INTERNATIONAL ENERGY AGENCY

IMPLEMENTING AGREEMENT FOR
HYDROPOWER TECHNOLOGIES
AND PROGRAMMES

ANNEX III

HYDROPOWER AND THE ENVIRONMENT:

PRESENT CONTEXT AND GUIDELINES FOR FUTURE ACTION

Subtask 5
Report

VOLUME III:
Appendices

May 2000

TECHNICAL REPORTS IN THIS SERIES

Hydropower Upgrading Task Force (Annex 1)
Guidelines on Methodology for Hydroelectric Turbine Upgrading by Runner Replacement – 1998 (available to non-participants at a cost of U.S. $1,000 per copy)

Guidelines on Methodology for the Upgrading of Hydroelectric Generators – to be completed in May 2000

Guidelines on Methodology for the Upgrading of Hydropower Control Systems – to be completed in 2000

Small-scale Hydropower Task Force (Annex 2)
Small-scale Hydro Assessment Methodologies – to be completed in May 2000 (available to non-participants on request)

Research and Development Priorities for Small-scale Hydro Projects – to be completed in May 2000 (available to non-participants on request)

Financing Options for Small-scale Hydro Projects – to be completed in May 2000 (available to non-participants on request)

Global database on small hydro sites available on the Internet at: www.small-hydro.com

Environment Task Force (Annex 3)
Survey on Positive and Negative Environmental and Social Impacts and the Effects of Mitigation Measures on Hydropower Development – 2000 (available to non-participants on request)

A Comparison of the Environmental Impacts of Hydropower with those of Other Generation Technologies – 2000 (available to non-participants on request)

Legal Frameworks, Licensing Procedures, and Guidelines for Environmental Impact Assessments of Hydropower Developments – 2000 (available to non-participants on request)

Hydropower and the Environment: Present Context and Guidelines for Future Action
Volume 1: Summary and Recommendations
Volume 2 : Main Report
Volume 3 : Appendices
– 2000 (available to non-participants on request)

Hydropower and the Environment: Effectiveness of Mitigation Measures – 2000 (available to non-participants on request)

Education and Training Task Force (Annex 5)
All of the following reports are available on the Internet at www.annexv.iea.org (some reports may consist of more than one volume)

Summary of Results of the Survey of Current Education and Training Practices in Operation and Maintenance – 1998 (available to non-participants on request)

Development of Recommendations and Methods for Education and Training in Hydropower Operation and Maintenance – 2000 (available to non-participants on request)

Survey of Current Education and Training Practice in Hydropower Planning – 1998 (available to non-participants on request)

Structuring of Education and Training Programmes in Hydropower Planning, and Recommendations on Teaching Material and Reference Literature - 2000 (available to non-participants on request)

Guidelines for Creation of Digital Lectures – 2000 (available to non-participants on request)

Evaluation of Tests – Internet-based Distance Learning – 2000 (available to non-participants on request)

Brochure
A brochure is available for the general public. Entitled "Hydropower – a Key to Prosperity in the Growing World", it can be found on the Internet (www.usbr.gov/power/data/data.htm) or be obtained from the Secretary. (address on the inside back cover)

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Annex III

I wish to thank the Annex III team, their companies and experts for the support and constructive and professional participation during all these 5 years. The Expert Meetings and Workshops have been characterized by an open, friendly and informal atmosphere, which have ensured common understanding with regard to professional content and the decisions made. During the 11 meetings the work has progressed steadily, with no steps back caused by misunderstandings or unclear decisions. Special thanks go to the National Representatives, Subtask Leaders and the Annex III Secretary for their enthusiasm, co-operation and achievement. On behalf of all the participants in our meetings and workshops, I would like to express our appreciation to the companies which were our hosts: Vattenfall, ENEL, UNESA, CRIEPI, NEF, Kemijoki OY and Hydro-Québec.

The credibility of the Annex III work has been greatly enhanced by the contributions from the participating experts representing: Ethiopia, Indonesia, Laos, Nepal, Philippines and Vietnam. Japan and Norway supported their participation. All Annex III countries and companies are thanked for financing additional internationally renowned experts in specialized subject areas. This ensured that progress was maintained and credibility was enhanced.

I also wish to thank the professionals who have filled in the comprehensive questionnaires. The participation from the World Bank and WCD has inspired the Annex III team and contributed to the actuality of our results.

The Executive Committee members are thanked for their guidance, support and co-operation.

Even if all names are given in the review of the IEA-Annex III Organization in Volume III, appendix C, I would like to draw special attention to the following persons due to their active participation and support over the years: Mr. Jens Petter Taasen (Annex III secretary and STL 1), Ms. Kirsti Hind Fagerlund (Annex III secretary and STL 1), Mr.Björn Svensson (STL 3), Mr. José M. del Corral Beltrán (STL 4), Ms. Cristina Rivero (STL 4), Mr. Jean-Étienne Klimpt (STL 5), Mr. Gaétan Hayeur (STL 6), Mr. Serge Trussart (STL 6), Mr. Joseph Milewski, Mr. Frans Koch (Executive Committee secretary), Mr. Luc Gagnon, Mr. Raimo Kaikkonen, Mr. Hannu Puranen, Mr. Mario Tomasino, Mr. Shuichi Aki, Mr. Jun Hashimoto, Mr. Tsuyoshi Nakahata, Mr. Kiyoaki Uchikawa, Mr. Yohji Uchiyama, Mr. Svein T. Båtvik, Mr. Rune Flatby, Mr. Geir Y. Hermansen, Mr. David Corregidor Sanz, and Mr. Magnus Brandel.

Oslo, 30 March 2000

Sverre Husebye, Operating Agent,IEA-Annex III

Subtask 5

We wish to thank the Annex III team for the constant support, drafting and on-going review of this Subtask report: Shuichi Aki, Svein Båtvik, Magnus Brandel, David Corregidor, Rune Flatby, Geir Hermansen, Sverre Husebye, Raimo Kaikkonen, Joseph Milewski, Hannu Puranen, Cristina Rivero, Björn Svensson, Jens Petter Taasen, Serge Trussart, Kiyoaki Uchikawa.

To our reviewers and colleagues, and those who spent long hours collaborating on sections of the report: Camille Bélanger, Gilles Bérubé, Louis Chamard, Yves Comtois, Dominique Egré, Luc Gagnon, Louis Gilbert, Frans Koch, Danielle Messier, Engelbert Oud, Martin Pérusse, Vincent Roquet, Louise Roy, Karin Seelos, Pierre Sénécal, Tor Ziegler.

To the Executive Committee for their guidance and comments,

To Jocelyne Baril for her patient editing,

To all those who took time to comment, review, edit and generally improve the contents of this report.

Montréal, 1 April 2000

Jean-Étienne Klimpt, Canadian Representative,
Annex III Subtask 5 Leader

PREFACE

The International Energy Agency (IEA) is an autonomous body, established in November 1974 within the framework of the Organisation 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:

- cooperation 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;
- cooperation 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, the United Kingdom and the 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, diversion of rivers and water withdrawals 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 US$ 805,305.00 while the task sharing part had a budget of 93 person-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

Appendix A

GLOSSARY

APPENDIX A
GLOSSARY

active storage	The volume of water contained between the highest regulated water level and the lowest regulated water level. Syn. *Live Storage*
afterbay	The area downstream of a dam where water having passed through the turbines of a generating station is released into the river. Syn. *Tailbay*
aggradation	Raising of riverbed due to sediment deposition; the opposite of degradation.
alevin	See *fry*
alternating current	An electrical current in which the electrons flow in alternate directions. For example, in North American electrical grids, the flow reversal is governed at 60 cycles per second (hertz).
anadromous fish	Fish that migrate from salt water to fresh water to spawn.
anoxia	Absence or deficiency of oxygen.
anthropogenic	Induced or altered by the presence or activities of humans.
arch dam	A concrete or masonry dam which is curved in plan so as to transmit the major part of the water load to the abutments.
base-load generating station	A power station that is designed to supply an electric power system's basic power needs and is generally operated to serve that purpose.
bed load, bed load sediment	Material moving on or near the stream bed by rolling, sliding, and sometimes making brief excursions into the flow a few diameters above the bed.
benthic fauna, benthos	Organisms that live on the bottom of water bodies. Bottom or depth-inhabiting organisms.
biotope	A physical habitat that has fairly clear boundaries and a strictly defined composition, and supports species that constitute a community.
borrow pit	An area from which fill is taken for use in dam, road, or other construction. Syn. *Borrow area*
brownout	An intentional voltage reduction used to reduce energy loads in an area. A brownout causes lights to dim and motors to run more slowly.

capacity	The maximum sustainable amount of power that can be produced by a generator or carried by a transmission facility at any instant. Usually measured in megawatts (MW).
catchment	The area which drains naturally to a particular point on a river.
cofferdam	A temporary structure enclosing all or part of the construction area so that construction can proceed in the dry. A diversion cofferdam diverts a river into a pipe, channel or tunnel.
combined cycle gas turbine plant	The combination of gas turbine and steam turbine in an electric generating plant. The waste heat from the first turbine cycle provides the heat energy for the second turbine cycle.
compaction	Mechanical action which increases the density by reducing the voids of a material.
compensation measure	Measure sought to compensate for impacts that cannot be mitigated and for residual impacts of the project after the implementation of mitigation measures. See *Mitigation measure. Enhancement measure.* See also *Subtask 6 report.*
compensation water	The fraction of stream flow released through a hydroelectric dam specifically to meet the needs of downstream users and/or habitats. Syn. *Ecological Flow*
contingency plan	A contingency plan seeks to design the technical elements needed to efficiently control the accidents that may occur during the construction and/or operation of a hydropower station.
cumulative impact assessment	The assessment of the impact on the environment which results from the incremental impact of an action when added to other past, present or reasonably foreseeable actions regardless of what agency or person undertakes such actions. Cumulative impact can result from individually minor but collectively significant actions taking place over a period of time. For example, a single automobile causes relatively minor impacts, whereas a million automobile cause significant cumulative impacts (on air quality, petroleum ressources, etc.).
dam-overtopping	Water flowing over the top of the dam in extreme conditions such as major floods or landslides.
dead storage	Volume of water in a reservoir below the lowest regulated water level.
decommissioning	For hydroelectric powerplants, refers to a permanent end to electricity generation, generally at the end of the plant's useful life. Decommissioning may involve dismantling of the generation equipment, and / or removal of the dam.

degradation	Lowering of riverbed due to erosion. Opposite of *aggradation*.
delta	Flat area of alluvium formed at the mouth of some rivers where the main stream divides into several distributaries before reaching a sea or lake.
demand side management (DSM)	Strategies for reducing electricity consumption by influencing when and how customers use electricity. Demand-side management includes such things as conservation programs and incentives for switching electricity use from mid-day to evening.
design criteria	Principles, rules or standards guiding our judgments on the suitability of outlines, sketches, or plans as of an edifice, or a machine to be executed or constructed.
Desorption	The process of desorbing. To remove (a sorbed substance) by the reverse of adsorption or absorption.
dike	A ridge, embankment, long mound or dam thrown up to resist the encroachments of the sea, or to prevent low-lying lands from being flooded by seas, rivers or streams. An embankment that prevents water in a reservoir from flowing along secondary valleys beyond designated boundaries.
direct current	An electrical current in which the electrons flow continuously in one direction. Direct current is used in specialized applications in commercial electricity generation, transmission, and distribution systems.
discharge	The volume of water flowing at a given time, usually expressed in cubic meters per second.
diversion	The act of redirecting part or all of a river's flow into another river or reservoir.
drawdown	The amplitude, or height, of water level fluctuation in a reservoir or a natural lake.
drawdown zone, or area	Reservoir shores exposed during low water levels.
drawdown agriculture	Seasonal agriculture along the reservoir shores exposed during low water levels.
earthfill dam	An embankment dam in which more than 50 % of the total volume comprises compacted or dumped pervious natural or crushed stone.
ecological flow	See *Compensation Water*
ecosystem	The complex formed by living organisms (community) and the physiochemical environment in which they live (biotope).

eelgrass	A submerged long-leaved monocotyledonous marine plant (Zostera marina) of the eelgrass family that has stems used especially in woven products (as mats and hats)
embankment dam	Any dam constructed of excavated natural materials or of waste materials.
energy	1. Force or action of doing work. Measured in terms of the work it is capable of doing; usually electric energy is measured in kilowatt-hours (kWh). 2. The capacity of a system to produce external activity.
energy payback ratio	Ratio of energy produced by a power plant during its life-span divided by the energy required to build, maintain and fuel the power plant.
enhancement measure	Measure used to improve existing environmental or social conditions which are not directly affected by a hydropower project. Such measures may be implemented outside of the project area. See *Mitigation measure*, *compensation measure.* See also Subtask 6 report.
environmental assessment (EA)	The systematic, reproducible and interdisciplinary identification, prediction and evaluation, mitigation and management of impacts from proposed development and its reasonable alternatives.
environmental justice	Pursuit of equal justice and equal protection for all people under the environmental statues and regulations. This concept recognizes that environmental impacts generally do not fall equally on everyone in society and tries to avoid these disproportionate impacts.
environmental management system (EMS)	A structured approach for determining, implementing and reviewing environmental policy through the use of a system which includes organizational structure, responsibilities, practices, procedures, processes.
epilimnion	The upper layer of a stratified lake or reservoir with essentially uniform warmer temperatures. *See hypolimnion*
estuary	A semi-enclosed coastal body of water where continental influences (freshwater discharges) and marine influences (tide, salt water) can be simultaneously observed. The mouth of a river subject to tides, forming a deep indentation in the coastline.
eutrophic	Of a body of water: characterized by the state resulting from eutrophication. See *oligotrophic*

eutrophication	1. A process where more organic matter is produced than existing biological oxidization processes can consume. 2. The process of fertilization that causes high productivity and biomass in an aquatic ecosystem. Eutrophication can be a natural process or it can be a man-made process accelerated by an increase of nutrient loading to a lake by human activity. 3. Process of nutrient enrichment of a body of water. In advanced state, causes severe deoxygenation of the water body.
evapotranspiration	Joint effect of the loss of water to the atmosphere from the soil surface (evaporation) and from the plant surface (transpiration).
ex-post evaluation	Done, made, or formulated after the fact, to determine the significance, worth, or condition by careful appraisal and study.
externality	A cost or benefit not accounted for in the price of goods or services. Often "externality" refers to the cost of pollution and other environmental or social impacts.
fetch	The maximum distance along the surface of a reservoir over which wind can generate waves that strike the dam.
flood control	Reducing the risk by building dams and/or embankments and/or altering the river channels.
flood management	Reducing flood risks by actions such as discouraging floodplain development, establishing flood warning systems, protecting urban areas and isolated buildings, and allowing the most flood prone areas to remain as wetlands.
flood recession agriculture	Flood cropping technique where crops are planted on floodplains at the end of the wet season to exploit the moisture left behind by the retreating floods.
flood releases	Releasing large volumes of water form a reservoir to simulate natural flooding conditions.
floodplain	Level land that may be submerged by floodwater.
frazil	Fine spiculae, plates or discoids of ice suspended in water. In rivers and lakes it is formed in supercooled turbulent waters.
freshet	A great rise in, or a sudden overflowing of, a small stream, usually caused by heavy rains or rapidly melting snow in the highlands at the head of the stream.
fry	A newly hatched and incompletely developed fish depending on its yolk sac for nourishment and still living in its nest or inactive on the bottom.
gabion	A cylindrical basket for filling with earth or stones, used in engineering.

Genco	A generic name for an electricity company that is exclusively concerned with electricity generation, as would occur after vertical de-integration of the industry.
generation	The act or process of producing electrical energy from other forms of energy. Also refers to the amount of electrical energy so produced.
generator	A machine that converts mechanical energy into electrical energy.
gravity dam	A dam constructed of concrete and/or masonry which relies on its weight for stability
greenhouse gases (GHGs)	Gases that trap the heat of the sun in the Earth's atmosphere, producing the greenhouse effect. The two major greenhouse gases are water vapor (H_2O) and carbon dioxide (CO_2). Other GHGes include methane (CH_4), ozone (O_3), chlorofluoro-carbons (CFC), and nitrous oxides (NO_x). Anthropogenic GHGs constitute the emissions generated by human activities.
groundwater	Subsurface water contained in saturated soils and rocks.
head pond	Reservoir behind a run-of-river dam.
head	1. The vertical height of water in a reservoir above the turbine. The more head, the more power that is exerted on the turbine by the force of gravity. 2. The difference between two water surface elevations.
headbay	Impoundment immediately upstream from a dam or hydroelectric plant intake structure. The term is applicable to all types of hydroelectric developments (storage, run-of-river, and pumped-storage). Syn. *Forebay*
hydroelectric	The production of electrical power through use of the gravitational force of falling water.
hydrological cycle	The continuous interchange of water between land, sea or other water surface, and the atmosphere.
hydrometric networks	Water data collection networks based on several recording stations measuring streamflow, lake levels and sediment data, etc.
hypolimnion	The lower layer of a stratified lake or reservoir with essentially uniform colder temperatures. See *epilimnion*
impact management plan	A structured management plan that outlines the mitigation, monitoring and management requirements arising from an environmental assessment.

impact monitoring	Monitoring of environmental/social/health variables, which are expected to change after a project has been constructed and is operational.
impounding	Creating a body of water [impoundment zone] by the construction of a dam.
independent system operator (ISO)	A neutral operator responsible for maintaining an instantaneous balance of the electricity grid system. The ISO performs its function by controlling the dispatch of some plants to ensure that loads match resources available to the system.
initial environmental evaluation / examination	A report containing a brief, preliminary evaluation of the types of impacts that would result from an action. Often used as a screening process to assess whether or not proposals should undergo full scale EIA.
integrated resource planning (IRP)	A planning process aimed at minimizing the costs of providing energy services by explicit consideration of all known resources for meeting the demand for such services, including alternative supply resources as well as DMS.
kaplan turbine	A type of turbine that has several blades whose pitch is adjustable. The turbine may have gates to control the angle of the fluid flow into the blades.
kilowatt (kW)	A unit of electrical power equal to 1,000 watts (equivalent to about 1.3 horsepower).
kilowatt-hour (kWh)	A basic unit of electrical energy equivalent to one kilowatt of power used for one hour.
lacustrine	Of, relating to, formed in, living in, or growing in lakes.
large dam	For the purpose of inclusion in the ICOLD World Register of Dams, a large dam is defined as any dam above 15 meters in height (measured from the lowest point of foundation to top of dam) or any dam between 10 and 15 meters in height which meets at least one of the following conditions a) the crest length is not less than 500 meters; b) the capacity of the reservoir formed by the dam is not less than one million cubic meters; c) the maximum flood discharge dealt with by the dam is not less than 200 cubic meters per second; d) the dam had specially difficult foundation problems; e) the dams is of unusual design.
lentic environment	Standing waters, such as lakes, ponds, and marshes.
level of service (of power plants)	Capacity of an electricity generation option to meet demand patterns within required quality standards.
limnology	The scientific study of bodies of freshwater (as lakes).

lining	With reference to a canal, tunnel or shaft, a coating of asphaltic concrete or reinforced concrete to provide water tightness, to prevent erosion or to reduce friction.
live storage	See *Active Storage*
load	The amount of electrical power or energy delivered or required at any specified point or points on a system. Load originates primarily at the energy-consuming equipment of customers.
local distribution company	A utility that owns and operates the local delivery network for commodities such as electricity, natural gas or water. Another generic term is Disco.
loess	Wind-deposited silt, the fine-grained portion of soil that is non-plastic or very slightly plastic and that exhibits little or no strength when air dry.
lotic environment	Flowing water, such as rivers and streams.
macroinvertebrates	Aquatic organisms without vertebrae that can be seen with the naked eye. Macroinvertebrates usually live under rocks or in the bottom substrate. Most macroinvertebrates are aquatic insects or the aquatic stages of insects, such as stonefly nymphs, mayfly nymphs, dragonfly nymphs and midge larva. They also include such creatures as snails, clams and aquatic worms.
macrophyte	A member of the macroscopic plant life especially of a body of water.
magnitude	A rating of a given earthquake, independent of the place of observation. It is calculated from measurement on seismographs and it is properly expressed in ordinary numbers and decimals based on the logarithmic scale.
marginal cost	The cost to the utility of providing the next (marginal) kilowatt-hour of electricity. Fixed obligations, such as interest on debt, are not included in marginal cost.
megawatt (MW)	A megawatt is one million watts, a measure of electrical power.
megawatt-hour (MWh)	A unit of electrical energy equivalent to one megawatt of power used for one hour. Gigawatt-hour (GWh) and Terawatt-hour (TWh) are one billion and one trillion watts of power used for one hour.
mitigation measure	Measure 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. See *compensation measure. Enhancement measure. Subtask 6 report*
modernization	Renovation activity aiming at improving the plant's utility through the use of more modern materials and technologies.

