

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
Access to reservoir and nautical safety	Construction of roads, of access ramps to the reservoir and of bank stabilization structures in order to create safe conditions for access and docking at various points in the reservoir	M	T-C	F	E	Meets intended objectives	◆ 50 ∗ 2, 17, 50, 65, 130, 131	◆ 50 ∗ 50
Nautical safety	Recovery of woody debris from the reservoir	M	C	F	E	Helps navigation in general but conflicts with the creation of shelters for fishing resources. To be done as needed in important sites. This measure generally requires substantial planning and financial support. It is important to know the impacts of this measure on the other components of the environment (e.g. aquatic fauna) before its implementation	∗ 2, 50, 65, 130,131	
Erosion and nautical safety.	Bank stabilization	M	C	F	E	Helps maintain state of shores, and thereby of docking, and navigation	∗ 2, 50, 130,	∗ 50
Safety	Dissemination of information on the dangers of travel on reservoir and river ice	M	C	F	E	Meets intended objectives	∗ 130	
Safety	Mapping of reservoir and of other hydrographic changes	M	C	F	E	Meets intended objectives	∗ 130	
Safety and public health	Program to manage contaminants and hazardous waste.	M	C	F	E	Meets intended objectives	∗ 67, 77	∗ 81
Safety of users on access roads	Prevention program for road safety	M	C	F	E	Meets intended objectives	∗ 65, 67, 77	∗ 81
Quality of life of local residents	Adequate work schedules and weekends in urban areas	M	C	F	E	Meets intended objectives	∗ 65, 67, 77	∗ 81
Quality of life and noise pollution	In urban areas, compulsory inspection of heavy vehicles and use of hydraulic rather than pneumatic drills, to reduce impact on sound environment	M	C	F	E	Meets intended objectives	∗ 65, 67, 77	∗ 81
Safety and public health	Project follow up by an expert panel, preparation and implementation of operation and emergency plans. Safety inspection after construction.	M	TR-T-C	M-F-S-W	ND	To eliminate risks to public safety	☐ 33	☐ 33

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
M: mountain, **F**: forest, **S**: savannah, **W**: wetland

Effectiveness
E: effective, **LE**: limited effectiveness, **NE**: non effective, **ND**: undetermined

References as per climatic zones
☐ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ∗ (**C**) cold region

TABLE 2.8: Mitigation, enhancement or compensation measures relative to the human environment – Impacts on hunting and fishing

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
Reservoir and related structures								
Use of fishing resources	Development of fishing areas in reservoirs and in sectors with high fishing potential. Creation of wetlands favorable for water fowl hunting by aboriginal communities. Construction of weirs in reduced flow rivers.	M	T-C	F	E	This measure must be applied in sites where the fishing potential is sufficiently important and accessible by the local community to justify its costs.	✱ 17, 50, 59, 130, 131	✱ 50
Loss of resources and increase in possibilities in adjacent areas	Intensive trapping and relocation of beaver	M-C	C	F	E	This measure depends significantly on the level of cooperation of users. Success in relocation is offset by the natural behavior of the beaver, which relocates itself.	✱ 60, 131	
Loss of traditional hunting grounds	Program to relocate trapping zones.	M-C	C	F	E	Cooperation with communities and users and extensive knowledge of local customs are essential for the success of this measure.	✱ 131	
Traditional activities	Clearing and cleaning of banks, sides of dam and certain secondary dikes in order to improve net fishing conditions.	M-C	C	F	E	This measure mitigates the impacts of a project from several angles. Mainly, it contributes to ensuring the maintenance of optimal conditions for net fishing and access to launching and docking ramps. It also reduces landscape impacts.	✱ 18, 59, 131	
Accessibility to fishing areas and loss of hunting resources	Construction of roads and access ramps to the reservoir. Construction and maintenance of access to resources in the new territories in compensation for losses of resources in the flooded territories.	M-C	C	F	E	It creates access to new resources to offset losses caused by flooded zones. It contributes to preserving the quality of existing navigation routes.	✱ 65, 130, 131	✱ 74
Loss of traditional activities	Use of minimum controlled flow in order to improve the success of local commercial and sports fishing methods downstream of the dam.	M-C	T-C	F	E	Reduction of flow and its subsequent control have made line fishing possible and new sites accessible.	◆ 2, 23 ✱ 2, 32, 50 ☐ 51	✱ 50, 64 ☐ 51
Overuse of resources	Management program for use of wildlife resources by workers.	M	C	F	E	Meets intended objectives	✱ 131	
Accessibility to resources	Creation of snowmobile routes.	M-E-C	C	F	E	Meets intended objectives	✱ 130, 131	

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
M: mountain, **F**: forest, **S**: savannah, **W**: wetland

Effectiveness
E: effective, **LE**: limited effectiveness, **NE**: non effective, **ND**: undetermined

References as per climatic zones
☐ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ✱ (**C**) cold region

TABLE 2.9: Mitigation, enhancement or compensation measures relative to the human environment – Impacts on recreational uses

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
Reservoir and related structures								
Use of territory	Restriction of use of lake waters for production of electricity in order to promote other riparian activities.	M	T	F	E	In the short term, this measure contributed to restoring a portion of the original conditions for water levels, recreational activities and facility of navigation. In the long term, reductions in power generation may become too expensive to justify such a measure	◆ 8, 12, 50 ∗ 50 □ 33	◆ 11 ∗ 50 □ 33
Economic activities and local benefits	Integration of installations into the landscape. Development of recreational and tourist facilities (paths, lookouts, camping sites, picnic areas, park creation, access for aquatic activities). Promotion of installations for tourism and educational purposes	E-C	T-C	F	E	This measure is unavoidable in any project. It is acknowledged that supplying information about a project facilitates its acceptance by local populations and improves cooperation. Groups and local communities should preferably be involved in the implementation of this measure, because it also allows the promotion of the region's own characteristics.	◆ 23 ∗ □ 33	□ 33
Use of resources	Financing and construction of an ecological interpretation center	C	T	F	E	Meets intended objectives	◆ 50	◆ 50

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
M: mountain, **F**: forest, **S**: savannah, **W**: wetland

Effectiveness
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References as per climatic zones
□ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ∗ (**C**) cold region

TABLE 2.10: Mitigation, enhancement or compensation measures relative to the human environment – Heritage impacts

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
Reservoir and related structures								
Heritage and archeology	Rescue of archeological material and dissemination of the information by its publication in a summary	M	TR-T-C	F	LE	This measure does not always appear to meet its intended objectives. It must be applied with careful planning, which is lacking in project specifications. Moreover, the sites selected for the relocation of elements affected do not generally correspond to the historical and cultural constraints of the original conditions. Social tensions are created in most cases.	● 54, 104, 111 ◆ 50 ∗ 50, 65, 131, 133 □ 33	◆ 50 ∗ 50 □ 33
Historical sites and archeology	Protection of archeological, paleontological, historical, religious and sacred sites.	M-C	TR-T-C	F	E	Meets intended objectives.	● 104 ◆ 23, 35, 50, 57, 139 ∗ 50, 65, 67, 131 □ 33	◆ 50 ∗ 50 □ 33
Archeological sites and preservation of cultural heritage	Construction of an archeological interpretation center.	E-C	C	F	E	Meets intended objectives.	∗ 65	
Loss of archeological artifacts	Program of archeological digs in the affected sectors.	M	TR-C		E	Meets intended objectives.	● 104 ◆ 23, 50 ∗ 50, 67, 131 □ 33	◆ 50 ∗ 50, 74 □ 33

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
M: mountain, **F**: forest, **S**: savannah, **W**: wetland

Effectiveness
E: effective, **LE**: limited effectiveness, **NE**: non effective, **ND**: undetermined