oligotrophic Deficient in plant nutrients. Especially: having abundant dissolved oxygen - an oligotrophic body of water.

off-peak hours Period of relatively low demand for electrical energy, as specified by the supplier, such as the middle of the night.

parr A young salmon actively feeding in freshwater.

peak load The maximum electricity demand in a stated period of time. It may be the maximum instantaneous load or the maximum average load within a designated period of time.

peak power Electricity supplied at times when demand is highest.

pelton turbine A type of impulse hydropower turbine where water passes through nozzles and strikes cups arranged on the periphery of a runner, or wheel, which causes the runner to rotate, producing mechanical energy. The runner is fixed on a shaft, and the rotational motion of the turbine is transmitted by the shaft to a generator. Generally used for high head, low flow applications.

penstock Conduit used to convey water from a reservoir to the turbines of a hydroelectric plant.

periphyton Any organism that lives attached to submerged plantlife or objects.

photic Penetrated by light, especially of the sun.

photovoltaïc The direct conversion of sunlight to electrical energy through the effects of solar radiation on semiconductor materials.

physiography Description of nature or natural phenomenon in general.

phytoplankton Planktonic plant life.

pisciculture Breeding, rearing and transplantation of fish by artificial means (fish farming).

plant factor Ratio between the actual amount of electricity a powerplant generates over a period of a year and its theoretical maximum capacity. Expressed as a percentage.

e. g., a plant factor of 50% means that a powerplant generates half the electricity it can theoretically produce, if the turbines worked 24 hours a day, 365 days a year, at optimum efficiency.

pondage-type hydropower Run-of-river plants with a minor reservoir capacity.

power exchange An entity responsible for pooling electricity generation and determining spot prices in order to facilitate economic dispatch, as well as providing other ancillary services of the electric system. A generic name is Poolco.

power Electrical energy generated, transferred, or used; usually expressed in kilowatts or megawatts.

powerhouse	Hydropower building or cavern housing turbines and generators.
primary energy	Refers to energy in the form of its natural occurrence which has not yet been transformed into other forms of energy (crude oil, natural gas, uranium, coal, etc.).
pumped-storage plant	A hydroelectric power plant that generates electrical energy to meet peak load by using water pumped into a storage reservoir during off-peak periods.
Refurbishment	Activity returning something to its original state. Refurbishment is generally aimed at restoring the plant to close to “as new” condition and performance with a view to reducing ongoing maintenance costs and extending plant life by a specified period, typically 25 years and up to 50 years.
regional environmental assessment (REA)	An environmental appraisal procedure applied to a relatively large geographic area that examines the likely impacts of sector-wide programs, multiple projects or development policies and plans.
regulated river	River of which the natural flow pattern is altered by a dam or dams.
rehabilitation	Activity aiming at replacing or restoring existing turbine-generator units near the end of their service life.
relicensing	In some countries (e.g., USA) the license for operating a hydroelectric equipment has to be renewed after a certain period encompassing generally the plant’s useful life (30-50 years). Relicensing is hence a procedure for processing a new license. The procedures are practically identical to those for an original license. In any license issued, the concerned agencies include terms and conditions (license articles) that are the requirements a licensee must comply with to keep the licence in effect. These requirements include engineering, safety, economic, and environmental matters. For example, they could include requirements for water quality monitoring, wildlife habitat conservation, a public safety plan, an erosion control plan, and engineering design drawings and specifications.
renewable resource	A power source that is continuously or cyclically renewed by nature. A resource that uses solar, wind, water, geothermal, biomass, or similar sources of energy.
reserve capacity	Generating capacity used to meet unanticipated demands for power or to generate power in the event normal generating resources are not available.
reservoir area	Areas which are converted from land, wetland or watercourse to an impoundment for storage of water, for use by the hydropower station. Includes the riparian zone.
reservoir storage	The volume of water in a reservoir at a given time.

retail competition Permitting end-use electricity customers to contract directly with competing electricity producers.

riparian Of, on, or pertaining to the bank of a river, pond, or lake.

riprap A layer of large uncoursed stones, broken rock or precast blocks placed in random fashion on the upstream slope of an *embankment* dam or on a reservoir shore or on the sides of a channel as a protection against wave and ice action.

risk assessment Assessment methodology used to estimate the frequency and severity of adverse events and to present the results in a form useful to management.

river diversion See *Diversion*

riverine ecosystem Zone of biological and environmental influence of a river and its floodplain.

run-off Precipitation which drains into a watercourse rather than being absorbed by soil.

salinization The accumulation of salt in soil or water to a harmful level.

scoping An early and open activity to identify the impacts that are most likely to be significant and require investigation during the EIA work. The results of scoping are frequently used to prepare terms of reference for the EIA.

screening Preliminary activity undertaken to classify proposals according to the level of assessment that should occur.

secondary energy Refers to energy resulting from a conversion process (refining, gasification, liquefaction, electricity generation, etc.) of primary energy forms into respective derivatives, i.e., motor gasoline, fuel oil, LPG, electricity, charcoal, etc.

sectoral environmental assessment An environmental appraisal procedure applied to a specific sector of the economy (energy, transportation, health, etc.) that examines the likely impacts of sector-wide programs, multiple projects or development policies and plans.

sediment flushing Method of reservoir operation in which the reservoir is temporarily lowered so that fast flowing water can erode accumulated sediments on the reservoir bed.

sediment load Amount of sediment carried by a river.

sediment sluicing Method of reservoir operation in which the reservoir is lowered at the start of the flood season, speeding the movement of water through the reservoir and hence reducing its capacity to trap *sediments*.

sediment Mineral and organic matter transported or deposited by water or air.

seismic intensity	Subjective measurement of the degree of shaking at a specified place by an experienced observer using a descriptive scale.
siltation	To become choked or obstructed with silt.
sluice	Structure with a gate for stopping or regulating flow of water.
spillway	A structure over or through which flood flows are discharged.
storage reservoirs	Reservoirs that have space for retaining water from high flow periods (spring snow melt, monsoons, etc.). Retained water is released as necessary for multiple uses – power production, fish passage, irrigation, and navigation.
stranded costs	Utility costs, which are at risk of not being recovered in a competitive electricity market, because the market price of new generation is less than the costs of existing plants.
strategic environmental assessment (SEA)	An environmental appraisal procedure that examines the likely impacts of proposed policies, programs and plans. Typically applies to government or corporate policy-making.
tailbay	See *Afterbay*
tailrace	Pipe or channel through which turbined water is discharged into a river.
tailwater	The water in the natural stream immediately downstream from a hydropower plant.
terms of reference (TOR)	Written requirements governing EIA implementation, consultations to be held, data to be produced and form/ contents of the EIA report. Often produced as an output from scoping.
thermal power plant	A facility that uses heat to power an electric generator. The heat may be supplied by burning coal, oil, natural gas, biomass or other fuel; by nuclear fission; or by solar or geothermal sources.
thermal stratification	The tendency in deeper lakes for distinct layers of water to form as a result of vertical change in temperature and therefore density.
topsoil	Superficial soil in which vegetation can grow.
Transco	A generic name for an electricity company that is concerned with electricity transmission. Another generic name is Gridco.
transmission grid	An interconnected system of transmission lines and associated equipment for the transfer of electrical energy in bulk between points of supply and points of demand.
trophic level	A level in the movement of matter and energy along a food chain or through a food web.
turbid	Of a body of water: thick or opaque with sediment.

turbine	Machinery that converts kinetic energy of a moving fluid, such as falling water, to mechanical power, which is then converted to electrical power by an attached generator.
upgrading	Renovation activity which aims at improving a plant's productivity.
uprating	Renovation activity aiming at obtaining an increase in plant output (kWh).
utility	A business organization (as an electric company) performing a public service and subject to special governmental regulation.
utilization factor	See *Plant factor*
water retention time	Theoretical residence time of water in a reservoir. Period during which water remains in a reservoir. also: water renewal time.
water table	Upper level of groundwater.
waterlogging	Saturation of soil with water.
watershed	Area drained by a river. (Catchment area)
watt-hour	Unit of energy (Wh) equivalent to the power of one watt over a period of one hour. One kilowatt-hour (kWh) is equal to one thousand watt-hours. One gigawatt-hour (GWh) is equal to 1 million watt-hours. One terawatt-hour (TWh) is equal to 1 billion watt-hours.
watt	Basic unit of electrical power. One kilowatt (kW) is equal to 1 thousand watts. One gigawatt (GW) is equal to 1 million watts. One terawatt (TW) is equal to 1 billion watts.
weir	A low dam or wall across a stream to raise the upstream water level. Termed fixed-crest weir when uncontrolled. A structure built across a stream of channel for the purpose of measuring flow. Sometimes described as m*easuring weir* or g*auging weir*. Types of weir include *broad-crested weir*, *sharp-crested weir*, *drowned weir* or *submerged weir*.
wetland	Area of land which is seasonally, intermittently or permanently waterlogged.
wholesale competition	Competitive electricity market in which the buyers are wholesale companies such as local distribution companies.
zooplankton	Plankton composed of animals.

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Appendix B

ACRONYMS

APPENDIX B
ACRONYMS

ADB	Asian Development Bank
BOT	Build, operate and transfer
BOOT	Build, own, operate and transfer
CFRD	concrete-faced rockfill dam
CAD	Computer-Aided Design
CI	Cumulative impact
CIA	Cumulative impact assessment
DSM	Demand-side management
EA	Environmental Assessment
EIA	Environmental Impact Assessment
EMS	Environmental Management System
GHG	Greenhouse gas
GIS	Geographic information system
HVCD	High voltage direct current
ICOLD	The International Commission on Large Dams
IEA	International Energy Agency
IHA	International Hydropower Association
IPP	Independent power producer
ISO	International Standards Organisation
ISO	Independent System Operator
IUCN	The World Conservation Union
LCA	Life-cycle analysis
LDC	Less-developed countries
NGO	Non-governmental organization
OECD	Organization for Economic Cooperation and Development
PM_{10}	Particulate Matter 10 microns or less
PV	Photovoltaic
POE	Panel of experts
R&R	Resettlement and Rehabilitation
RA	Risk assessment

REA	Regional Environmental Assessment
RCC	Roller compacted concrete dam
SEA	Strategic Environmental Assessment
SIA	Social Impact Assessment
SMES	Super magnetic energy storage
TOR	Terms of Reference
US EIA	United States Energy Information Administration
WCD	World Commission on Dams
WEC	World Energy Council

Appendix C

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APPENDIX C
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Appendix D

PHYSICAL AND CHEMICAL ENVIRONMENT

APPENDIX D
PHYSICAL AND CHEMICAL ENVIRONMENT

Table of Contents

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Hydroelectric developments have major repercussions because they alter the physical environment. The creation of reservoirs can modify many environmental components, among them the following:

- hydrologic regime
- hydraulic characteristics
- sedimentation characteristics
- seismic activity
- climatic conditions
- water quality.

Since the scope of the modifications depends on the purpose of the development as well as the nature of the host environment, it is important to understand the interrelations between these different aspects of hydroelectric structures to obtain a good understanding of the environmental impacts.

1 Types and Locations of Developments Considered

1.1 Hydrologic Regimes

A number of natural factors play a role in determining river flow:

a) Inflow volume
  - rainfall: regime, intensity, frequency and seasonal distribution
  - snowmelt
  - glacier melt.
  - groundwater*.

b) Inflow distribution
  - riverbed slope
  - slope of valley sides
  - existence of lakes and marshy areas
  - soil type (loam clay, sand)
  - type of ground cover (forest, grassland, bare rock).

Other factors include the following:
  - Natural losses by evaporation and evapotranspiration* as well as by infiltration into deep soil layers.

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* See Appendix A: Glossary.

– Modifications to natural regimes due to human activities (agriculture, clearing, irrigation, diversions).

River runoff naturally depends on regional rainfall distribution. At latitudes or altitudes where some of the precipitation falls in the form of snow, runoff tends to decrease during the winter season and then increase dramatically at snow melt.

The Earth's hydrologic regimes can be categorized as follows.

- *Equatorial and wet tropical regime: flow* is generally constant, with two wet seasons occurring when the sun is at its zenith in the region. Typical rivers: the Amazon and the Congo.
- *Monsoon regime:* two rainy seasons of unequal intensity, the heavier one generally beginning suddenly and lasting for several months. Each of the rainy seasons is followed by a dry season during which there may be occasional light rain. Typical rivers: the Ganges, the Brahmaputra, the Mekong.
- *Dry tropical regime:* a single wet season followed by a very dry season without rain. Typical rivers: the Senegal and the Zambezi.
- *Arid regime:* sparse rainfall, generally brief and violent, causing rapid flooding interspersed with droughts of varying duration. Typical rivers: the wadis of North Africa and the Arabian Peninsula, the rivers of Texas.
- *Temperate oceanic regime:* Rainfall relatively well distributed throughout the year, with more in winter, however, and less in summer. Typical rivers: the Seine, the Thames and the Rhine.
- *Temperate continental regime:* Precipitation well-distributed throughout the year with slightly more in spring and fall. Winter precipitation falls in the form of snow. The result is heavy spring floods (because snowmelt coincides with spring rains), a slight low water in summer followed by mild fall flooding and a pronounced winter low water. Typical rivers: the Ottawa, the St. Maurice, the Saint John and the Volga.
- *Boreal regime:* Precipitation distribution similar to temperate continental regime, with less abundant precipitation year round and more severe winters. Typical rivers: the La Grande, the Manicouagan, the McKenzie, the rivers of Siberia and northern Scandinavia.
- *Alpine regime.* The regimes of rivers whose basins are in high mountains are characterized by sudden, heavy flooding in rainy seasons, steady flow during the warm season (because of glacier melt) and a low discharge[*] in the cold season: Typical rivers: rivers in British Columbia and the Andes, tributaries of the Indus (Ravi, Chenab).

The descriptions above apply to rivers whose entire course is in one zone. Many large rivers run through several zones and their hydrologic regimes incorporate features of all of them.

For example:

- *The Nile*. The Nile originates in an equatorial zone, runs through a dry tropical zone and ends in an arid zone.
- *The Niger.* The Niger originates in a dry tropical zone, runs through an arid zone, returns to a dry tropical zone and ends in an equatorial zone.

[*] See Appendix A: Glossary.

- Many rivers that begin in alpine zones end in lowlands with a contrasting climate: the Yangtze, the Rhone, the Columbia, etc.

For hydropower purposes, 3 general categories can be used: 1. Equatorial and Tropical, 2. Temperate oceanic and continental. 3. Boreal and Alpine.

1.2 Reservoir-induced Modifications to Hydrologic Regimes

A hydroelectric project uses river inflows to generate electricity.

Demand for electricity depends on community activities (industry, transport, lighting) and climate (heating, air-conditioning), and it fluctuates on several time scales (annual, seasonal, daily and hourly).

As indicated above, natural inflows fluctuate seasonally depending on the climate. Hourly, daily or yearly distribution depends on the timing of rainfall or snowmelt episodes.

Natural inflows do not coincide with fluctuations in electricity demand. To maximize the use of natural inflows many hydroelectric developments include a reservoir so that inflows not needed to meet demand can be stored and used later when inflows are less abundant.

Reservoirs in hydroelectric developments can be classified by the type of regulation they provide:

- *Year-to-year*. These are very large reservoirs, large enough to store excess inflows of one or more wet years for gradual release during subsequent dry periods. Reservoir storage[*] capacity is generally equal to or more than 50% of mean annual river inflows at the reservoir site. These types of reservoirs are found on the Volta (Ghana), Indus (Pakistan), Tennessee (USA), La Grande (Canada), Nile (Egypt) and other rivers.
- *Seasonal*. These are medium-size reservoirs that store water during a wet season for release the following dry season. Storage capacity generally equals 10 to 20% of annual inflows. Reservoirs of this type are found on the Rio Lempa (Salvador), Ravi (India), Dordogne (France), Ottawa (Canada) and other rivers.
- *Daily or hourly*. These are often small reservoirs that store just enough water to allow the power plant to operate at design capacity for several hours or days to meet a very specific demand. These types of power plants are frequent in continental Europe (France, Switzerland, Germany), where electricity is generated mainly by thermal or nuclear plants and hydroelectric facilities are used only to meet peak demand.

2 Impact of Streamflow Control on Hydrologic Regime

This section discusses the impact of streamflow control on hydrologic regime depending on reservoir size and climatic zone.

[*] See Appendix A: Glossary.

2.1 Year-to-year Reservoir

Year-to-year reservoirs have a significant impact on hydrologic regimes downstream no matter what the climate type. These reservoirs guarantee a steady outflow, eliminating not only seasonal flooding and low waters but also differences between dry years and wet ones. During exceptional flooding, spilling can be substantial, but it is still generally less than or at most equal to the *discharge* under natural conditions, before streamflow control.

The impact of a year-to-year reservoir is particularly marked in dry tropical zones, where the dry season is very pronounced and there can be no flow at all for several months. With the reservoir, this regime is usually replaced by constant flow equal to the mean annual *discharge* prior to impounding*.

2.2 Seasonal Reservoirs

These reservoirs have the same type of impact on hydrologic regime as a year-to-year reservoir but less intense. Discharges during wet seasons diminish and those during dry seasons increase. Spilling is frequent during heavy flooding, and in very dry years, the river may dry up if the storage is completely depleted.

2.3 Daily and Hourly Storage Reservoirs

These reservoirs are used mainly to allow the power plant to work at maximum *capacity* over a short period; the turbined flow is then reduced to balance inflows. The result is a succession of rapid fluctuations in *discharge* downstream. This practice is generally restricted to a small stretch of the river; plants that operate this way are installed immediately upstream of a larger reservoir that can even out outflows, or a downstream equalizing reservoir is built for this purpose.

2.4 Other Types of Hydropower Plants

Some hydropower plants have no reservoir. These are called run-of-river plants; they turbine some of the inflows (to plant capacity) and the remainder continues on into the normal riverbed. Run-of-river plants are of two very different types.

- Low-head* plants built on large rivers. With these plants, it is the height of the dam that produces the head. The dam is sometimes built at a natural falls to increase the useful head. Low-head plants have almost no impact on hydrologic regime.

➢ Examples

  - Cascade dam projects on large European rivers (the Rhone, the Rhine and the Danube). With these developments, a flood wave generated from the uppermost reservoir can be managed to reach the most productive plants when *energy* demand peaks.
  - Developments composed of small power plants in northeastern North America.

* See Appendix A: Glossary.

- Diversion tunnel or canal plants in mountains or along rapids. In this case, an intake weir* is built along a steep mountain stream or upstream of a set of rapids. The water is diverted into a tunnel within the mountain or into a canal dug parallel to the river. It flows into a penstock* and the turbines before being returned to the river. The drop between the water intake and the outlet may be as much as several hundred meters.

This type of development has a significant impact on the hydrologic regime of the short-circuited river stretch between the intake and the tailrace*. Natural flow is systematically reduced by the amount of flow diverted towards the power plant. When the power plant stops operating this flow is returned to the natural riverbed, generating a succession of sudden fluctuations in flow in this stretch.

2.5 Basin or Flow Diversion

There are many reasons (irrigation, water supply, energy generation, etc.) why the waters of a river might be diverted for other uses or into a neighboring basin. In these cases, the hydrologic regimes in both basins are affected:

- Flow is systematically increased in the basin to which the water is diverted.
- Flow in the diverted river is reduced or eliminated immediately downstream of the dam. Flow then gradually increases downstream, though it is always less than it was before the hydroelectric project was built because of the diverted flow. In case of heavy floods, excess flows are returned to the original river, which then recovers the inflows of the diverted portion of the drainage basin minus a flow equivalent to the carrying capacity of the diversion structures.

3 Hydraulic Characteristics

All hydroelectric structures affect hydraulic characteristics. For example, water level upstream of a dam will always be higher or at least the same as it was before the dam was built. The immediate result is that an environment that was once fluvial becomes at least partly lacustrine*. Currents are less strong and waves are higher because the water surface provides a longer wind fetch. In addition, water management actions causes fluctuations in water levels, the amount depending on the mode of operation and the type of regulation (interannual, seasonal, daily or hourly).