References as per climatic zones
□ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ∗ (**C**) cold region

TABLE 2.11: Mitigation, enhancement or compensation measures relative to the human environment – Impacts of rivers with a modified flow and diversion canal

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
Loss of agricultural land and revenues	Restriction of use of lake waters for production of electricity in order to promote other riparian activities.	M-C	TR	F-S-W	ND		☐ 33	● 26 ☐ 33
Economic activities	Assistance for support agencies in diversifying diversification of economic and social activities	C	TR	F-S-W	ND		☐ 33	● 26 ☐ 33
Economic development	Institutional strengthening.	C	TR	F-S-W	ND		☐ 33	● 26 ☐ 33
Social development	Promotion of diversification of women's activities to generate revenues	M-C	TR	F-S-W	ND		☐ 33	● 26 ☐ 33
Quality of life	Improvement of living standards in rural communities.	M-C	TR	F-S-W	ND		☐ 33	● 26 ☐ 33
Land use planning	Avoid the development of large neighborhoods in a single village on either side of a diversion. Plan for assigning lands in the project influence zone. Maintain water resources in appropriate quality and quantity for irrigation land.	M-C	TR	F-S-W	ND		☐ 33	☐ 33
Land use planning	Respect the identity and cohesiveness of existing land holdings and hamlets	M-C	TR	F-S-W	ND		☐ 33	● 26 ☐ 33
Quality of access roads	Restoration of access roads in poor condition	M-E-C	TR	F-S-W	E	Meets intended objectives.	☐ 33	● 26 ☐ 33
Conservation of archeological and historic sites	Preservation of historic, sacred and archeological sites.	M-C	TR-C	F-S-W	E	Meets intended objectives.	☐ 33	☐ 33
Human health	Systematic monitoring of the health of workers	M	TR-C	F-S-W	E	Meets intended objectives.	∗ 131 ☐ 33	● 26 ☐ 33
Drinking water quality	Installation of reservoirs intended to filter water from the diversion for use in drinking water by residents.	M	TR	F-S-W	ND		☐ 33	● 26 ☐ 33
Drinking water quality	Protect and monitor drinking water reservoirs to avoid unrestricted access by people or cattle.	M	TR	F-S-W	ND			● 26
Drinking water quality	Maintain water intakes ensuring permanent supply of perimeters and village reservoirs	M	TR	F-S-W	ND			● 26
Drinking water quality and human health	Install a settling basin at the entrance to the intake canal to serve as a mollusk trap (intermediate host for schistosomiasis)	M	TR	F-S-W	ND			● 26
Human health	Maintenance of canal to avoid development of aquatic plants able to serve as support for intermediate hosts of water-borne diseases.	M	TR	F-S-W	ND			● 26

Measure Type
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Effectiveness
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References as per climatic zones
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TABLE 2.11: Mitigation, enhancement or compensation measures relative to the human environment – Impacts of rivers with a modified flow and diversion canal (Cont'd)

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
Public safety	Protection and safety of users (chain link fences near bridges and walkways, awareness, education)	M	TR	F-S-W	ND			● 26
Public and livestock safety	Construction of road bridges, pedestrian walkways and walkways for cattle and large wild animals.	M	.TR	F-S-W	ND			● 26
Security of users	Dissemination of information on the risks associated with circulation on ice.	M	C	F	E	Meets intended objectives.	∗ 130	
Quality of life and sound pollution	Reduction of sound pollution by installing mufflers on internal combustion engines used in large earth moving machinery.	M	C	F	E	Meets intended objectives.	∗ 67	
Land use	Construction of weirs in order to maintain water levels for recreational boating and other activities.	M-C	C	F	E	Meets intended objectives.	∗ 50	∗ 50,64
Land use	Displacement of access paths for recreational and tourist activities.	M	C	F	E	Meets intended objectives.	∗ 50	∗ 50,64
Use of resources	Installation of obstacles that cannot be penetrated by sports fishing species so that adequate fishing quality is maintained.	M	C	F	E	Meets intended objectives.		∗ 64
Use of resources	Maintenance of controlled flow to preserve adequate fishing quality.	M-C	C	F	E	Meets intended objectives.	◆ 2 ∗ 2, 50	∗ 50, 64