Downstream of the power plant, flows are generally greater during the low discharge season and less during the natural peak discharge season compared to natural conditions. Water levels and current velocities are altered in the downstream river stretches.

4 Erosion and Sedimentation

4.1 Sedimentation Process

The sediment-carrying capacity of a stream depends entirely on its hydraulic characteristics (slope, current velocity, water depth), the nature of the sediment in the riverbed and the

* See Appendix A: Glossary.

material available in the catchment*. In other words, for a given grain size, any increase in slope, current speed or water depth entails an increase in sediment load*. Each of these factors can increase the amount of energy dissipated in the river, causing more turbulent flow. A turbulent flow dissipates more energy and has a greater capacity for moving sediment. The finer the sediment, the more likely that it will be put into motion.

In general, the sediment load of a stream comprises two components:

- sediment from the riverbed, generally sand and gravel
- sediment generated by erosion of the drainage basin, general fine sand, silt and clay.

Riverbed sediment can be transported by bed load* (coarse sediment), siltation* or suspension (fines). Relative proportions of these three modes of transport depend mainly on the hydraulic characteristics of the stream. Sediment generated by drainage basin erosion is transported by suspension.

As Table D1 shows, streams with large sediment loads are found mainly in arid, semi-arid or mountainous regions.

Table D1: Sediment Loads and Annual Sediment Yields in Several Large Rivers

River	Basin size	Average flow	Mean annual sediment yield	Mean annual sedimentation rate
	1000 km^2	1000 m^3/s	1000 Metric Tons	Metric Ton / km^2
Yellow (China)	715	1,6	1 900 000	2 600
Ganges (India)	960	12	1 500 000	1 400
Colorado (USA)	640	0,17	140 000	380
Mississippi (USA)	3 200	19	310 000	97
Amazon (Brazil)	6 100	190	360 000	60
Congo (Zaire)	4 000	42	65 000	16
Yenisey (Russia)	2 500	18	11 000	4

Source: Strahler and Strahler, 1978.

Arid or semi-arid regions are very often characterized by bare soil highly sensitive to erosion provoked by intense rains. The sediment produced, which is generally fine, ends up in the rivers and constitutes the suspended load. Examples are the wadis of North Africa and the Yellow River in China where the fine sediment comes mainly from flatlands without loess* in the river's middle course.

The Ganges transports sediment from the steep slopes of the Himalayas and the heavily cultivated lowlands in the lower part of the basin, which are subject to torrential monsoon rains. The Colorado is a special case; though most of its flow comes from snowmelt and precipitation in the Rocky Mountains, most of its sediment load comes from tributaries which drain semi-arid flatlands.

* See Appendix A: Glossary.

The sediment loads of rivers in mountainous regions come from drainage-basin and shoreline erosion. The loads can be exceptionally heavy in the event of landslides or failure of natural dikes retaining glacial lakes.

The sediment load of the Mississippi comes mainly from the semi-arid basins of the prairies that drain the Missouri in the northwest portion of the basin.

Despite the size of the basins of the Amazon and the Congo, sediment loads of rivers in tropical regions of middle latitude are generally low because of the abundant plant cover. In tropical basins at higher latitudes, the small loads are due rather to the small amount of precipitation. The sediment load then comes exclusively from the riverbanks.

The relatively small load of the Yenisey River is attributable to the taiga forest that covers its immense drainage basin, the topography, the nature of the substrate and the subarctic climate.

4.2 Impact of Dams on Sedimentation Balance

Dams slow down current velocity and appreciably reduce the slope of the water body upstream of the structures. The result is a decrease in sediment-carrying capacity—which means sediment is deposited and reservoirs silt up in the long term. The scope of this impact depends on the sediment load. For example, siltation is very low in many Canadian reservoirs.

Reservoirs built in mountainous areas, on the other hand, or in semi-arid or arid regions tend to silt up rapidly, and the regulation achieved by building the structures disappears, in part, after several years. With structures built to generate hydroelectricity, reservoir siltation can mean that sediment is carried into the intake, leading to wear of equipment (by erosion)—particularly if the sediment has a high percentage of quartz. Sediment traps are then required to keep out sand and gravel.

Creation of a large reservoir can also promote shoreline erosion due to wind-induced wave action in the unstable drawdown[*] area.

Reservoir creation leads not only to accumulation of sediment upstream of the dam but also to a smaller sediment load in water discharged on the downstream side. Since the stream seeks to restore the sedimentation balance as quickly as possible, turbulence will cause riverbed erosion downstream of the structure, especially in rivers with a high sediment-carrying capacity.

In certain parts of the world, floods deposit loam that fertilizes the soil. With large dams[*], floodwaters are controlled (routed) or eliminated entirely. This coupled with the drop in sediment load can negatively effect soil fertility. The elimination of flooding can also lead to increased soil salinity.

In addition, sediment suspended during flooding generally builds up and maintains delta[*] at the mouths of large rivers. When this sediment is intercepted by a reservoir, the delta may regress under wave action and ocean currents.

[*] See Appendix A: Glossary.

➢ Available Mitigation Measures*

The current trend with hydroelectric developments on rivers with heavy sediment loads is to establish operating instructions for flood management*. With new projects, it is now common practice to open the spillway* gates during flood periods and lower the water level in the reservoir. This way, most of the sediment load is transported during flooding.

In Japan, rubber dams have been employed as gates for sedimentation protection. (source: Annex III, ST1 report)

In some cases, especially in alpine regions, large falls can be created by building a low dam (i.e., a reservoir with a small storage capacity) with long tunnels to carry the water to the power plant. With this type of development, the spillway gates can be opened wide during flood periods without much loss of head so that sediments are not intercepted. Such projects must however be equipped with sediment traps.

Where large reservoirs are required, a number of measures can be used to prevent reservoir siltation.

- Measures to promote vegetation maintenance or growth in the drainage basin (e.g., control of agricultural and forestry practices and creation of nature reserves).
- Construction of small auxiliary dams along small tributaries to the main reservoir to retain sediment.
- Construction of bottom dam outlets for use mainly during flooding .

All these measures, however, are only partially effective.

Placement of rockfill or riprap* is the main measure used to counter erosion of the shores of the reservoir and the riverbed downstream of a dam.

5 Induced Seismic Activity

Isostatic pressure generated by impounding a reservoir can cause seismic events such as earthquakes. The first case of seismic activity related to a dam and to impounding of its reservoir dates back to the 1930's and involved the Mead reservoir created by Boulder dam (USA). This reservoir was impounded in 1935 (Goldsmith, E. and N. Hildyard, 1984).

Earthquakes can also cause landslides. This is probably what happened at the Vaiont Dam in Italy, where a landslide provoked a tremendous wave that killed more than 2000 people in the early 1960's. According to Kiersch (1964, cited in Galay, 1987), the wave that overtopped the dam was more than 100 m high and completely destroyed the village of Longarone.

Though there are more than 70 known cases of reservoir-induced seismic activity, earthquakes registering 5 or more on the Richter scale occurred at only 11 reservoirs and those registering 6 or more occurred at only four reservoirs. The must violent event (6.3) was at the Koyna Dam, an earthfill structure still subject to major seismic activity more than thirty years after impounding. In 1993, more than 4000 events registering 1.7 or more on the Richter scale were recorded near Koyna, including two shakings registering more than 5. One of these recent events (February 1994) registered 5.4, causing damage and increasing seepage

* See Appendix A: Glossary.

in the dam (Talwani, Pradeep, 1995). These events are related to the particular geological conditions at the site.

As these figures suggest, reservoir-induced seismicity can be intense and have serious consequences. It is important to note, however, that not all structures are affected. Chadwick et al. (1978) reviewed dams and reservoirs built in the United States. Of the 36 cases studies, increased seismic tremors was noted in only six cases following reservoir impounding. In two other cases, the seismic activity reported was not clearly related to the impounding or presence of a reservoir.

In addition, induced seismicity caused by reservoir impounding is a temporary phenomenon. In most cases, the most severe tremors takes place soon after impounding and their intensity gradually decreases thereafter. After about 10 years, a new equilibrium is achieved and the reservoir no longer affects local seismicity any more than a natural lake (Rastogi, B.K., 1990).

➢ Available Mitigation Measures

Potential risks can be greatly reduced by studying induced activity for any reservoir with a storage capacity of more than 1 km^3 or deeper than 100 m, or wherever preliminary examination suggests a significant risk (ICOLD, 1983).

Other measures can be taken to minimize the risks of induced-seismicity with large reservoirs:

- conduct geotechnical investigations prior to site selection
- slow down the pace of reservoir impounding
- do not keep water level high for too long
- avoid rapid reservoir drawdown.

These measures are not 100% effective. However, experience with the Bhatsa and Srisailam dams in India suggests that proper reservoir management during impounding makes it more likely that a new equilibrium will be achieved. The rate of accumulation of geological stress and water pressure at depth can be controlled through good management so that seismic energy is released gradually in small tremors and not violent movements (Rastogi, B.K., 1990).

6 Climatic Conditions

Climate changes generated by large reservoirs are often minimal and difficult to distinguish from normal climatic fluctuations (Météoglobe, 1989; ICOLD, 1994). Any changes are, however, often observed over the life time of the reservoir. Seasonal impacts are more pronounced than annual ones.

6.1 Temperature

The main effects on local temperature are as follows.

- Narrower annual temperature range (in temperate climates, cooler in spring, later onset of the growing season, a warmer fall and early winter, and a later freeze-up).
- Narrower daily temperature range (warmer at night and cooler during the day).

- Change in atmospheric stability (more stable conditions in spring and less stable conditions in winter).

The changes in temperature range are due to the thermal capacity of the water masses. Studies of the very large Rybinsk reservoir in Russia (subpolar climate with moderate precipitation; reservoir area = 4560 km^2) demonstrated a 3^oC decrease in diurnal variation in early summer and a 3 to 4^oC increase in night-time temperatures from June until freeze-up. In addition, the freeze-free period increased by 5 to 15 days in the reservoir's zone of influence. At the La Grande complex (Canada, northern temperate climate; total reservoir areas ≅ 11 000 km^2), a drop in spring temperatures and an increase in fall temperatures were noted, and the freeze-free period increased by 15 days. With the Tarbela reservoir in Pakistan (semi-arid, subtropical climate; reservoir area = 260 km^2), average minimum temperature dropped 0.5^oC but average maximum temperature did not change. This reservoir, however, has a very short retention time and is fed by relatively cold waters from snow melt and glacier melt.

6.2 Wind

The creation of a large body of water flattens the general topography, reducing air flow resistance. The modification of atmospheric stability generated by the presence of a large reservoir also plays a role in changing wind conditions. In addition, the wind zone of influence depends on wind fetch, which is greater over even terrain.

With the impounding of the Rybinsk reservoir, frequency of strong winds near the reservoir increased 25 fold at night and threefold during the day. At the La Grande complex, the frequency of strong and average winds increased by 25 and 50% respectively.

6.3 Precipitation

Very large reservoirs also modify local precipitation and precipitation regimes (shift in peak periods). The effects are, however, variable.

In hot, dry climates, reservoirs generally promote an increase in total precipitation. For example, rain has appeared in the Aswan region in Egypt since the creation of Lake Nasser (5000 km^2). In the Lake Volta (6400 km^2) region in Ghana, a change in precipitation regime was noted as well as a shift in maximum rainfall period from the month of October to the months of July and August. At the Tarbela dam in Pakistan, annual precipitation increased by about 30%.

In temperate climates, large water bodies absorb thermal energy in spring and summer and release it in fall. The result is an increase in cloudiness with frequent storms in spring and early summer and the opposite in fall and early winter. In the Fraser valley in Canada and close to the Nojiri reservoir in Japan, precipitation decreased by about 20% in summer (July) but increased by about 10% in winter. A 5 to 7% decrease in precipitation was noted in summer in the riverine zones of Lake Omega (Volga in Russia).

6.4 Evaporation and Humidity

Size and depth of the reservoir, sunshine exposure, atmospheric pressure (altitude) and wind conditions (relief) are the main factors that affect evaporation. To determine modifications to the evaporation regime, the difference between the evaporation regime of a free water mass and that of the surface before impounding must be considered. At the reservoirs of the La Grande complex (Canada), for example, annual evaporation seems to have decreased because of the persistence of the ice cover into spring, the greater evaporative capacity of vegetation compared to water, and higher temperatures and greater instability in the fall. In hot, dry climates, reservoir creation causes an increase in evaporation, which can affect the hydraulic efficiency of the structures.

Humidity level depends on evaporation and precipitation. Humidity generally increases near reservoirs in hot, dry climates. At the Tarbela reservoir (Pakistan), humidity level increased 5 to 10% within a 15-km radius of the reservoir. At Rybinsk reservoir, relative humidity in summer increased 1 to 14%.

6.5 Fog

Fog can form on cold days, as during the night or in the morning, when hot, wet air passes over a body of cold water. This happens mainly above large reservoirs.

Fog can also appear in the fall when cold air passes over warm water or when cold air from the mountains is advected over a warm water surface. In winter, the lack of ice downstream of reservoirs also promotes formation of fog, which can cause hoar frost and ice to appear in waterfront areas.

6.6 Greenhouse Gas Emissions and Air Quality

Reservoir emission of greenhouse gases[*] is a relatively new environmental issue and the subject of debate in recent years in discussing energy generation methods.

Creation of a hydroelectric reservoir can contribute to GHG emissions when a large biomass is flooded during impounding (Gagnon and Van de Vate, 1997; Kelly et al., 1997). Gases generated by aerobic and anaerobic decomposition are mainly carbon dioxide (CO_2), methane (CH_4) and, to a lesser extent, nitrous oxide (N_2O). A run-of-river plant, of course, does not cause this problem. Creation of a reservoir in a wet environment generally promotes an increase in GHG emissions because of the large biomass in these environments.

The flooded biomass partially decomposes depending on its nature and the ambient physicochemical conditions, temperature and dissolved oxygen content in particular. After several years, there seems no longer to be any significant correlation between emissions and reservoir age or inundated soil and vegetation (Duchemin et al., 1995, Väisänen et al 1996). Decay of flooded biomass is no longer the main mechanism of GHG production in the reservoirs; a substantial portion of the emissions comes rather from organic matter of the drainage basins and the phytoplankton life supported by the environment.

Project service life, global-warming potential of the gases emitted, quantity of submerged biomass and consideration of the entire energy system (energy used for facility construction, fuel processing and transportation, etc.)—all these parameters have a major impact on the results of any comparative analysis of different modes of power generation. Greenhouse gas emissions are minimal when the ratio of energy generated to area flooded is high (Gagnon and Van de Vate, 1997). Siting hydroelectric projects in mountains is thus theoretically a

[*] See Appendix A: Glossary.

good way to reduce GHG emissions. And a tropical environment is theoretically a poor location for a reservoir because there is a larger biomass in this type of environment. Among other things, the size of the biomass and the higher temperatures promote anoxic conditions and formation of methane, which has a greater warming potential. However, few experimental studies of tropical environments have been conducted to quantify emissions.

Emission estimates vary widely. For the same amount of energy generated over a 100-year period, Gagnon and Van de Vate (1997) estimate that Canada's hydropower plants emit 30 to 60 times less GHG than fuel-fired power plants. Väisänen et al (1996) estimate that the hydroelectric reservoirs of Finland generate one-tenth of the GHGes emitted by fuel-fired plants.

Despite the disagreement as to amounts, it is now generally acknowledged that creation of large reservoirs provokes GHG emissions but that per unit of energy generated, hydroelectric plants generate far fewer emissions than thermal plants. (Goodland et al., 1993; IPCC, 1995). The growing awareness about global warming is thus a plus for hydroelectricity. Compared to methods of producing energy that depend on fossil fuels, hydroelectricity also produces few or no air pollutants (precursors of urban smog or acid rain) such as sulfur dioxides, nitrogen oxides, carbon monoxide, volatile organic compounds (VOCs), etc.

7 Water Quality in Reservoirs and Downstream

7.1 Effects on Reservoir Water Quality

Reservoir creation transforms a fluvial environment into a lacustrine one, inundating soil and organic matter. Modifications to water quality depend on the following:

- quantity and composition of the inundated soil and vegetation
- rapidity of impounding, which affects the quantity of biomass available over time
- reservoir retention time
- tributary water quality
- climate
- reservoir morphology.

After the biomass inundated during impounding has decomposed, most water-quality parameters become comparable to those of neighboring lacustrine environments. Table D2, summarizes changes noted in very large reservoirs around the world.

➢ Temperature

Modifications to thermal regime stem mainly from the transformation of a fluvial environment into a lacustrine one. Thermal stratification* generally occurs in reservoirs with a long enough retention time that are at least 10 m deep (Tiblin, 1991; ICOLD, 1994). This phenomenon may occur both in natural lakes and reservoirs. Thermal stratification is caused by differences in water density, which arise mainly from differences in temperature, salinity and suspended solids (Fisher et al., 1979; Harleman, 1982). Warming of surface water (by sunshine or thermal exchange with air) is generally a hindrance to vertical mixing. Wind,

* See Appendix A: Glossary.

waves and cold air (which fosters a drop in surface water temperatures) increase thermal stratification—which occurs when the warming forces exceed the forces of vertical mixing. Depending on climate type, reservoir morphology and retention time, one or more thermal destratifications can occur annually, promoting re-aeration and general improvement in water quality.

Thermal stratification is more stable and intense in deep reservoirs in tropical regions than in reservoirs in temperate regions (Garzon, 1984). Stratification produces a thermal barrier, reduces water mixing by wind and, in some cases, prevents water mass inversion. This can provoke hypolimnion* anoxia* , which is accentuated if there is a lot of organic matter whose decomposition consumes dissolved oxygen.

- *Available Mitigation Measures*

Reservoir operating mode and morphology have a major impact on thermal stratification (Smalley and Novak, 1978; Harleman, 1982). Mixing can be provoked by placing an intake midway up the dam. Tributary inflows can generate additional mixing, although inflows with a temperature different from the epilimnion* can also promote stratification.

➢ Dissolved oxygen

Low dissolved oxygen level is unfavorable to many heterotrophic organisms and can contribute to anoxic conditions—which promote release of toxic metals present in soil and sediment (Wetzel, 1983). Decomposition of organic matter from soil and vegetation inundated during reservoir impounding also plays a role in lowering dissolved oxygen level, especially at depth (Baxter and Glaude, 1980; ICOLD, 1994). Reservoirs in tropical environments are particularly susceptible to this problem.

A detailed analysis of photic-zone* water-quality trends after impoundment of three very large reservoirs of the La Grande complex was performed (Schetagne, 1991; Hydro-Québec, 1996). Biomass decomposition caused a drop in dissolved oxygen levels and a concomitant increase in dissolved inorganic carbon levels during the first three years. With depletion of the readily decomposable biomass, these levels gradually returned to normal after about ten years.

Reservoir management can affect dissolved oxygen levels in the reservoir as well as in water discharged downstream (Tiblin, 1991). The position of the intakes, for example, can promote or discourage thermal stratification, affecting re-aeration of deep layers (Wetzel, 1983).

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* See Appendix A: Glossary.

Table D2: Changes in water quality in reservoirs around the world

Reservoir (climate)	Area flooded in km² (A)	Annual inflow volume km³ (B)	Ratio: Area flooded / Annual inflow volume	Changes noted: Degree of mineralization and pH	Changes noted: Increase in nutrients and plant growth	Changes noted: Dissolved oxygen
La Grande 2, Canada (boreal)	2 600	54-108	24-48	• 0.3 unit drop in pH • No change in conductivity	• 5 µg/L increase in total phosphorus	• Slight decrease in surface water saturation • Anoxia in deep water only at the end of the ice-cover period
Caniapiscau, Canada (boreal)	3 400	25	137	• 0.3 unit drop in pH • No change in conductivity	• 9 µg/L increase in total phosphorus	• Slight decrease in surface water saturation • Anoxia in deep water only at the end of the ice-cover period
Aswan, Egypt (dry tropical)	2 700 - 4 500	80	34-56	• Increase in dis-solved salts due to evaporation	• No increase in nutrients following impounding	• Anoxia at depth only during the period of thermal stratification
Danjankou, China (hot temperate)	700	40	18	• No change in pH	• No negative impact due to increase in nutrients	• Good oxygenation of surface waters • Oxygen depletion at depth during thermal stratification period
Lake Volta, Ghana (wet tropical)	6 400	44	145	• Decrease in pH	• Increase in nutrients • Proliferation of phytoplankton and aquatic plants	• Major decrease in dissolved oxygen in surface water • Anoxia at depth
Lake Kariba Zambia (dry tropical)	4 200	57	74	• Change in conductivity caused by increase in evaporation	• Temporary circulation of nutrients • Virtually constant proliferation of algae during impounding	• Anoxia under the thermocline
Lake Brokopondo, Surinam (wet tropical)	1 350	8,5	160	• No change in conductivity	• Proliferation of algae and water hyacinth	• Substantial loss of dissolved oxygen in surface waters • Anoxia below 2.5 m (thermal stratification)
Lake Kainji Nigeria (wet tropical)	700	67	10	• No change in conductivity	• Proliferation of phytoplankton and aquatic plants	• Decrease in dissolved oxygen in surface waters, but concentrations still exceed 4 mg/L • Anoxia under the thermocline

Source: ICOLD, 1994.

➢ pH

The drop in pH generally observed stems from release of organic acids due to leaching or decomposition of the biomass and formation of carbonic acid from carbon dioxide generated by biomass decomposition. (Sylvester and Seabloom, 1965). To a lesser extent, the mineralogic composition of the soil can also affect pH. The drop in pH promotes dissolution, desorption[*] or formation of contaminants. The capacity of the water to resist fluctuations in pH (alkalinity) is a key factor. At La Grande complex, the maximum drop in pH during impounding and the first years of operation was about 0.3 units. In tropical environments, the drop can be greater.

➢ Suspended Solids, Turbidity and Color

Submersion of soil and vegetation promotes a temporary increase in suspended solids, which alters water clarity (ICOLD, 1994). Water coloring by certain organic compounds produced by leaching or decomposition of the biomass may also occur (Sylvester and Seabloom, 1965). In some cases, increased absorption of solar radiation contributes to an increase in water temperature.

After first filling and stabilization of the reservoir, the decrease in flow velocity caused by the transformation from a fluvial to a lacustrine regime promotes deposition in the reservoir of sediment carried by tributaries. This helps to improve water transparency and increase biological productivity in the reservoir and downstream. However, in certain cases of high sediment loading, reservoirs may cause persistent turbidity problems in the waters downstream.

➢ Salinity

Salinity in a reservoir depends on tributary loads and the mineralogic composition of the inundated soil. In dry, hot climates, evaporation can cause salt to concentrate in reservoir water (ICOLD, 1985), as in the Aswan (Egypt) and Kariba (Zambia) reservoirs. In addition, if there is substantial water infiltration from such reservoirs into the soil, the water table[*] may rise and soil salinization[*] can occur. In temperate climates, these changes are generally negligible.

➢ Nutrients

Urban, agricultural and industrial activities in reservoir sub-basins can cause an increase in nutrient levels in streams that feed a reservoir. In addition, reservoir creation often promotes an increase in such activities in the drainage basin.

The initial biomass leaching and decomposition when a reservoir is created fosters an increase in nutrients. Water temperature, reoxidation capacity, reservoir retention time, type and size of the inundated biomass all affect the scope and duration of the nutrient increase (Sylvester and Seabloom, 1965; Goodland et al., 1992; ICOLD, 1994). A high ratio between area inundated and volume of water feeding the reservoir may give rise to a substantial impact.

[*] See Appendix A: Glossary.

In tropical regions, nutrient input is substantial during impoundment because the biomass is high (Garzon, 1984). In addition, the warm water and the substantial energy input accelerates decomposition, reaction kinetics and biological processes. There is generally less of a problem in cold or temperate climates because the water is colder and the biomass lower. At the La Grande complex, for example, nutrient concentrations peaked after two to four years and then decreased, returning to normal within 10 years.

A moderate nutrient input can sometimes promote development of aquatic life. If the nutrient input (phosphorus and nitrogen) is too great, however, eutrophication* can result (Wetzel, 1983). The symptoms of eutrophication are overproduction of aquatic plants, algae and suspended microorganisms, decrease in transparency, increase in water temperature, anoxic conditions in deeper water layers and subsequent release of hydrogen sulfide and toxic metals (ICOLD, 1994).

- *Available Mitigation Measures*

Removing the biomass from the reservoir flood zone can help to limit the scope of the problem. This is only possible, however, when the reservoir is small and the nutrient input from the tributaries is relatively small (ICOLD, 1985). For large reservoirs or in tropical regions, biomass removal is not often technically or economically feasible.

➢ Contaminants

Urban, agricultural and industrial activities in the drainage basin of a reservoir can lead to water contamination by toxic metals, pesticides or other synthetic organics. The presence of a reservoir can promote accumulation of these compounds by sedimentation, adsportion, bioaccumulation, etc.

Soil and organic matter submerged during impoundment can also be a source of contaminants (Baxter and Glaude, 1980). Anoxic conditions as well as a drop in pH and in oxidation-reduction potential (signs of eutrophication) can promote desorption, redissolution or formation of pollutants such as sulfur compounds and ferrous or manganous ions (Wetzel, 1983; Urdangarin et al., 1991; Shimizu et al., 1991).

- *Available Mitigation Measures*

In these cases, hypolimnion aeration and lower offtakes are possible mitigation measures.

➢ Mercury

In temperate northern regions, reservoir creation often causes a significant increase in mercury levels in the flesh of fish (Lucotte, 1999, Jackson, 1988; Morrison and Thérien, 1991; Hecky et al., 1991). This has also been noted elsewhere but seems to be less of a problem in warmer regions (Rosenberg et al., 1997). Monitoring of reservoirs in Finland and Canada has demonstrated that mercury accumulation in the flesh of fish peaks after five to ten years and decreases thereafter, returning to normal in 20 to 30 years (Brouard et al., 1990; Bodaly et al., 1997).

Mercury is present in the organic soil, the terrestrial vegetation and the mineral soil when the reservoir is impounded (Grisel, 1978; Brouard et al., 1990). In northern Canada, atmospheric

* See Appendix A: Glossary.

transport over long distances has been identified as the main source of mercury (CBJM, 1995), coming from thermal power plants. The organic matter stimulates the activity of bacteria that turn inorganic mercury into organic mercury via methylation; and in its organic form, mercury is assimilable into the food chain. The process of methylation and subsequent bioaccumulation in the food chain also occurs in natural environments, but it is intensified by rapid flooding of a large biomass. The drop in pH and in dissolved oxygen concentrations also promote mercury methylation.

Since mercury accumulates in the food chain, dissolved mercury levels in the water are very low. Unlike with other contaminants, tributary dilution of reservoir water has a less beneficial effect (ICOLD, 1994). In a small reservoir, mercury levels can be kept down by removing the vegetation before impounding.

- *Available Mitigation Measures*

In large reservoirs, the problem can be mitigated by minimizing the total area flooded and avoiding submersion of wetlands* (Kelly et al., 1997). Selective fishing of the most contaminated specimens and reseeding of the reservoir with young uncontaminated fish can also help. In addition, monitoring of fish contamination trends and issuing of consumption guidelines have been effective in controlling human exposure to this type of contamination.

7.2 Impacts Downstream

Water quality downstream of a reservoir depends on water quality in the reservoir, intake level, flow conditions and stream recovery capability (which depends on the morphology of the drainage basin).

➢ Temperature

Thermal stratification of a reservoir can lead to downstream discharge of colder or warmer water than under natural conditions. The change in the temperature of the discharge can affect physicochemical processes and the biological environment downstream.

When reservoir water is drawn from the hypolimnion in a temperate climate, water temperature downstream is warmer in winter and colder in summer than under natural conditions. When water is drawn from the epilimnion, the reservoir increases the water temperature downstream in summer but has less effect in winter.

The effects are the same in tropical climates but without the seasonal fluctuations. In cold climates, frazil* and ice jams may form downstream if the warmer water prevents formation of an ice cover (ICOLD, 1985). In some cases, it may be necessary to build weirs to slow down the current and facilitate ice-cover formation.

➢ Dissolved Oxygen

Discharge of reservoir water can provoke supersaturation of dissolved air in the water downstream (Legg, 1978). This occurs when pressure conditions in the reservoir discharge structures (very steep spillway chute) force air into the water. The water remains

* See Appendix A: Glossary.

supersaturated for some time and can affect fish that absorb dissolved gases through their gills. The air subsequently released into the blood stream, causing air bubbles.

Problems can also arise downstream if reservoir water is drawn from a hypolimnion poor in oxygen. The low dissolved oxygen content can affect aquatic fauna for some distance until reoxygenation restores the dissolved oxygen level.

➢ Chemical Quality

Anoxic conditions in the hypolimnion of a reservoir cause reducing conditions that promote formation of chemical elements such as ferrous and manganous ions, sulfides, etc. In addition, when biomass is flooded during impoundment, leaching and decomposition of organic matter promote an increase in nutrients in the deeper reservoir layers in the first years after impounding.

In such cases, contaminants or nutrients appear in the water downstream when water is drawn from the hypolimnion. The problem is less pronounced if the water comes from the epilimnion because it is better oxygenated and generally less loaded with nutrients.

➢ Estuarine Environment

The effects described above can appear a considerable distance downstream of the reservoir, the chemical water quality impacts in particular.

If the stream empties into an estuarine environment, the effects rapidly become negligible because of dilution effect. Changes in flow can alter saltwater front trends, however, affecting estuarine fauna and flora. If average flow drops significantly during or after impounding (diversion, irrigation, major evaporation), saltwater intrusion into the estuary or the groundwater may occur. There may also be ice problems due to increases in fresh water inflows into coastal areas.

u *Available Mitigation Measures*

The problem of low dissolved oxygen content and associated water quality problems may be mitigated with variable level water offtakes.

8 Conclusion

The impacts on the physical and chemical environment depend on the type of structure built (year-to-year, seasonal, daily or hourly storage reservoir; low-head power plant; diversion power plant; basin diversion) as well as the characteristics of the host environment—geomorphologic conditions and climate type in the host drainage basin in particular. Some types of structures are more suitable for a given environment than others, and it is therefore important that environmental considerations be incorporated from the early design stages of a project, including analysis of alternatives.

Certain mitigation measures can, however, reduce structure impact on the physical environment. These are listed below for each of the environmental problems discussed.

- Hydrologic regime and hydraulic characteristics
  - appropriate type of regulation

- minimal ecological flows*
- reservoir management procedures.

- Sediment
  - flood management
  - sediment traps
  - facilities built in the drainage basin upstream of the reservoir.
- Induced seismicity
  - risk assessment prior to site selection
  - management of the pace of impounding
  - management of fluctuations in reservoir level.
- Climatic conditions
  - evaluation of climatic changes prior to site selection .
- Water quality
  - intake position and depth
  - removal of vegetation and soil (small reservoirs only)
  - impoundment rate
  - weirs to counter frazil formation.

The construction of a hydroelectric development nonetheless remains a major intervention that modifies the host environment. Most of the modifications are, however, reversible. In addition, if the project is well adapted to conditions at the site selected and if suitable mitigation measures are taken, the negative effects can be minimized.

* See Appendix A: Glossary.

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Appendix E

THE FLORA AND THE FAUNA

APPENDIX E
THE FLORA AND THE FAUNA

Table of contents

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1 Flora

1.1 Terrestrial Plants

The loss of vegetation caused by deforestation and the impoundment of reservoirs constitutes the main impact of hydroelectric projects on terrestrial plant life. This impact can be significant in cases where plant life is dense and extensive and where populations have a high floristic value. Other losses occur in rivers with a modified stream flow, along power lines and in various other infrastructures. Changes in local climate may also affect terrestrial vegetation.

Reservoirs

The primary impact of a reservoir on terrestrial plant life occurs when there is deforestation before the reservoir is filled. The harvesting of economically valuable wood and the removal of cutting residues in the area to be flooded, in part or in whole, is a common practice employed for several reasons, one of which is to reduce the problems of water quality that accompany biomass decomposition. When there is no deforestation, the impact on terrestrial plants is caused by their submergence.

➢ Available Mitigation Measures

The removal of vegetation in an area to be flooded is of particular benefit for hydroelectric projects whose functions are (World Bank, 1998):

- the supply of water to municipalities or industry
- navigation
- water sports such as boating, fishing, swimming and water-skiing.

Although the deforestation of reservoirs may often be desirable, it is not an absolute necessity for certain projects. These generally include those whose uses are limited to (World Bank, 1998):

- the development of fish or wildlife populations
- flood control[*]
- Irrigation.

The degree of the impact depends mainly upon the size of the reservoir to be created, the biome, environmental conditions, the nature of the soil and the state of plant life conservation before submergence. In the case of undisturbed environments, plant densities are more significant in tropical regions than in temperate or dry regions. Humid tropical forests may contain between 3 and 10 x 10^5 kg/ha of biomass, whereas biomass in temperate forests rarely exceeds 4 x 10^5 kg/ha (World Bank, 1998). The density of plant biomass in northern temperate forests is rarely more than 1,2 x 10^5 kg/ha (Association Poulin/Thériault, 1993).

[*] See Appendix A: Glossary.

To reduce the impact on terrestrial plants, the following measures may prove effective.

- Optimization of the location and size of the reservoir to minimize loss of vegetation.
- Conservation of the wooded area adjoining the reservoir by establishing rigorous and effective protective measures.
- Creation of conservation units in floristic areas similar to those in the affected area (e.g., protection of reservoir islands).
- Collection and protection of seeds and other germinative elements for the *ex situ* conservation of the genetic heritage.
- Creation of forest arboretums for the *in situ* conservation of genetic heritage.
- Application of protective measures to prevent the erosion of banks.

Because of the vast areas and the economic factors associated with the creation of large reservoirs, deforestation is often limited to a portion of the site. In tropical regions, the time required for the deforestation of large reservoirs may be very long owing to high plant density. Even before the end of deforestation operations on a future reservoir site, new plants will have sprung up on parts of the area already cleared. When this happens, the re-growth provides new rapidly degrading biomass (new shoots) that is further likely to affect water quality during the first years of impoundment (Gérard, 1990).

In northern temperate environments, deforestation of reservoir shores encourages the regeneration of shrubby riparian plants, but the development of riparian habitats is restricted by fluctuations of the reservoir water level, the drawdown[*], that generally operates contrary to the natural hydrologic cycle (Hellend-Hansen et al., 1995). The re-establishment, over the long term, of the quality of habitats lost during the creation of large reservoirs has proven to be difficult. Thus, deforestation is of little value for generating habitats favorable to fish, except at the mouth of tributaries where it may facilitate access for fish (Pellerin and Fortin 1992).

The Nam Theun Two Dam (Laos)
The Nam Theun Two project is planned for construction on the Theun River, a tributary of the Mekong River, and the reservoir will cover an area of 470 km^2. The harvesting of lumber and the removal of most biomass in the reservoir of the future largest hydroelectric project in Laos are almost completed. The reservoir area, access roads and power line corridors must be free of wood before the production of electricity. The central government of Laos has allocated an area of 1,7 million hectares of land as a forestry concession in the provinces of Khammouane and Bolikhamxay. The formation of a 3,710 km^2 conservation unit in the drainage basin of the Nam Theun Two dam has been proposed by authorities in charge of the project to compensate for the creation of the reservoir. In 1993, the prime minister of Laos decreed that restrictions be placed on the use of natural resources and land development. Since 1994, a number of experts have been contributing to the knowledge of the natural environment by conducting surveys on the plants and wildlife of the Nam Theun drainage basin.
Sources: Dorcey et al., (1997); Monbiot (1997)

[*] See Appendix A: Glossary.

The increase in shore length that accompanies an increase in the area of a river may lead to a greater quantity of riparian habitats. Coasts and marshes are created when the reservoir offers an appropriate morphology. In dry lands, the reservoirs promote the growth of riparian plants: extremely dry weather conditions are the main reason plant growth is so limited before impoundment (Pulford et al., 1992). However, Julien and Laperle (1986) have shown that in certain reservoirs in Canada's northern temperate region, the riparian habitat is reduced to being a border on the upper boundary of the water drawdown zone*.

The Aswan Dam (Egypt)
The Nasser reservoir was created in 1969 following the construction of the Aswan dam on the Nile. The periodic increase in the water level of the reservoir produces significant lateral displacements of the water, which floods the dry lands of the Wadi Allaqi region. Successive plant communities have become gradually distributed into five distinct zones over a distance of more than twenty kilometers from the reservoir. A multidisciplinary team set up in 1987 determined that the floods caused heavy plant growth upstream from the reservoir. The greatest influence of the Nasser reservoir on the ecology of the Wadi Allaqi is seen in the development of plant communities dominated by riparian species adapted to humid soil conditions.
Source: Pulford et al. (1992); Springuel et al. (1989).

On the whole, it is more profitable to conduct enhancement* activities outside the periphery of a reservoir in places having a high floristic potential.

Downstream Reaches

The disappearance of heavy natural floods produced by stream regulation alters the natural flooding cycle of flood-plains located downstream from dams. These cycles contribute to vegetation maintenance in the humid zones along streams or in deltas* (Goodland, 1989; Bolton, 1986). A significant reduction in or absence of flooding may lead to an impoverished vegetation and serve to modify the dynamic involved in the stages of plant development (Dorcey et al., 1997; Rosenberg et al., 1997).

In northern temperate zones, the disappearance of heavy natural floods reduces the erosive action of ice and strong currents upon vegetation. Moreover, whenever there is a reduction of total stream flow (for example, following a diversion*) and relatively stable water levels, the emerged environments evolve more and more rapidly into varied riparian and terrestrial habitats (Denis and Hayeur, 1998; Helland-Hansen et al., 1995), but this creates problems during floods as the river carrying capacity is reduced.

The reduction of aquifer refill and the lowering of the surface of the groundwater* downstream from dams may disturb the renewal of humid zones and affect vegetation during flooding (Acreman, 1996b; Dixon et al., 1989). Low-altitude tropical and dry regions are

* See Appendix A: Glossary.

more likely to be affected by these phenomena (Acreman, 1996b), whereas there are few if any effects in northern temperate zones.

Intermittent stream flows in dry regions can be made permanent by outflow regulation at the dam. The new and more stable conditions of the environment may then contribute to the growth and development of vegetation along banks (Wieringa and Morton, 1996; CIGB, 1985). Despite the disappearance of natural floods, the colonized part may extend beyond habitually flooded zones and offer a terrestrial and riparian vegetation that is at once more varied and more abundant (Wieringa and Morton, 1996).

➢ Available Mitigation Measures

The following measure may prove effective in reducing adverse impacts on vegetation:

- Design and management of hydroelectric development so that the periodic regulation of outflows recreates in part the natural flood cycle.

The Glen Canyon Dam (United States)
The Colorado River, located downstream from the Glen Canyon dam, has a more regular flow rate during the period of exploitation and is free from the heavy floods of spring and the beginning of summer. Before hydroelectric development, riparian vegetation was concentrated in narrow areas adjacent to the high water line. Since 1992, data generated by environmental follow-up studies indicate that riparian vegetation has extended beyond the naturally flooded areas, and that the number of species to be found there is now greater. Plants that are not particularly resistant to floods have gradually spread out over sandy beaches and the banks of streams.
Source: DOI (1995).

Power Line Corridors and Other Infrastructures

The development of a hydroelectric network involves setting up transmission lines and power poles in specific corridors. In addition to the creation of a reservoir, activities involved in the establishment of a hydroelectric plant include the construction of access roads, dikes, dams and related buildings.

Impacts on terrestrial plant life during construction are linked mainly to deforestation and the utilization of loose soil materials (quarries and sandpits). The initial components of stripped soils are often damaged and delay the natural recolonization of vegetation (Labbé and Pellerin, 1995).

➢ Available Mitigation Measures

The following measures may mitigate or compensate for the adverse effects on vegetation when loss is significant.

- Optimization of power line routing with respect to the protection of terrestrial plant life in sensitive or exceptional areas.

- Optimization of the routing of access roads towards and within the project site to minimize loss of vegetation.
- Exploitation of quarries and sandpits in areas within the boundaries of the future reservoir.
- Preliminary conservation of surface soils in work areas for utilization before the next planting stage.
- Planting of selected indigenous species of vegetation according to their capacity to survive and grow in sites where the soil has been disturbed (Labbé and Pellerin, 1995).
- Planting of trees and bushes in temporary work areas of zones adjacent to power line corridors.
- Re-management of quarries and sandpits, landscaping and vegetating of waste rock pits from excavation and tunneling.

The purpose of controlling vegetation in corridors is to remove large arborescent species that may trigger power failures through the formation of electric arcs or damage power lines. Access roads in corridors must also be free of vegetation so that maintenance and repair can be carried out. The methods most often employed to control such vegetation are herbicides, mechanical or manual cutting and controlled fires.