Measure Type
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TABLE 2.12: Mitigation, enhancement or compensation measures relative to the human environment – Impacts of power lines and related structures

Impacts	Measures	Type	Climatic Zone	Biome	Effective-ness	Comments	Measures applied	Measures proposed
Quality of life and sound pollution	Maintenance of vehicles in good operating condition (air pollution, noise, soil contamination).	M	C	F	E	Meets intended objectives.	∗ 67, 77	
Quality of life and air pollution	Use of authorized dust controls (water, calcium chloride ammonium or calcium lignosulfonate)	M	C	F	E	Meets intended objectives.	∗ 67, 77	
Quality of life and air pollution	Avoid traffic by heavy vehicles near inhabited zones and execution of noisy work outside normal working hours.	M	C	F	E	Meets intended objectives.	∗ 67, 77	
Land use	Avoid obstructing paths for recreational and tourist activities.	M	C	F	E	Meets intended objectives.	∗ 67, 77	
Landscape impacts	Arrange towers in such a way as to avoid their being too visible from communications paths.	M	C	F	E	Meets intended objectives.	∗ 67, 77	
Use of land and right-of-ways	Promote multiple uses in right-of-ways (gardening, green space, public infrastructure, recreational area).	M	C	F	E	Meets intended objectives.	∗ 67, 77	
Drinking water quality	Avoid using machinery near drinking water supply points, water intakes and leach fields.	M	C	F	E	Meets intended objectives.	∗ 67, 77	
Soil and ground water quality	Protect against accidental spills of contaminants in storage areas.	M	C	F	E	Meets intended objectives.	∗ 67, 77	
Soil and ground water quality	Establish and apply an emergency plan for accidental spills of contaminants	M	C	F	E	Meets intended objectives.	∗ 67, 77	
Public safety	Limit rock demolition destruction of rocks in the right-of-way by using blasting mats, staggered distribution of charges or desynchronization of explosions.	M	C	F	E	Meets intended objectives.	∗ 67, 77	
Access to and use of agricultural land	Access to right-of-way in farming areas on existing roads and crop lands and develop access in consultation with farmers.	M	TR-C	F	E	Meets intended objectives.	● 42 ∗ 67, 77	
Heritage conservation	Protect identified archeological sites.	M	C	F	E	Meets intended objectives.	∗ 67, 77	
Public safety	Protect and increase public awareness about the dangers of climbing power transmission towers.	M	TR	F	E	Meets intended objectives.	● 42	
Environmental protection	Apply mechanical wood clearing and regrowth control with herbicides to protect sensitive areas.	M	TR	F	E	Meets intended objectives.	● 42 ∗ 67, 77	
Protection of agricultural land	Avoid key agricultural or pasture zones.	M	TR-C	F	E	Meets intended objectives.	● 42 ∗ 67	
Loss of agricultural land and production	Compensation for loss of agricultural land.	M-C	TR	F	E	Meets intended objectives.	● 42	
Agricultural production	Synchronize construction with agricultural seasons and avoid dry seasons.	M	TR	F	E	Meets intended objectives.	● 42	
Local economy	Hire local manpower.	M	TR-C	F	E	Meets intended objectives.	● 42	∗ 68

Measure Type
M: mitigation, **E**: enhancement, **C**: compensation

Biome
M: mountain, **F**: forest, **S**: savannah, **W**: wetland

Effectiveness
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References as per climatic zones
□ general, ● (**TR**) tropical region, ◆ (**T**) temperate, ∗ (**C**) cold region

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