Where conditions justify their application, the following measures can be taken in corridors.

- Biological or ecological methods of arborescent plant control (Brown, 1995; Meilleur and Bouchard, 1995).
- Plant control aimed at the management of habitats favorable for wildlife (Harlow et al., 1995; Amer et al., 1995).

Plant Management and Control (Canada)
Since 1974, Hydro-Québec has been collecting data on the winter yards of the white-tailed deer in power line corridors. Results indicate that plant management and control can improve covered areas and twig production for these deer. In order to maintain quality winter habitats, Hydro-Québec has drawn up technical guidelines to improve its interventions in corridors. The main objectives of management are more frequent, localized treatments, the treatment of half of the corridor at a time, the removal of undesirable plant species and winter cuts.
Source: Doucet et al. (1995).

1.2 Aquatic Plants and Productivity

The most negative impact of reservoirs on aquatic plant life is the excessive proliferation of plants and algae, a problem most likely to occur in reservoirs in tropical regions of high biological productivity. “Run-of-the-river” dam reservoirs are less likely to cause this problem because of their low volume and the water's short residence time. This adverse impact is generally not significant in northern temperate zones, although there are examples of excessive macrophyte* growth in areas subject to acidification (Eie et al. 1997)

Reservoir

➢ Primary Production of the Reservoir

The rapid availability of nutrients and minerals following the leaching of soils and the decomposition of unstable organic matter leads to an increase in the primary production of a reservoir. Physico-chemical changes in the water set off a chain reaction which sparks an increase in the production of phytoplankton and zooplankton (Wright, 1967). Reservoir productivity depends upon a variety of factors, notably light penetration, water quality, thermal and chemical mixing, stratification and biotic colonization (World Bank, 1998).

The impact of submerged biomass on nutrient production rates tends to be strongest during the reservoir's first years. In time, these nutrients will be gradually utilized and productivity will tend to stabilize. The importance of nutrient inputs, then, will depend mainly upon the water quality of affluents feeding the reservoir. In northern temperate zones, the effects on productivity of the decomposition of organic matter in reservoirs generally cease after 8 to 10 years of impoundment (Schetagne, 1992).

➢ Eutrophication and Stratification of the Reservoir

Excessive biological productivity in reservoirs may induce eutrophication* and generate adverse impacts on the aquatic environment. Reservoirs established in tropical regions, particularly those that are shallow in depth, often suffer from acute problems of eutrophication owing to the decomposition of a large quantity of submerged biomass.

The heavy organic loads generated by industrial, urban and agricultural activities in the drainage basin of reservoirs may be a major factor in water enrichment. An overabundance of rapidly propagating aquatic plants (water hyacinths, water lettuce, herbs, moss and ferns) and the proliferation of algae can be observed at certain times of the years in eutrophic reservoirs (EGAT, 1990). Dense carpets of macrophytes floating on the surface of reservoirs significantly increase the evapotranspiration* of the water, reducing light penetration and gas exchange on the water's surface (Helland-Hansen et al., 1995).

Even after the decay of organic matter has stabilized, eutrophication may persist owing to high temperatures and the thermal stratification of the water column. The surface layer of warm water in reservoirs (epilimnion*) facilitates the rapid oxidation of organic matter and accelerates photosynthesis and the development of aquatic vegetation. The decomposition of organic particles and their sedimentation serve to deplete the oxygen supply in the bottom layer (hypolimnion*) of the water in the reservoir. Conditions of anoxic decomposition may then produce toxic substances that will affect aquatic life (Ayres et al., 1997).

* See Appendix A: Glossary.

The Brokopondo (Surinam) and Pehuenche (Chile) Reservoirs
– Aquatic plants grow very rapidly in tropical regions. In the Brokopondo, colonies of water hyacinths had propagated over a 410-km^2 surface between 1964 and 1966, an average rate of progression of 6 m^2 per second over a two-year period. To produce 30 megawatts of electricity, hydroelectric development necessitated the submergence of 160,000 ha of humid tropical forests. The number of hectares of land submerged for each megawatt produced is 5 333. Submerged areas have made available a large quantity of decomposable biomass, and eutrophication has favored the rapid propagation of aquatic plants.
Source: World Bank (1988).
– During work on the 500 megawatts Pehuenche hydroelectric project in Chili, 400 ha of terrestrial environments were submerged with minimal damage to vegetation and wildlife and without significantly affecting the water quality of the reservoir. The number of hectares of land submerged for each megawatt is smaller than 1. The site of this hydroelectric project is known to be one of the best of 50 large dam projects in the world, in terms of inundated area per installed MW.
Source: Ledec et al. (1997).

➢ Available Mitigation Measures

The following measures may prove effective for minimizing the consequences of eutrophication (not applicable to reservoirs in northern temperate zones).

- Deforestation and removal of vegetation before submergence when this is shown to be effective.
- Limiting the number of shallow bays submerged.
- Control of industrial, urban and agricultural activities to reduce the nutrient load of affluents.
- Outflows at different levels of the dam to induce vertical mixing and avoid thermal stratification in the reservoir, lowering of the water level in reservoirs to control or destroy aquatic vegetation.
- Biological control or the local use of non-toxic herbicides for aquatic plants not targeted by the operation (may be costly when repeated applications are required to control large plants).
- Harvesting of macrophyte and algae for reuse (compost, forage, fuel, bio-gas production).

Downstream reaches

It is difficult, on the whole, to define the biological impacts of the modification of habitats, water quality and stream flow on the organisms of the lower trophic levels – plants – of rivers located downstream from dams (World Bank, 1998; Ward and Standford, 1979). These effects vary considerably according to the conditions of a particular environment, the organisms involved and the conditions found in a reservoir (Power et al., 1996). “Run-of-the-river” management activities coupled with low-volume reservoirs are less likely to affect the productivity of streams and rivers in the short run. In the long run, their influence will be negligible.

Sedimentation and the deposit of organic matter in reservoirs reduce the quantity of nutrients transferred downstream. Primary production may then decrease there and affect other levels of the trophic chain (CIGB, 1985). This impact on the upper links of the food chain may have repercussions that extend as far as the mouths of streams (Rahman, 1986).

On the other hand, the improvement in water transparency that results from a lower sediment load and less turbidity in streams can prompt an increase in primary production (Wieringa and Morton, 1996). The exportation downstream of a portion of the nutrients made available in the reservoir following an increase in biological productivity likewise contributes to stream enrichment. (Schetagne and Roy, 1985). Environmental response, then, depends upon a certain interlocking of these factors that may vary from one project to another.

In northern temperate zones, the scope of these repercussions will be considerably reduced owing to the oligotrophic character of the water and a generally very low incidence of erosion and sedimentation.

In hot dry areas, a reduction of a stream's flow rate together with a significant loss of water owing to evapotranspiration or to the multi-purpose use of water (irrigation, supplies to municipalities and industries, etc.) may encourage the excessive proliferation of aquatic plants (Power et al., 1996; Dixon et al., 1989). This proliferation is even more extensive if the presence of a dam compromises the annual cycle of heavy floods (Lavergne, 1986). The strong flows generated during flooding prevent aquatic plants from taking root along the banks of rivers.

The Glen Canyon Dam (United States)
Under natural conditions in the Colorado River, floods in spring and the beginning of summer transported a large quantity of sediments which were then left deposited on sandy beaches after the waters had receded. These annual floods limited the number of plant and wildlife species as well as the abundance of specimens. The presence of the Glen Canyon dam ensures that sediments remain trapped in the Powell reservoir and are thus essentially absent from water pouring downstream from the dam. Greater water transparency and an increased flow rate during the low water period have prompted an increase in primary production in the Colorado River. This new source of nutrient inputs has encouraged the development of varied associations of aquatic plants and organisms.
Source: Wieringa and Morton (1996).

The modification of salt circulation and nutrient input may affect aquatic vegetation in estuaries. In Canada's northern temperate zones (the La Grande complex), however, there is no evidence that the coastal salinity existing since the operation of dams has affected the distribution, density and biomass of the eelgrass* communities distributed in the shallow bays of the coast (Hydro-Québec, 1995). The production of eelgrass appears to be a consequence, mainly, of natural variations in the water level and the influence of climate (Julien et al., 1996). Thus, the growth and distribution of salt marsh plant communities have not undergone any notable change owing to new winter salinity conditions, since they are protected, as before, by an ice cover of up to one meter thick (Hydro-Québec, 1995).

➢ Available Mitigation Measures

The following measures may be applied to mitigate impacts on the aquatic vegetation of streams and rivers located downstream from dams (not applicable to reservoirs in northern temperate zones):

- Curbing eutrophication in the reservoir.
- Ensuring sufficient outflows at the dam to compensate for water loss caused by evapotranspiration (Davies et al., 1994).
- Designing and managing hydroelectric plants so that artificial floods recreate to some extent the natural flood cycle.

2 Aquatic Fauna

2.1 Aquatic Macroinvertebrates

The creation of a reservoir and the reduction of stream flow can modify the abundance and specific composition of aquatic macroinvertebrates* ; in extreme cases, a drying-up of parts of a river can result in the complete destruction of specimens.

The main impact of hydroelectric development upon aquatic macroinvertebrates lies in the repercussions these organisms have on the higher links of the trophic chain.

Reservoirs

The essentially immobile populations of aquatic invertebrates that inhabit lotic environments* can disappear during a reservoir's first years. However, newly-created aquatic habitats promote the rapid increase of organisms that are mobile and require little dissolved oxygen (Schetagne, 1992).When the support provided by flooded vegetation becomes available, the density and biomass of macroinvertebrates may be higher than those found in natural environments (De Silva, 1988; Boudreault and Roy, 1985). Surveys of the reservoirs of northern temperate zones indicate that zooplankton develops rapidly there and becomes 10, 30 or even 50 times more plentiful than that in rivers (Hydro-Québec, 1996). When it comes to evaluating the impact of fluctuations in water level on aquatic macroinvertebrates, results differ from one hydroelectric project to another (Vallières and Gilbert, 1992; Düthie and Ostrofsky, 1975; Grimas, 1961).

In dry and tropical areas, sections of a reservoir that are shallow and protected from waves may create habitats favorable to disease-carrying insects and mollusks, such as mosquitoes, snails, etc. (World Bank, 1998). In these regions, the development of aquatic vegetation in

* See Appendix A: Glossary.

reservoirs intensifies the proliferation of these organisms (Helland-Hansen et al., 1995; Gérard, 1990, Roggeri, 1985).

➢ Available Mitigation Measures

The most effective mitigative measures are:

- Elimination of shallow pools and ponds by means of draining, pumping, filling or building dikes.
- Introduction of predatory or competitive species for purposes of control.
- Use of selected pesticides on targeted species (may be costly and induce resistance).

The creation of a reservoir may, on the other hand, submerge zones of fast running water, causing the habitats of other disease-carrying insects to be destroyed.

Downstream Reaches

The abundance and specific composition of aquatic macroinvertebrates can be modified in rivers located downstream from hydroelectric dams (Casado et al., 1989; Wade, 1980). The modification of hydrologic, thermal and chemical regimens plays an important role in the development and production of these organisms (Irvine, 1985; Spence and Hynes, 1971).

Gersich and Brusven (1981) have observed that the colonization time of macroinvertebrates is greater in regulated streams than in natural environments. A drop in water level may cause a greater drift of macroinvertebrates downstream, particularly in the shore area, where the effects of a reduced stream flow upon the height of the water column are strongest (Perry and Perry, 1986). Tolerant species will predominate in areas that remain consistently humid when stream flows are at a minimum (Abbot and Morgan, 1975). On the other hand, a moderate increase in the current velocity of a stream may accelerate the development and abundance of periphyton[*] (McIntire, 1966).

Less transportation of nutrients in a stream may have adverse impacts on macroinvertebrates. A decrease in the sediment load, however, clarifies the water and may increase primary production and, subsequently, the development of macroinvertebrates. (World Bank, 1998).

As with fish, the modification of estuaries by saltwater intrusion may change the spatial distribution of ecological zones and affect the communities of aquatic macroinvertebrates. According to a study by Liebenthal (1997), there are few cases – as, for example, those of Bayano and Fortuna in Panama – where an alteration of stream flow has brought about a significant change in the saline and circulatory conditions of estuaries. With respect to Bayano, such a phenomenon would have affected the shrimp populations that migrate into an estuarine environment to reproduce.

➢ Available Mitigation Measures

Depending upon individual circumstances, the mitigative measures suggested earlier for improving water quality downstream from hydroelectric dams may prove effective for

[*] See Appendix A: Glossary.

encouraging the production of aquatic macroinvertebrates. However, it is not yet possible to predict the biological consequences of the modification of stream flow on the production of macroinvertebrates with a high degree of accuracy (World Bank, 1998; Bell, 1991).

2.2 Fish

Fish are among the main organisms of aquatic wildlife to be affected by the construction of a hydroelectric plant. Their habitat may be completely modified following the impoundment of a reservoir, and the effects of this may extend to the downstream reaches of the river. The large volumes of water generated by the creation of a reservoir provide new aquatic habitats for fish. The high phytoplankton* productivity of reservoirs increases fish biomass and offers opportunities for subsistence and commercial fisheries development.

Reservoir

The creation of a reservoir causes profound changes in fish habitats when a riverine environment is transformed into a lacustrine one, although in some cases, reservoirs are created by raising the water level of natural lakes.

New conditions generally induce a change in the specific composition of fish communities (Alam et al., 1995; United Nations, 1990). Species of fish typical of river environments are disadvantaged in favor of those having a greater tolerance for lake conditions, which then become more abundant (Kinsolving and Bain, 1993).

Home ranges for the reproduction, feeding and breeding of fish may be modified, and species having a greater power of adaptation to such conditions will increase in number (World Bank, 1998); these are often ubiquitous species which expand at the expense of rare species with narrow habitat requirements. Depending on the circumstances, access to a sufficient number of tributaries on the periphery of the reservoir will allow species requiring running water for part of their life cycle to reproduce in streams and to continue their growth cycle in reservoirs (Bodaly et al., 1989; Boucher and Roy, 1985), although species that migrate over long distances or need to reach coastal areas or sea will be severely reduced.

During the first years of submergence, reservoirs undergo an increase in aquatic productivity following the decomposition of plant biomass. The species of colonizing fish capable of rapidly using this new and abundant food (phytoplankton, zooplankton*) will tend to dominate until biomass decomposition has stabilized (Alam et al., 1995). Submerged vegetation provides nests favorable to periphyton and benthic* invertebrates, which attract in their wake fish capable of deriving benefit from them, followed by predatory species that feed off these fish (De Silva, 1988; CIGB, 1985).

The high production of fish (kg/ha) observed in reservoirs generally exceeds that of natural bodies of water (Sarma, 1990; Dixon et al., 1989; De Silva, 1988; Goldsmith and Hildyard, 1984). The vast areas and volumes of water made available during the creation of reservoirs provide additional habitats for aquatic wildlife. The net increase in the number of hectares of aquatic habitats generates high fish production (kg), which generally encourages recreational and commercial fishing (World Bank, 1991a, Sarma, 1990; Dixon et al., 1989; De Silva,

* See Appendix A: Glossary.

1988; Goldsmith and Hildyard, 1984). In Canada, this phenomenon has given rise to the development of numerous recreational fishing outfitters on the periphery of reservoirs. Aquatic biomass produced in reservoirs in northern temperate zones is higher than the terrestrial wildlife biomass that is available for harvesting (Hydro-Québec, 1993a).

Saguling and Cirata Dams (Indonesia)
An innovative program introduced by authorities in charge of the Saguling (1986) and Cirata (1991) dams makes use of the recent creation of the reservoir for fishery development. Fish-farming technologies have been adapted for small producers with an established tradition of aquaculture in ponds or rice paddies. In 1992, follow-up activities demonstrated that the floating cage farming system of both reservoirs made possible the hiring of 7 500 families and produced 10 000 tons of fish. This harvest exceeds the ten tons produced annually by the river of origin. Fisheries revenues from both reservoirs have exceeded ten million dollars US per year, higher than the value of rice harvests from submerged farm lands. Furthermore, 21 000 additional jobs have been created in enterprises for fish food production, cage maintenance, marketing, etc. Fishery management in other reservoirs likewise generates a significant number of jobs and major revenues, among them, the Akosombo in Ghana, the Kedung Ombo in Indonesia, the Kariba in Zambia and Zimbabwe, the Mangla and Tarbela in Pakistan and the Nam Ngum in Laos.
Source: Liebenthal (1997).

In dry and tropical regions, the eutrophication of reservoirs may induce adverse impacts on fish populations following the degradation of water quality. The danger for resident fish increases when there is stratification in the reservoir and a limited exchange of oxygen between layers of water.

Fish will be able to survive in the upper part of the water column (epilimnion) where the quantity of oxygen is greater following aeration and photosynthesis. Conditions will be adverse, however, for fish on the bottom layer (hypolimnion) because of anoxic decomposition and the liberation of toxic substances (World Bank, 1998). These adverse conditions may subside following the stabilization of organic biomass decomposition in the reservoir. With respect to northern temperate zones, the La Grande complex (Canada) shows that water quality has always been adequate for the survival of fish (Schetagne, 1992).

The mitigative measures described above in the section *Aquatic Plants and Productivity* (1.2) can be used to counter the negative effects of eutrophication.

The many purposes for which reservoirs are used (flood control, drinking water, irrigation, hydroelectric production, navigation, recreation) exacerbate the difficulties of managing biological resources. Reservoirs are usually renowned and heavily used for fishing, and producers of electricity often modify their management accordingly or take particular measures to encourage the development of fish resources (Olmsted and Bolin, 1996); however, exotic fish species introduced to reservoirs may spread to downstream or upstream lakes and rivers.

➢ Available Mitigation Measures

On the whole, the following mitigative measures are beneficial for fish communities in reservoirs:

- Management of water levels (making spawning areas available and optimizing the spawning period, preventing freezing of eggs, controlling predators, providing greater accessibility to tributaries).
- Creation of artificial spawning grounds.
- Stocking with fish, *in situ* incubation of eggs, integrated fish-farming basins in the reservoir.
- Clearing of tributaries to facilitate access.
- Construction of weirs to maintain water levels in bays.
- Application of measures for bank stabilization.

Management Practices (Canada/United States)
– In 1980 Hydro-Québec set up a program of ecological management that included stocking fish for the purpose of developing the Outardes-2 reservoir (Canada). To introduce a population of lake trout into the reservoir, Hydro-Québec stocked more than 600 000 fry* and parr*. The rainbow smelt was also introduced as a foraging species of fish. Access to additional spawning areas was made possible by the construction of a migratory pass on the Loup Marin river. Tributaries were managed so that quality habitats and reproductive potential were increased.
Source: Lessard (1995).
– The Duke Power Company (United States) has been stabilizing the water level of six of its largest reservoirs for the past twenty years in order to optimize the reproduction of the large-mouth bass. The company also manages the water level of the James reservoir in the spring to allow walleyed pike to reach the shallow areas of rivers for reproduction.
Source: Olmsted and Bolin (1996).

Fishery management in reservoirs has often promoted the introduction of exotic species for ecological reasons (control of macrophytes, manipulation of fish communities) or for commercial and recreational reasons (Olmsted and Bolin, 1996). The introduction of exotic species as a mitigative measure, however, calls for a rigorous examination of initial biophysical conditions in order to ensure the favorable consequences of such a practice, notably on specific diversity and the indigenous species developed (Kohler et al., 1986).

Dams

The presence of dams on streams and rivers may restrict the movement of migratory species of fish, modify traditional migration routes or fragment home ranges, unless additional sites

* See Appendix A: Glossary.

are created or special passes are set up. However, non-dammed rivers often flow over natural obstacles which also impede the movement of fish upstream, such as waterfalls. Hydropower plants built at such locations do not create additional obstacles to fish migration.

The downstream migration of fish in streams is generally affected by the presence of dams and by work on power production (Goldsmith and Hildyard, 1984). The physical obstacle of a dam or the control of stream flow may slow the movement of fish downstream, and the passing of fish into turbines may cause trauma or mortality.

“Run-of-the-river” hydroelectric management can also have a major impact upon the migration of fish. The cumulative effect of the presence of dams on the same river must be considered when evaluating the impacts and effectiveness of mitigative action (Hill and Hill, 1994; Netboy, 1986).

Recent research indicates that certain types of passes set up in tropical regions can prove just as effective as those in temperate regions (Acreman, 1996a, b), although success in temperate regions is variable.

➢ Available Mitigation Measures

The measures most widely used to enable fish to cross dams or reach additional parts of the river are:

- Fish passes (Larinier, 1992; Powers and Orsborn, 1985).
- Locks and fish elevators.
- By-pass / diversion channels around the dam.
- Harvest and transportation of fish by vehicle, boat, aircraft, etc. (Hildebrand et al., 1980).

The optimal use of any one of these measures depends upon the physical characteristics of the site and the stream, the species targeted, the geographic location and various other limiting factors.

The Susquehanna River Basin (United States)
Between 1904 and 1992, four dams were constructed on the lower part of the Susquehanna River. One consequence was a sharp reduction in the shad harvest; in 1921 very few shad could be caught. Since that time, the four utilities companies that own the projects have installed elevators and traps that make it possible to transport shad upstream from the dams. At the end of work on the passes, scheduled for the year 2000, shad will be able to reach breeding areas distributed over more than 300 km. In 1980, the population of shad consisted of almost 3 000 specimens; ten years later, it had increased to approximately 100 000.
Sources: Olmsted and Bolin (1996); PP&L Resources (1995).

To mitigate these impacts, a variety of steps can be taken.

- Increased outflow at the dam during periods of downstream migration.
- Use of types of turbines that minimize risks for fish (according to the height of fall).

- Optimization of the physical layout of the power plant (location of turbines, feeder canal, water inlet) and turbine operations.
- Use of nets, barriers or screens to prevent fish from passing into turbines or to direct them towards additional outlets (Taft et al., 1995).
- Use of strobe lamps, sound waves, bubble curtains or electric fields to prevent fish from entering specific areas (EPRI, 1994).

Downstream Reaches

The quality of the water downstream from a hydroelectric dam is affected by water flows from the reservoir located upstream. Physico-chemical conditions in the hypolimnion (dissolved oxygen, temperature, turbidity, toxic compounds) may prove harmful to aquatic wildlife and may extend downstream when outflows originate from the bottom layer of reservoir water (Cushman, 1985; Lillehammer and Saltweit, 1984; Brooker, 1981; Ward and Stanford, 1979). In periods of high flow, the adverse effects of bottom layer outflows will be reduced when water from the top layer of the reservoir overflows through spillways or other structures.

Impacts on the receiving stream will depend upon the size of outflow from the dam and the water input of downstream tributaries. Impacts may be more pronounced during periods of low flow (dry season), when operation restrictions limit outflows. This situation arises mainly with seasonal storage reservoirs in dry tropical regions. Impacts will be more pronounced when the water residence time[*] in large reservoirs is long and when vertical water circulation is reduced by thermal stratification. The impact will be lower for “run-of-the-river” dams, where the ratio of inflow to volume is large (Olmsted and Bolin, 1996). In temperate regions, there will be fewer impacts.

A change in the temperature of a stream can modify the structure of fish communities and their prey (Blanz et al., 1969; Alam et al., 1995). Changes in water temperature act on the metabolism, behavior and mortality rate of fish (Mihursky and Kennedy, 1967) and invertebrates. However, an outflow of cold water is beneficial for the maintenance of salmonid populations in areas where they reside (Olmsted and Bolin, 1996; Wieringa and Morton, 1996).

The concentration of oxygen in the water may increase following outflows from weirs[*] or sluices[*]. In extreme cases, supersaturation of dissolved oxygen may be produced by aeration immediately downstream from dams, particularly at structures having a steep configuration or a high distance of fall. The high oxygen content in the water may have adverse impacts upon aquatic organisms, particularly fish. Warm-water species are typically more tolerant of strong and rapid variations in the rate of dissolved oxygen than are cold-water species. Likewise, adult fish tolerate higher concentrations of oxygen in the water than do small or immature fish (World Bank, 1998).

In rivers containing a heavy sediment load, dams trap the organic and inorganic particles in the stream that had previously been carried downstream to the sea. This decrease in the quantity of nutrients may reduce aquatic productivity and affect fish communities (Power et al., 1996). On the other hand, an increase in water transparency owing to a reduction of the

[*] See Appendix A: Glossary.

sediment load may lead to an overall increase in primary production and fish populations, and a downstream drift of reservoir plankton which changes the food webs in lower reaches.

➢ Available Mitigation Measures

Measures available to mitigate these impacts are:

- Discharge at different levels of the dam to avoid an outflow of anoxic or cold water.
- A submerged deflector in front of the hydro intake to induce outflows of water from the surface layers of the reservoir.
- Injection of air or of gaseous or liquid oxygen, local de-stratification by means of pumps or propellers, mechanical aeration (Hauser and Morris, 1995).
- An air inlet or deflectors in the turbine room.
- Design and management of hydroelectric development so that artificial floods partly simulate the natural flood cycle.
- Use of weirs downstream to improve oxygen conditions (Eie et al., 1997).

Artificial fluctuations and the control of stream flow can alter the habitat and structure of fish communities, particularly those of riparian species (Petts, 1984; Cushman, 1985; Bain et al., 1988). The decrease in heavy flooding reduces the area of flood plains* and lowers the availability of home ranges for a large number of fish species (Bailey, 1995; Sparks, 1995). Dry, low-altitude tropical regions may be particularly affected by the disappearance of floods (Acreman, 1996b). In some cases, the use of water for other purposes (irrigation, drinking water, etc.) may compound the effects of a reduced flow rate in streams, as has been observed in the Colorado River in the United States (Rosenberg, et al., 1997).

A reduction in the flow rate of large rivers also lowers the degree of fragmentation of fish habitats, mainly in productive zones on the margins of streams. A lower current velocity reduces the relative significance of specialized habitats for fish and may lead to a greater number of productive zones in the stream as a whole (Stalnaker et al., 1989). Furthermore, a reduction of current velocities along with an increase in the water's stay induce a greater biological productivity and a net gain in better-quality fish habitats, but at the expense of biodiversity.

The Manantali Dam (Senegal)
The Manantali power project involves the construction of a 200-megawatt hydroelectric plant on the site of an existing dam that was erected in 1988. The development plan includes compensatory measures that will make it possible to produce periodic outflows at the dam in order to recreate the natural flood cycle in the Senegal River. Negotiations are under way among various authorities to determine the area of the zone to be flooded downstream once the turbines have begun operating.
Sources: Pottinger (1997); Dorcey et al., (1997)

* See Appendix A: Glossary.

The scope of saltwater intrusion dictates the types of fish communities that prevail in estuarine environments. Under natural conditions, estuaries are generally bathed in fresh water. When stream flow is reduced, however, saltwater intrusion displaces ecological zones upstream and produces a spatial readjustment of fish populations. The new estuary* turns into an extended zone for marine species, whereas it becomes inhospitable for fresh water species. The reproduction of certain littoral and deltaic species of fish may be affected if floods are not heavy enough to inundate spawning areas with fresh water. A decline was observed in sardine fisheries at the mouth of the Nile in the eastern Mediterranean following the construction of the Aswan dam in Egypt (World Bank, 1998).

The La Grande River and Eastmain Estuaries (Canada)
At the La Grande complex in Canada's northern temperate region, the winter flows of the La Grande River generated after hydroelectric development have increased 8 to 10 times relative to those of the natural hydrologic cycle. Environmental impact studies show that the estuary of the river remains home to the same fish communities and provides favorable spawning and wintering conditions for all species. The stay of migrating fish in James Bay proceeds as under natural conditions, and the return to the river occurs during the same period. The reduction of stream flow in the Eastmain River has resulted in a more pronounced intrusion of marine species into the river, and fresh water species have been forced back upstream. In this new environment, marginal species were observed to become more rare, whereas dominant species have prospered. Fifteen years later, the modification of stream flow has not brought about any perceptible change in the composition of stocks, the reproductive capacity or the food strategy of anadromous* migrating fish. The spawning and wintering habitats of the main fish species have been maintained despite saltwater intrusion. These results confirm the adaptability of these species, which have been able to survive in a highly changeable natural environment.
Sources: Hydro-Québec (1995); Groupe Environnement Shooner (1993).

➢ Available Mitigation Measures

Impacts produced by the control of or fluctuations in stream flow may be mitigated by applying the following measures.

- Establishment of a guaranteed reserved or minimal stream flow.
- Construction of weirs downstream to regulate the water level (Shane et al., 1982, Sjöström et al., 1993).
- Production of artificial floods to create, or to clean the substratum of, spawning areas (Yin et al., 1996; Ligon et al., 1995; Kondolf et al., 1991).
- Modification of stream flow to create a water intake for parent fish, to prevent the dry up of eggs and to encourage the movement of fry downstream (Carnie and Waterman, 1993; Davies, 1979).

* See Appendix A: Glossary.

- Supporting populations by stocking with fish from piscicultures[*] fed by warm water from the surface layer of the reservoir.

3 Terrestrial and Avian Fauna

3.1 Mammals and Other Non-avian Organisms

The impacts of hydroelectric projects upon terrestrial fauna must be evaluated concomitantly with the impacts on flora and their habitats, particularly those on habitat vegetation. Deforestation and the impoundment of reservoirs are unarguably the two major sources of disruption for terrestrial wildlife. Floods force individuals to migrate outside flooded areas, which generally contributes to an increase of intra– and inter-specific competition. Certain specific measures can be taken to mitigate or compensate for adverse impacts on wildlife and their habitats.

Reservoirs

The creation of a large reservoir has, inevitably, major impacts upon local vegetation and wildlife habitats. The scope of the impacts varies according to the area of the affected zones, the species that reside there and the characteristics of the habitats. Habitats in humid tropical regions have a density and diversity of wildlife that are much greater than those of temperate regions.

Modifications of habitat affect the use of feeding, breeding and reproduction areas by resident and migratory species (CIGB, 1985). These impacts result in profound changes in ecosystems[*], which may in turn modify the abundance and composition of species (World Bank, 1998).

During the flooding of a forest environment, wildlife move away from the affected area as the water level rises. This displacement increases competition with wildlife on the periphery of the reservoir (Villela, 1996). According to the increase in water level and the physiography[*] of the area, islands will form on the reservoir. Specific composition on large islands, however, will be similar to that of islands in natural lakes (Crête et al., 1997). Reservoir islands that are far from banks and protected from restrictive natural occurrences or human intervention become climactic microcosms that can serve as examples of local and regional biological diversity.

The physical components of a hydroelectric project may restrict displacement and access to the feeding, breeding and reproduction areas of species (Goldsmith, 1984). Traditional migration routes can be disturbed and the home ranges of species fragmented, although more studies need to be done on the actual consequences of these effects. In Canada, follow-up studies on the caribou in the north of Québec indicate that the frozen water of reservoirs has no interference and may even facilitate migration in winter (Hydro-Québec, 1993b).

The physical disturbance and noise produced by hydroelectric construction activities impose an additional stress upon wildlife and may lead to increased migrations (World Bank, 1998). These disturbances may indeed be stressful for wildlife, but several examples reveal that

[*] See Appendix A: Glossary.

some species are able to adapt and to thrive successfully in affected zones owing to the phenomenon of habituation.

➢ Available Mitigation Measures

In order to counter the adverse impacts of the creation of a reservoir on terrestrial wildlife, the measures described in the section on terrestrial plants (1.1) together with the following measures may prove effective.

- Overall plan for the protection of wildlife and the relocation of specimens in zones that are under-utilized by displaced species.
- Re-establishment in affected environments of specimens captured outside the project area.
- Creation of conservation units in habitats offering good wildlife potential.
- Reproduction in captivity and reintroduction of specimens in zones under-utilized by species.
- Development and management in habitats offering good wildlife potential.
- Planting in selected areas or areas that have been disturbed by construction activities or by other sources.
- Intensive harvesting of species developed in environments targeted by management activities in order to reduce exploitation in peripheral environments.

The creation of a reservoir may promote the development of new habitats favorable for colonization by a large number of animal species (Goldsmith and Hildyard, 1986). In dry areas especially, but in tropical and temperate regions as well, the presence of new littoral, marshy and humid zones will serve to increase the volume of vegetation and the density of wildlife (CIGB, 1985). The quantity of habitats produced will depend, among other things, upon the morphology of the reservoir, the topography of the environment, the nature of the soil and latitude.

The Itaipú Dam (Brazil/Paraguay)
The environmental program set up by authorities in charge of the Itaipú dam on the Paraná River has made it possible to capture over 30 000 animal specimens since impoundment began in 1982. These specimens were transferred to the two reserves or five sanctuaries created after work on the hydroelectric project was begun. The total conservation area of the terrestrial ecosystem represents 992 km^2 , more than half of which serves as en environmental protection belt around the reservoir. A center for reproduction in captivity (CASIB) makes it possible to protect species having a particular status by reintroducing them into the natural habitat. Reproduction and breeding activities carried out by the center focus mainly on those species in Brazil and Paraguay that are rare or in danger of extinction, as well as on other less abundant species in the region. The purpose of the CASIB is to recreate an ecosystem around the reservoir that is similar to the one that existed before the development of agriculture.
Sources: Itaipú Binacional (1997); World Bank (1989); Kohlhepp (1987).

Power line Corridors and Other Infrastructures

The deforestation of power line corridors and related activities reduce the number of habitats available to terrestrial wildlife. However, the regrowth of vegetation in corridors creates a mosaic of heterogeneous habitats that may lead to an increased concentration and diversity of wildlife, mainly on the edges of the forest (Deshaye et al., 1996; Lunseth, 1988). New habitat conditions make it possible to satisfy the biological requirements of the various animal species at one time or another of their life cycle.

Opening the forest landscape for corridors generally prompts an increase in floristic diversity and the food available for mammals (Lunseth, 1988; Goodwin, 1975). In temperate regions, this new food source has been exploited mainly by ungulates and rodents (Ricard and Doucet, 1995; Brunelle and Ouzilleau, 1991). The quantity and quality of food produced in corridors may differ according to the type of plant control carried out during maintenance activities (Garant and Doucet, 1995.) Shrubby screens that offer a combination of open and closed environments can support relatively abundant populations of small mammals, amphibians and reptiles (Deshaye et al., 1996). However, in alpine or tundra areas, corridors can create a barrier to movement or migration.

➢ Available Mitigation Measures

The mitigative measures proposed in the section on terrestrial plants (1.1) are useful for improving habitat conditions for wildlife in power line corridors.

Management Practices for the White-tailed Deer (Canada)
In Quebec, power line corridors run through approximately forty winter yards for the white-tailed deer. As a result, there must be periodic interventions to control vegetation. Hydro-Québec has carried out experimental winter cuts on the vegetation at two tower sites. The purpose of these activities was to determine the effectiveness of this measure on the additional nutrient input for deer and the acceleration of browse regrowth. The first winter, deer browsed a maximum of 73% of the stems cut. The following spring, new shoots represented 80% of all the browse available at the two sites. The study proved that winter cuts in corridors can be an immediate source of food for deer during the period of high energy demand.
Source: Garant and Doucet (1995).

3.2 Birds

Although the loss of terrestrial habitats has an effect on birds during the development of a hydroelectric project, the presence of a body of water may prove beneficial for them. Humid habitats can develop on the sides of reservoirs, and the regulation of the flow rate of rivers located downstream from dams may lead to a renewal of vegetation in dry areas. Some birds will be able to benefit from these new environmental conditions.

Accidents caused by collisions or electrocutions may occur in power line corridors. However, measures may be applied that will substantially reduce the risks caused by the presence of these structures.

Reservoirs

The deforestation and impoundment of reservoirs are not immediate sources of threat to adult birds. The loss of habitats and food supply is the main adverse impact of the creation of reservoirs on avifauna. The specific composition and abundance of populations may be modified following alteration of the home ranges of species (World Bank, 1998), and the level of specific competition may increase following the displacement of birds outside the submerged area.

➢ Available Mitigation Measures

The following measures serve to reduce adverse impacts on birds.

- Deforestation, whenever possible, after young birds have left the nest.
- Managing the water level of reservoirs to encourage nidification (of little use in northern temperate zones where the effects of such a measure are insignificant (Olmsted and Bolin, 1996; Julien and Laperle, 1986).
- Creating conservation units in habitats that have good wildlife potential.
- Weirs in bays may be advantageous.
- Managing wildlife habitats for the benefit of waterfowl (of little use in northern temperate regions where the benefit-cost ratio is not justified).

Reservoirs are generally beneficial for the avifauna of regions that are dry and poor in vegetation (Gérard, 1990). The transformation of riparian ecosystems into lacustrine ecosystems creates new habitats for colonization by birds (World Bank, 1991b). Coastal and marshy areas are created when the morphology of a shore is appropriate. The partially submerged tree trunks and macrophytes of reservoirs are also attractive to birds (CIGB, 1985). These new environmental conditions generally lead to increased populations of waterfowl and shore birds (World Bank, 1998). In temperate regions, reservoirs that do not freeze offer important wintering habitats and nidification sites for migratory species (Helland-Hansen et al., 1995). In the former Czechoslovakia, about 22 000 mallard ducks found refuge in these habitats, at least for a part of the winter (Fiala, 1980).

The Diama Reservoir (Senegal)
The purpose of the Diama dam, which began operating in 1985, is to prevent saltwater intrusion by the sea during the low water period and to allow for the flooding, permanent and seasonal, of depressions in the delta and in the lower valley. The high water level in the Diama reservoir acts as an artificial flood which inundates the upstream part of the drainage basin. The large quantities of water have made it possible for 12 000 pink flamingoes as well as thousands of cormorants, terns and small flamingoes to find areas for reproduction in the flooded islands and forests. The region is of exceptional importance for nature conservation.
Source: Euroconsult (1990).

Downstream Reaches

The repercussions of hydroelectric management on the avifauna of rivers located downstream from hydroelectric dams are very closely linked to the resulting modification of vegetation. A reduction of heavy periodic flooding may impoverish the vegetation of rivers, humid zones and deltas (Acreman, 1996b; Euroconsult, 1990), thereby changing the specific composition and abundance of bird communities (ERL, 1993). However, a permanent stream flow generated in the scattered rivers of dry tropical regions encourages the development of vegetation and colonization by birds (Pulford et al., 1992). Furthermore, a reduced stream flow in the rivers of northern temperate zones promotes the development of riparian environments that are more attractive to waterfowl, as was observed during environmental follow-up activities on the La Grande complex in Canada (Hydro-Québec, 1994).

The following measure may prove useful for reducing adverse impacts on avifauna:

- Design and management of hydroelectric development in a way that allows the production of artificial floods to recreate in part the natural flood cycle and promote the development of vegetation.

The Colorado River (United States)
A greater number of peregrine falcons frequent the drainage basin of the Colorado River because of the prey made available by an increase in primary production and a greater diversity of aquatic plants and organisms. Marshes and riparian habitats, formerly rare in the Grand Canyon, have developed and add to the diversity and quality of the environment. The population of peregrine falcons that reproduce in the Grand Canyon is presently the highest in North America.
Source: Wieringa and Morton (1996).

Power Line Corridors and Other Infrastructures

The deforestation of power line corridors, access roads and other infrastructures poses a threat to the reproduction of birds. As with reservoirs, deforestation after young birds have left the nest strongly reduces this impact.

The presence of power lines may cause bird mortality through collisions (Arnold et al., 1995; ERL, 1993). Problems arise in very specific conditions when various factors interact to create strong collision potential. One example of this is the presence of power lines in migration corridors (ERL, 1993). Although collisions may affect local populations of birds, they are not a threat to the survival of species (Brown et al., 1984; Anderson, 1978; Lee, 1978).

Mortality from electrocution can result when birds use wires or power poles for perching or nesting (Dawson and Mannon, 1994,; Benson, 1981). In dry regions, the risk of electrocution is higher because the scarcity of vegetation causes birds to perch on power lines (ERL, 1993).

Accidents from collision or electrocution depend mainly upon the species, the age or behavior of birds, the characteristics of electric power lines and poles, weather conditions, the topography of the area, the time of day and, possibly, a combination of several or all of these factors relative to the major migration routes (EEI, 1996; Bridges and Lopez, 1995; EEI, 1994).

➢ Available Mitigation Measures

The following measures make it possible to reduce the adverse impacts of transmission lines and power poles on birds.

- Use of plant screens or other types of screens close to power lines to force birds to increase their flight altitude (Reavel and Tombal, 1991).
- Modification or creation of habitats close to power line corridors to create strategic areas that encourage the displacement of birds on the same side of a power line (EEI, 1994).
- Markers on power lines or guard wires (Brown and Drewien, 1995; Morkill and Anderson, 1991; Brown et al., 1987; Beaulaurier, 1981).
- Sufficient space between two electric conductors or between a ground wire and an electric conductor.
- Installation of anti-perching devices or platforms specially designed to encourage birds to perch or nest in safer places (EEI, 1996; EEI, 1994).

Optimization of power line routing with respect to topography and avian migration corridors.

Collisions and Electrocutions
– Placing fluttering banners and brightly-colored (orange, yellow, white, etc.). spirals on power lines has made it possible to reduce accidents from collisions by up to 89% (Africa, United States, Europe). Effectiveness depends, above all, on the type and size of the marker used, as well as on the distance between them.
Source: Brown and Drewien (1995); Ledger et al. (1994); Koops (1993, 1987).
– Perches installed on top of 12,5 kV power poles in Colorado (United States) encourage birds to perch in places where the danger of electrocution is lowest.
Source: Bridges and Lopez (1995).

4 Biological Heritage

4.1 Hydroelectric Projects and Biodiversity

Broadly speaking, biodiversity refers to all forms of life and all types of habitats found on earth. In *The World Strategy on Biodiversity*, outlined in 1992 by the World Resources Institute (WRI), The World Conservation Union (IUCN) and the United Nations Environment Programme (UNEP), biological diversity or biodiversity is defined as the measure of all of the genes, species and ecosystems of a given region. The *Convention on Biological Diversity* (CBD) defines it as the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part.

Most scientists recognize, however, that not only is total conservation of biodiversity impossible, it is also unsustainable from a biological viewpoint (Costanza, 1992). Biological systems are in a constant state of flux, and adverse impacts vary according to the scope of the change in environmental conditions and the adaptive capacity of populations (Coleman, 1996). An ecosystem is considered healthy when all its component parts are present and capable, over time, of maintaining its organization, autonomy and power to react to restrictive impacts. The loss of a particular species or its replacement by a regional distribution species does not necessarily entail a loss of integrity, unless this change affects the processes supporting them. Broadly speaking, the dynamic of a given population often involves temporary or local extinction that are balanced by re-colonization resulting from the dispersal of specimens (Hanski and Gilpin, 1991).

The domains discussed so far (flora and aquatic, terrestrial and avian fauna) describe the basic elements that must be taken into consideration by the hydroelectric industry when developing a framework of effective action to ensure the sustainable development of the habitats and natural ecosystems that support species and their biological diversity. Reaching this objective presupposes a knowledge of the fundamental elements of biodiversity in environments where power plants and transmission lines are located. Identifying the impacts of hydroelectric projects makes it possible to pinpoint the environmental factors that influence biodiversity and to develop and apply correct measures for protection and conservation. Thus, the choice of an appropriate site for the installation of infrastructures, the implementation of correct environmental practices and the development of effective mitigative measures are all tools available for the protection of biodiversity. The management of biodiversity calls for a comprehensive approach to ecological systems and the implementation of long-range action plans to ensure the durability of species.

Hydroelectric projects, like all else that intrudes upon the environment, act on biodiversity in a multitude of ways, and the response of ecosystems is correspondingly varied and complex. Certain effects on the biological environment are immediate and obvious, others are gradual and more subtle (Petts, 1980; Brookes, 1994). Impacts on biodiversity may be positive or negative, and the elements affected often relate to the specific composition and abundance of specimens, their habitats, the interaction between populations and communities, and the processes that govern the various functions of ecosystems.

The effects of power projects on the biophysical environment are due mainly to the construction of dams and the creation of reservoirs. The construction of power lines and of other infrastructures related to work on the production of electricity are likewise disruptive. The significance of impacts upon the natural environment depends upon many factors: the type of power project, the biome and the species present, the degradation of environments, human intervention and the multiple uses of reservoirs.

With respect to hydroelectric power projects, the main potential sources of impacts on biodiversity are:

- loss or creation of terrestrial and aquatic habitats
- modification of water quality

- regulation of stream flows downstream from dams
- flood control in flood plains
- obstacles to fish migration
- introduction and dispersal of exotic species.

The effect of loss of land upon biodiversity depends on the exceptional or critical character of the terrestrial habitats lost with respect to the area of insertion, as well as the biodiversity of the aquatic ecosystems which could benefit from an increase in aquatic home ranges. In rivers of low biological diversity, the creation of a reservoir will ensure productive, good-quality habitats for other species. Furthermore, dry and dry tropical regions in particular benefit from reservoirs, because they promote the development of a diverse and abundant plant life in humid terrestrial areas.

The high productivity of reservoirs generates high biomass, which is represented by the various organisms of the trophic chain. There is an increase in interaction between trophic networks for resident species and, in cases of displacements owing to migration, the presence of other species adds to this new ecosystem dynamic. The productive conditions of aquatic, riparian and terrestrial environments may intensify the diversity and abundance of plant and animal life.

A similar phenomenon is observed in rivers located downstream from dams. A greater water transparency combined with a decrease in turbidity may prompt an increase in primary production and favor the development of trophic levels. The regulation of stream flows in the scattered rivers of dry tropical regions supports the maintenance of suitable habitats for plant and wildlife. As with reservoirs, new environmental conditions may lead to an overall improvement of biodiversity.

A higher degree of biological diversity may occur in power line corridors, mainly in border areas, where numerous species of terrestrial wildlife benefit from the existence of heterogeneous habitats and a more diverse plant life.

A new balance in biological conditions comes about following perturbations of the environment generated by the establishment of hydroelectric projects. Biological heritage, although changed, may well be as varied as it was in its original state.

New “integrated” techniques of conservation and management include tools that provide for a harmonization of the multi-purpose uses of dams. The contribution of the hydroelectric industry lies in its effective management of biodiversity, which helps to create a modern vision of the actions brought to bear on ecosystems.

The following section deals with legal agreements and other mechanisms that furnish nations and developers with the tools of support needed to implement action aimed at conserving the biological heritage.

4.2 Tools for Conserving the Biological Heritage

Conventions

Because human intervention affects the integrity of biodiversity to a greater and greater degree, legislation has been drawn up to ensure the protection of species and habitats. The goal of *The Convention on Biological Diversity* in 1992 was the conservation of biological diversity, the sustainable use of biological resources and a fair and equitable distribution of the benefits to be derived from the use of these resources.

One of the oldest treatises on biodiversity is the *Convention on Wetlands of International Importance, Especially as Waterfowl Habitat*. This agreement, adopted in 1971, supplied multinational corporations with a list of wetlands all over the world. The major wetlands are designated on a list kept by the World Conservation Union and the International Waterfowl and Wetlands Research Bureau.

The *Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)*, another essential instrument in effect since 1975, seeks to protect wild species from overexploitation by international trade by regulating international displacements of plant and animal species.

In effect since 1975, the *Convention for the Protection of the World Cultural and Natural Heritage* recognizes the obligation of the signing countries to protect unique natural and cultural areas. The committee for the world heritage makes and publishes a list of sites having exceptional natural and cultural value.

Some other regional or sector-based agreements for the conservation of biodiversity are:

- Agreement on the Conservation of Nature and Natural Resources (1971)
- Convention for the Protection of the Natural Resources and the Environment of the South Pacific Region (1986)
- African Convention on the Conservation of Nature and Natural Resources (1968)
- Convention on Nature Protection and Wildlife Preservation in the Western Hemisphere (1940)
- United Nations Convention to Combat Desertification in those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa (1994).

Protected Areas

Whereas many natural habitats are successfully transformed for human purposes (agriculture, forestry, water resources, etc.), the natural value of certain other areas is such that they must be used with great care or left alone. Societies are equipped with mechanisms to preserve environments deemed sensitive or exceptional, and the establishment of protected areas constitutes an effective lever for ensuring their durability. Protected areas may be defined or decreed by:

- national or local legislation (national parks, reserves, etc.)
- international conventions (sites belonging to the world heritage, wetlands of international importance, etc.)
- UNESCO (biosphere reserves).

The goal of legislation is, essentially, the strict protection of many areas; however an outright ban on all human activity may be necessary for some others.

Inherent Mechanisms in Hydroelectric Projects

Protecting biodiversity means safeguarding the habitats that support the vital functions of diverse species within ecosystems. Many of the conservation efforts of the hydropower industry have been based on the protection of species that are rare or in danger of extinction for economic or other reasons; it is, however, essential to broaden intervention to improve the health and integrity of the ecosystems that support species (Pipkin, 1996). Measures for the protection of species must take into account their natural habitats as well as the interactions and processes that influence all types and levels of life of specimens.

As regards the establishment of power plants, mechanisms for protecting the biological heritage can be integrated directly into the process of environmental assessment[*]. As an example, there is the World Bank, which has issued specific guidelines regarding biodiversity that must be considered during studies of environmental assessment (World Bank, 1997). Other policies relative to biodiversity prepared by the World Bank offer guidelines with respect to practices involved in power plant development, such as the operational procedures relative to natural habitats (OP 4.04), forestry (OP 4.36), water resources management, (OP 4.07) and indigenous peoples (OP 4.20).

Various other organisms also consider biodiversity when outlining guidelines and policies, among them the International Association for Impact Assessment (IAIA), the World Conservation Union (IUCN), the United Nations (UN), the Asian Development Bank (ADB) and the Inter-American Development Bank (IDB).

Environmental assessment recommends options to eliminate, mitigate or compensate for environmental impacts likely to affect biodiversity. In general, the practice describes the mitigative or compensatory measures used within the framework of hydroelectric power plants that will prove effective if correctly applied (Liebenthal, 1997).

Choosing the right site for a power project is one of the most important measures for minimizing the scope of the environmental effects of hydroelectric development. General criteria for the siting of power plants have been outlined by Ledec et al. (1997).

Generally speaking, the best sites are located upstream, often in deep valleys with a steep slope. The goal is to select sites where loss of natural habitats and wildlife will be kept to a minimum and where the risks to biodiversity can be limited.

During the establishment and exploitation of power plants, the most effective management practices will be implemented to reduce environmental impacts and to determine the consequences of court decisions on the protection and conservation of biodiversity. Identifying sectors where biodiversity is compromised helps integrate new environmental concerns in order to minimize losses with respect to biodiversity. Continuous basic research on the natural processes, functions and interactions of ecosystems makes it possible to influence decisions made regarding biodiversity and to determine priorities of action.

[*] See Appendix A: Glossary

The hydroelectric industry has been in the forefront of the creation of programs for environmental protection and sustainable support for biodiversity (Heydlauff, 1996; Olmsted and Bolin, 1996). It is ever on the watch for more effective tools to adapt its practices to the environments where installations are located. Not only do many hydroelectric projects proceed in conformity with existing environmental laws, but some also voluntarily exceed these requirements. Often partnerships have been established with authorities in charge of natural resource management and with NGOs concerned about the conservation of habitats. In 1996, at a meeting in Williamsburg, Virginia (United States), the consensus of professionals in the power industry was that the conservation of biodiversity can no longer viewed as an option: it is now an absolute necessity. (Mattice et al., 1996).

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Appendix F

SOCIOECONOMIC ENVIRONMENT

APPENDIX F
SOCIOECONOMIC ENVIRONMENT

Table of Contents

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1 Introduction

In the following section, the reader will find a summary description of the socioeconomic impacts and relevant mitigation and compensation* measures that are typically associated with hydropower projects.

1.1 Generic and Specific Socioeconomic Issues of Hydropower Projects

The socioeconomic impacts are addressed under four headings: Land Use, Economic Impacts, Health and Safety Impacts, and Social Impacts. These categories correspond to impacts, positive and negative, that generally occur with hydropower projects:

- Hydropower, as a human intervention in water basins, has a basic land use component.
- Hydropower, as an infrastructure project, has a significant economic dimension.
- Hydropower, as a human intervention in water basins and as an infrastructure project, has a significant health and safety dimension.
- Hydropower as a supplier of electricity to consumers, as a land use and economic intervention has impacts on communities and society as a whole.

Because of their particular importance, specific issues related to resettlement and rehabilitation are addressed separately at the end of this appendix.

1.2 Difficulties Related to the Prediction of Socioeconomic Impacts of Hydropower Projects

Hydropower projects are complex and long-lasting infrastructures that have a significant impact on their local human environments, both as instruments of economic development and as instruments of social change. Even when they can be reasonably well circumscribed within relatively isolated communities, the socioeconomic impacts of hydropower projects are often hard to distinguish from those of other ongoing sources of social and economic change. They tend to occur over long periods of time, both before and after project construction and implementation. Whether as a result of new access roads and power transmission networks or as a result of induced economic benefits in far off urban centers, they also tend to affect communities on a wider geographical scale than is the case for project-related physical and biological impacts.

Predicting the irreversible, the long-term and the short-term socioeconomic impacts of hydropower projects is therefore extremely difficult. It involves anticipating on a large time-scale the beneficial and adverse effects likely to be induced directly and indirectly by such projects. It also requires developing the means to either avoid or mitigate the harmful effects, or to maximize the benefits of such projects.

* See Appendix A: Glossary.

Moreover, the existing literature on socioeconomic impacts of hydropower projects is of uneven quality and is hindered by the lack of sufficient monitoring and follow-up data on existing projects. Whether because of a lack of funding or of interest, few long-term longitudinal studies of hydropower projects based upon solid socioeconomic baseline data and recurrent surveys have been carried out.

For more clarity, the following discussion of socioeconomic impacts and corresponding mitigation and compensation* measures associated with hydropower will focus mainly on major or large projects in sub-tropical or tropical environments. It is important to remember that most potential new hydropower sites remain to be developed in emerging economies and often densely populated sub-tropical or tropical regions. In addition, socioeconomic impacts of large hydropower projects tend to be more acute in such environments and must, therefore, be planned with even greater care.

1.3 Critical Importance of Mitigation and Compensation Measures

To a greater degree than for their physical or biological impacts, the socioeconomic impacts of hydropower projects are largely conditioned by the nature of project related mitigation measures and compensation packages and by the process leading up to their design and implementation. To a large extent, the actual design and implementation of mitigation measures and compensation packages determine whether a hydropower project is likely to become a means of local development or an instrument of local impoverishment and dependence. For instance, the creation of a tropical reservoir may lead to increased incidences of water-borne diseases; if, however, the project promotes a comprehensive public health program as a mitigation measure, public health conditions may well improve when compared to pre-project conditions.

In many cases in the past, hydropower projects have resulted both in winners and losers: locally affected communities have often born the brunt of project related economic and social losses, while the regions and industries to which they are associated have profited from a better access to affordable power and to regulated downstream water flows and water levels.

The process leading up to the design and implementation of hydropower projects also plays an important role in determining the manner in which locally affected communities perceive the socioeconomic benefits or impacts of such projects. Local perceptions are tied to the values that people hold. Such values are colored by cultural or social distinctions. Where values held by local populations markedly differ from those held by project proponents, conflicts are likely to arise if local concerns are not given due consideration.

2 Land Use

By their very nature, hydropower projects generate a significant amount of long term impacts on existing and future land uses. They usually lead to the disappearance of valuable resources and land uses in reservoir impoundment zones and to widespread modifications to existing land uses, both upstream and downstream of the power plants. Changes to land uses are generally a consequence of the submergence of large areas in river valleys, permanent

* See Appendix A: Glossary.

modifications to upstream and downstream water levels and water flows and induced development associated with the regulation of water flows and the creation of large reservoirs.

2.1 Changes to Upstream Land Uses

2.1.1 Impacts on Reservoir Backwaters

Reservoir backwaters created upstream of hydropower dams may raise the water levels and reduce the water velocity of upstream rivers, with increasing upstream sedimentation and raising upstream groundwater[*] levels. In such cases, existing land uses along upstream rivers are liable to be affected by higher incidences of flooding, of water logging and potentially of water-borne diseases.

Hydropower projects can become barriers to fish migration, thereby reducing the diversity and the quantity of available fishery resources in upstream rivers. Reduced catches may result in losses of livelihoods, in lower protein intakes and in related health problems for upstream populations.

Even if downstream river flow regulation and low flow augmentation are likely to facilitate large-scale commercial and recreational navigation below the dam and reservoir, the damming of a river can also isolate existing inland ports and river-edge communities from regional or international commercial shipping and river navigation, either by separating upstream navigation from downstream navigation, or by increasing siltation rates in upstream inland ports.

2.1.2 Impacts on Upstream Catchments

Steep or fragile slopes that are highly susceptible to erosion are vulnerable to the opening up of new access roads to hydropower plants. Better access to isolated and undeveloped catchment[*] areas often leads to:

- the creation of new human settlements
- the clearing of forest cover
- the opening up of new agricultural land
- the exploration and mining of mineral deposits
- the uncontrolled presence of visitors and tourists.

Improved access to isolated but already inhabited catchment areas can also be the source of conflicts between traditional land uses and new land uses. Such changes to land use patterns in sensitive upstream catchment areas may result in widespread environmental degradation through increased soil erosion and sedimentation, loss of forestry resources and of wildlife habitats, and increased pollution. In turn, by shortening the life spans of reservoirs and by damaging power plant turbines, increased sediment flows from upstream catchment areas can significantly reduce the number of years of operation and the cost efficiency of power plants downstream.

[*] See Appendix A: Glossary.

2.1.3 Mitigation and Compensation Measures

The impacts of hydropower projects upon upstream river fisheries and river navigation can be mitigated to a certain extent. Hydropower dams can be designed with fish elevators, ladders or screens to facilitate the passage of migratory fish and to reduce fish entrainment into power plant turbines and conduits. Reservoir backwaters can also be used to develop inland fishery management plans, including training and support for the creation of sustainable fishponds and aquaculture.

Backwater sedimentation of reservoirs, which can hinder upstream river navigation, can be mitigated to a certain degree by dredging. Hydropower dams can also be equipped with locks, ship lifts or cleared shipping lanes to facilitate the passage of commercial shipping and local river navigation.

The impacts of hydropower projects upon upstream catchments can be mitigated substantially by the implementation of watershed protection programs which may involve the acquisition of sensitive conservation areas, the control of vegetation cover and the regulation of watershed development.

The Nam Theun Two Project (Thailand)
In the case of Lao's proposed 450 square-kilometer Nam Theun Two hydropower project, plans have been made to conserve the 3,710 square kilometer watershed as an offset to compensate in perpetuity for the loss of biodiversity in the impoundment zone and to vastly reduce sedimentation risks upstream of the dam. The creation and management of such a conservation zone could be financed by the allocation in perpetuity of a small fraction of the hydropower project's income.
Source: Goodland (1997) p. 91.

However, the long-term sustainability of watershed protection programs is largely conditioned by the efficiency of institutional and financial frameworks negotiated by concerned governments with watershed inhabitants. The success of such programs requires that local populations become partners and beneficiaries in their management and implementation. Past practices of resettling watershed communities outside of designated conservation areas (the traditional approach to conservation) are being replaced by sustainable resource management practices that are based on the active involvement of local populations.

2.2 Changes to Reservoir Area Land Uses

2.2.1 Impacts on Reservoir Area Land Uses

The flooding of the impoundment zone behind a hydropower dam may results in the irreversible disappearance, fragmentation or dislocation of existing human settlements and infrastructure. It also leads to the loss through submergence or fragmentation of riverine agricultural land, vegetation and alluvia, forests and wildlife areas, mineral resources, historic, cultural and religious resources, and scenic areas. The man-made lakes created upstream of hydropower dams thus modify natural and human ecosystems*.

In densely populated areas, particularly in the tropics, the shores of new reservoirs are rapidly resettled by displaced populations and colonized by newly arrived migrant populations. The creation of advantageously located settlements around the reservoirs may be accompanied by the relative isolation of previously well established communities. The progressive reestablishment of disrupted terrestrial and riverine communication systems results in new patterns of exchanges and trade between reservoir and outside communities. Improved navigation due to the presence of deep standing water bodies and improved terrestrial transportation brought about by new access roads can facilitate travel and trade over longer distances for hitherto isolated communities.

Even in relatively un-populated regions in northern or sub-tropical environments, the creation of new hydropower reservoirs can significantly modify the configuration and distribution of livestock migration routes or of traditional hunting and fishing grounds, to the benefit of some and the disadvantage of others.

The creation of hydropower reservoirs in densely populated tropical and sub-tropical areas generally leads to the proliferation of lacustrine fish species which are better adapted to standing water bodies than riverine species. The significant increase in the total numbers of fish in such reservoirs can support the development of lake fisheries after impoundment. Following submergence, the drawdown* area surrounding the reservoir can also support, under certain circumstances, the development of drawdown agriculture*, particularly in semi-arid regions that are often afflicted by prolonged droughts.

More intensive land use patterns around new reservoirs often contribute to an overuse of vulnerable environmental resources on less fertile inland soils. This may result in environmental degradation within and around the reservoirs through the loss of forestry resources and of wildlife habitats, increased sediment entrapment, changes in water quality, and increased agricultural, urban and industrial runoff, ground water contamination and air pollution.

In tropical or sub-tropical regions, changes to reservoir water quality may lead to the creation of new habitats for water weeds and algae, such as water hyacinth or water lettuce that can proliferate at an extraordinary rate in stagnant or eutrophic reservoirs. This can result in the contamination of local water supplies, in increased evaporation losses, in blockages of dam intakes and of navigation, and in algal blooming and fish die-offs.

2.2.2 Mitigation and Compensation Measures

Resettlement and rehabilitation programs constitute the principal means to mitigate and compensate local communities for the flooding of the impoundment zone behind a hydropower dam. As discussed further in following section 6, such programs consist of two closely related yet distinct processes: displacing project-affected people and rebuilding their livelihood.

* See Appendix A: Glossary.

Another type of measure that can also contribute significantly to the mitigation of community impacts in the impoundment zone is based on the development of reservoir fisheries. Critics of large dams have tended to underestimate the importance of reservoir fisheries for project-affected people. Where properly designed and implemented, the impacts of hydropower projects upon reservoir area* land uses can be compensated to a large extent by long-term efforts to develop and sustain reservoir fisheries and drawdown agriculture, as well as associated infrastructure and commercial and public services.

However, to ensure that project-affected people actually become beneficiaries, training and technical assistance are required, as are the protection of water titles for project-affected people involved in pisciculture*. Otherwise, more competitive fishers from existing reservoirs and natural water bodies can be expected to dominate the new fishery.

The Kariba Reservoir (Zambia/Zimbabwe)
"…The development of the Lake Kariba reservoir fishery illustrates effective ways for incorporating project-affected people. For an initial five-year period, the fishery was closed to immigrants. During that time a training center was built that offered short courses to small-scale commercial fishermen. Improved boats were designed with local carpenters trained in their manufacture. Credit was made available to buy boats and other gear. Lakeside markets were provided with accessible feeder roads for exporting fresh and sun-dried fish… "…Although they did not previously have the technology for fishing mainstream Zambezi waters, the response from local people was rapid, with over 2,000 resettlers, hosts and other project-affected people catching over 3,000 tons annually within a four year period. Not only were loan repayments over 90 percent, but savings were invested in ways that enabled a majority of fishermen to shift to other activities when the now predictable decline in the reservoir's initial productivity occurred…The fishery also provided a major mechanism for further incorporating village women within a market economy by providing them with an outlet for the sale of village produce and the manufacture of beer within the fish camps…"
Source: Scudder (1997) pp. 58-59

Where properly planned for, other types of socioeconomic benefits can also help to compensate local communities for the flooding of the impoundment zone behind a hydropower dam: in certain cases, new reservoirs can support such new activities as recreational navigation, sport fishing or tourism.

2.3 Changes to Downstream Land Uses

The nature of changes to downstream land uses is largely dependent upon the configuration of the lower river valley and the extent of river flow regulation. Such changes are particularly severe in those rivers which flow through wide and gentle valleys (as opposed to canyon-shaped river courses) and in which agriculture has been historically based on the recurrence of natural and limited annual floods.

* See Appendix A: Glossary.

2.3.1 River Flow Regulation

The major effects of river flow regulation on downstream land use systems are related to flood control* and to irrigation. Downstream river flow regulation and low flow augmentation are also likely to facilitate commercial and recreational navigation below the dam and within the reservoir.

Even if the effectiveness of dam-related water management practices for ensuring flood control is sometimes questioned, the presence of dams upstream strongly encourages local populations to settle closer to the downstream river bed or within the limits of the flood plain. The presence of regulated river* flows and low flow augmentations often support the development:

- of irrigated agriculture and cash crops
- of industries that require large and regular supplies of river water
- of various service industries that supply inputs to and market the products from agricultural and industrial concerns.

In turn, these new economic activities, often in combination with other factors, are liable to generate additional series of indirect or induced socio-economic benefits and impacts, which become progressively more and more difficult to trace back to the original hydropower dam project. For instance, increased economic activity may attract an influx of migrants from outside the watershed and lead to greater downstream population densities and to the growth of new urban communities.

Though it is the source of increased agricultural activity and higher food production, the application of large quantities of water for multi-annual cropping in downstream irrigation areas may result in the proliferation of agricultural pests, the raising of local water tables and the water logging of soils. In turn, higher ground water levels and water logging may contribute to the salinization of soils and to long-term losses of soil fertility if proper drainage is not available.

Salinization induced by widespread irrigation can also spread to underground wells and affect the quality of local drinking and agricultural water supplies. The application of fertilizer and pesticides to irrigation land, as well as substantially increased releases of industrial and urban air pollution, run-off and untreated wastewater, may all progressively contribute to degrade downstream water quality. Water logging, salinization and loss of fertility of irrigation areas due to highly intense cultivation methods, constitute major challenges in sub-tropical and tropical environments, particularly in densely populated semi-arid regions such as India and Pakistan.

These problems are often compounded by other problems such as the abandonment of irrigated plots for socioeconomic reasons and failure by governments to ensure the proper and timely supply of required financial and technical support. Because of such difficulties, the expected downstream benefits of regulated river flows for the development of irrigated agriculture have in some cases been overestimated.

* See Appendix A: Glossary.

In other cases, the detrimental effects of the disappearance of annual floods for downstream subsistence agriculture or fisheries have been largely neglected. Studies carried out by the Institute for Development Anthropology on the downstream impacts of the Manantali dam on the Senegal River have clearly documented such issues (Horowitz, 1991 and Salem-Murdock and Horowitz, 1994).

2.3.2 Disconnection of Downstream River from Upstream River and Reservoir

As mentioned earlier for reservoir backwaters, by separating upstream rivers from downstream rivers, hydropower projects frequently become barriers to fish migration, thereby reducing the diversity and the quantity of available fishery resources. In densely populated areas, reduced catches may result in losses of livelihoods, in lower protein intakes and in related health problems for downstream populations.

2.3.3 Reduced Sediment Loads and Changed Water Quality and Salinity

Reduced sediment loads can result in significant long-term erosion of downstream riverbeds and estuaries and to coastal erosion. In turn, riverbed erosion and the subsequent lowering of groundwater levels can lead to:

- the caving in of river embankments
- the loss of infrastructure through the undercutting of foundations (bridges, weirs, jetties, underwater cable crossings, etc.)
- the drying up of groundwater wells and water supply problems
- losses of riverbank forest cover due to groundwater levels falling below the root zones of trees.

The flooding of biomass in the upstream impoundment zone and changes to river flows can substantially affect downstream water quality for drinking, fisheries and navigation. In certain cases, the reduced sediment load in downstream estuaries leads to the gradual disappearance of fertile soils under the combined effects of accelerated erosion and increased salinity intrusions from the estuaries. Long-term reductions of sediment outflows in marine coastal zones can unbalance the annual rates of replenishment of sediment loads along coastlines, inducing the gradual disappearance of beaches and the deterioration of coastal settlements, tourist resorts and public infrastructure.

2.3.4 Mitigation and Compensation Measures

Ensuring a sustainable basis for downstream irrigation and rain-fed subsistence agriculture requires the design and implementation of carefully thought out agricultural management plans that take into account the interests of concerned stakeholders.

Such management plans could combine various types of irrigation perimeters with more traditional agricultural land uses, such as flood recession* farming, fishing and animal husbandry. Where feasible, the rules of operation of upstream hydropower dams could be adapted to enable controlled releases for agricultural purposes.

* See Appendix A: Glossary.

…Controlled flood releases are not a new concept. In the monsoon climate area of China, engineering structures have passed on flood waters through sluices for hundreds, if not for thousands of years, just as the Three Gorges Dam is designed to sluice on most of the annual flood, as well as its important silt load. Releases on a smaller scale, called flushes, are currently utilized in the Western USA and elsewhere for the benefit of fisheries…Because of the historic emphasis on flood control in Europe and the USA, as opposed to flood management, controlled releases have yet to receive the attention that they deserve. A series of careful studies are needed to assess the extent to which the Senegal experience, or the Pongolo experience in South Africa, are applicable to other river basins, not just in Africa, but elsewhere in the tropics and subtropics; the Mekong River Basin is a possible example. (Scudder, 1994, pp. 107-108).

The Manantali Dam (Senegal)
Studies carried out by the Institute for Development Anthropology have demonstrated the feasibility and socioeconomic benefits of an alternative water management regime downstream of the Manantali dam on the Senegal River. Such a regime would allow controlled water releases from the dam (with acceptable trade-offs in power generation capacity) and would substitute the natural annual flood with an artificial annual flood. This could protect the needs of downstream small farmers in terms of irrigation water and the livelihoods of downstream fishing communities, thereby mitigating much of the adverse downstream socioeconomic impacts of dams.
Sources: Horowitz, 1991 and Salem-Murdock and Horowitz, 1994.

3 Economic Impacts

Because of their long-term structural impact, there is no doubt that well sited and designed hydropower projects generate significant regional and national economic benefits. It is difficult to overstate the economic importance of hydropower and irrigation dams for densely populated developing countries affected by scarce water resources for agriculture and industry, limited access to indigenous sources of oil, gas or coal, and frequent shortages of electricity.

Nonetheless, such projects do not contribute to sustainable development in a net sense unless their direct and indirect benefits are larger than their direct and indirect costs, including environmental and social benefits and costs.

3.1 Direct and Indirect Economic Benefits

In regions or countries blessed with indigenous hydropower resources, hydropower dams offer a potentially important means of acquiring one of the most important underpinnings of modern development: a reliable supply of electricity. Electricity supplied by hydropower projects allows many developing countries to replace large quantities of expensive and non-renewable fuel imports used for electricity production by both indigenous and renewable sources of energy.

A recent preliminary desk review by the World Bank's Operations Evaluation Department (OED) examined the outcomes of 50 completed large dams assisted by the Bank (World Bank, 1996). The projects were approved between 1956 and 1987, and schemes still under construction such as the Sardar Sarovar (Narmada), in India, were excluded. Given the long implementation periods common to large dam projects, most of the reviewed projects were appraised before the Bank adopted guidelines on resettlement (1980) and on environmental protection and management (1986).

The OED study concluded that the large majority of the dams reviewed yielded benefits that far outweighed their costs, including the costs of adequate measures to mitigate their adverse environmental and social impacts. The study also concluded that adding the probable costs of measures that the projects could have taken to satisfy today's guidelines on resettlement and the environment would make little difference to the estimate of economic returns.

It is generally agreed that besides improved power supply, the three other major direct and indirect economic benefits that frequently apply to hydropower projects are flood control and river flow regulation, irrigated agriculture and water supply. With respect to these benefits, the OED study concluded that:

> …The 50 dams reviewed have made major contributions to economic development. They have created an installed power generation capacity of 39 000 MW and they replace the equivalent of 51 million tons of fuel in electric production annually. They control floods and provide water for urban populations and industrial development. They have extended irrigated areas by about 1.8 million hectares and improved irrigation for another 1.8 million hectares, substantially increasing cropping intensity and yields of major food crops. (World Bank, 1996).

Other secondary direct or indirect economic benefits of hydropower projects include:

- improved balance of payments (associated for instance with reduced imports of oil for power production or of high value food products such as rice)
- development of new power intensive industries such as aluminum, steel, etc.
- new sources of revenue for local and regional labor markets and suppliers
- improved navigation
- development of reservoir fisheries, tourism and resort activities
- new cultivation and grazing zones in reservoir drawdown areas.

3.1 Direct and Indirect Economic Costs

Where they occur, the most significant social costs of hydropower projects are related to large-scale resettlement. Social costs associated with resettlement (particularly when involving indigenous or tribal peoples) are difficult to mitigate. Nevertheless, when properly designed and implemented, community development programs for displaced populations and other project-affected communities can ultimately lead to positive outcomes. These issues are discussed further in section 6.

Many of the other direct and indirect environmental and social costs associated with hydropower projects have been discussed in the previous section on land use.

Other social costs of hydropower projects that are frequently observed in developing countries include:

- increased health and safety risks (discussed further in section 4)
- demographic and institutional impacts, impacts on community traditions and ways-of-life, class or gender related impacts, impacts on vulnerable minority groups, impacts on human heritage and landscapes, and geopolitical impacts (discussed further in section 5)
- long-term national debt burdens.

All of the direct and indirect environmental and social costs mentioned above should be integrated into the overall project cost-benefit analysis.

Nonetheless, it is important to keep in mind that when compared to other non-renewable sources of power production (such as coal, oil, gas or nuclear energy), the hydropower industry is characterized by high internalized environmental and social costs related to required mitigation and compensation measures[*] and to low externalized environmental and social costs related to air, water and soil pollution (UNIPEDE, 1997).

4 Health and safety Impacts

The considerable modifications to upstream and downstream land use systems introduced by hydropower projects, as well as the varied distribution of project benefits and costs among various stakeholders, have a wide range of consequences on human health and on public safety. These impacts are discussed hereafter.

4.1 Impacts on Human Health

Large public infrastructure projects, such as hydropower dams and reservoirs and their accompanying modifications to local land uses, may have a strong direct and indirect influence on human health. The most perceptible changes are an increase in the frequency of occurrence of diseases and of the number of people contracting diseases. However, project induced diseases are not the only factors that affect the health of local and regional populations: other factors come into play, such as indirect or induced development associated with hydropower projects.

Hydropower projects, and especially large or major projects, affect two important factors that strongly influence public health: local and regional hydrological systems and local and regional population densities. Modifications to hydrological systems and increases in population densities are direct consequences of the construction of a dam and the presence of a man-made reservoir (Goldsmith and Hildyard, 1984; Hunter, Rey and Scott, 1982).

4.1.1 Waterborne Diseases Due to Modifications to Hydrological Systems

Public health concerns related to hydropower projects in northern or temperate environments are largely limited to the bio-accumulation of methylmercury in reservoirs. However, modifications to local and regional hydrological systems in tropical or sub-tropical

[*] See Appendix A: Glossary.

environments have a perceptible influence on the spread of waterborne diseases both upstream and downstream of a hydropower project.

In tropical or sub-tropical environments, the creation of large artificial lakes (reservoirs) upstream of a dam may favor the multiplication of waterborne disease vectors (flies, mosquitoes, snails, parasites, etc.) and the introduction of new ones. Downstream, favorable habitats for the multiplication of waterborne disease vectors are created when water levels are lowered and stagnant pools of water appear along the riverbanks (United Nations, 1985).

Furthermore, the spillways and tailrace outlets create areas of fast flowing water, which are favorable for the development of mosquito vectors responsible for filariasis and black fly vectors responsible for river blindness. The numbers of people in tropical or sub-tropical environments likely to be infected with waterborne diseases as a consequence of a hydropower project may thus increase if nothing is done to mitigate the risks. Increased occurrences of diseases that may be induced by such modifications typically include malaria, schistosomiasis (or bilharzia), lymphatic filariasis and onchocerciasis (or river blindness), as well as other diseases such as yellow fever, Japanese B encephalitis and dengue. Most of these diseases are widespread, and several are on the rise for a variety of reasons (World Bank, 1991).

The release of mercury (in the form of methylmercury) in the water through the decomposition of organic matter in the impoundment zone has been linked relatively recently to the flooding of hydropower reservoirs. Mercury finds its way into the food chain and is ingested by local populations particularly when piscivorous fish species are part of their diet. Long-term exposure to toxic levels of methylmercury translates into problems linked to equilibrium, coordination and vision. These symptoms may be mistaken with symptoms associated with other diseases (diabetes, Parkinson's disease, etc.) or simply with the normal aging process.

The James Bay Reservoirs (Canada)
In Northern Québec, the levels of mercury observed in the James Bay reservoirs vary according to their location and have tended to return to a natural level over a 20 to 30 year period after impoundment (James Bay Mercury Committee, 1995). According to a recent study carried out by the Cree Board of Health and Social Services and McGill University, the proportion of the James Bay Cree population that had serious mercury contamination problems (30 mg per kg) diminished from 1,7% in 1988 to 0,2% in 1993-94. The authors of the study largely attribute this reduction in the number of cases of mercury contamination to changes in the population's diet brought about by public information campaigns.
Source: Dumont (1998).

4.1.2 Behavioral Diseases Due to Increases in Population Densities

Increases in population densities are mainly induced by two consequences of dam construction: the arrival of large numbers of workers and migrant settlers from other localities and regions, and the forced resettlement of populations displaced by flooding of inhabited areas. Increased concentrations of people in isolated rural areas, often with diverse cultural and social backgrounds may result in:

- local increases in sexually transmissible diseases
- the spread of locally prevalent contagious diseases such as tuberculosis, leprosy, leishmaniasis, etc.
- the introduction of new diseases as yet unknown in the area of the hydropower project
- the exposure of displaced populations to diseases that did not exist in their original habitat.

4.1.3 Indirect Project Related Diseases and Other Factors Influencing Human Health

The presence of a hydropower project greatly influences local and regional development, attracting industries and favoring the creation of new agglomerations and an intensification of agricultural practices, amongst others. The health benefits or impacts of such induced development are largely dependent upon local development policies and implementation capabilities. If not properly managed, such induced changes are liable to be the source of new health problems for local populations. However, they may also lead to reduced health risks if development is accompanied by improved diets, living conditions, and health and social services.

Irrigation and water intensive activities such as rice production offer favorable habitats for the multiplication of disease vectors (slow moving water in ditches and flooded rice fields). In addition, the use of pesticides and chemical fertilizers and the methods used to apply them can expose local populations to toxic chemical compounds.

Industrial, commercial and residential development in the vicinity of a hydropower projects can be considered as a positive effect requiring however environmental management in order to avoid pollution which may modify local (and possibly regional) air and water quality. The release into a reservoir of large quantities of untreated sewage from newly developed urban areas can be a widespread source of public health problems. Local air and water quality degradation may induce respiratory problems, various intestinal diseases or simply a general physical weakening that can render the population more susceptible to contract various aggressive illnesses.

4.1.4 Mitigation and Compensation Measures

Mitigation and compensation measures to minimize human health degradation brought upon by diseases are numerous and well documented. Efficient measures include, amongst others:

- the containment and treatment of urban and industrial wastewater and air pollution around the reservoir
- the design and implementation of waterborne disease vectors control programs, which generally involve both the suppression of potential vectors of disease and the control of stagnant waters
- the introduction of easily accessible medical clinics and dispensaries in project-affected communities and in areas where population densities are increasing, the hiring and training of the required staff for these new facilities, and regular support for acquiring the drugs required for disease control

- the design and implementation, by a team of specialists, of case detection and epidemiological surveillance programs to monitor changes to public health for local and regional populations
- the design and implementation of public health education programs directed at the populations affected by the project.

Mitigation measures that can reduce the presence and health effects of methylmercury in large man-made lakes include public information programs directed toward local populations for whom fish constitutes an important part of their regular diet and, where required, assistance in identifying safe species or locations for subsistence fishing.

Overall institutional capacity is the most important requirement for ensuring minimal project related health benefits for local populations. As efficient as individual public health measures may be locally, they have next to no effect overall if they are not implemented through an efficient and adequately structured governmental (or non governmental) organization at the regional and local levels. Such an agency must be able to centralize the information provided by groups concerned by the management of local public health issues. It must also be able to make necessary modifications to public health programs in response to incoming information.

Sadly, many tropical hydropower projects in the past have not taken into account the fundamental link between public health and economic development. In several countries, the absence of co-operation between agencies responsible for the design and implementation of such projects and public health officials has had serious consequences for locally affected populations. The management of outbreaks of diseases related to power and irrigation projects has in most cases been delegated to under-funded and weak health care services.

To avoid such occurrences, part of the costs of health care services should be included in those of proposed water impoundment schemes which pose a risk to public health. Recurring costs for health education should also be included in the recurrent operational costs for such schemes as a whole. Health maintenance costs after the completion of an impoundment scheme could be partly supported from the gross income of that scheme or from some proportionate equivalency of it, as for example, a small percentage of gross income from power generation or from cash crop production (Hunter, Rey and Scott, 1982).

The control of the health effects of excessive population increases around hydropower reservoirs requires managing the influx of migrant workers or migrant settlers from other localities and regions and minimizing the flooding of inhabited areas. Imposing limitations on development around a reservoir cannot be undertaken without a strong governmental (or non governmental) planning agency responsible for adopting and implementing an efficient regional land use planning and control program to oversee and orient development.

4.2 Impacts on Public Safety

The following briefly describes the potential hazards for public safety associated with the design, the construction, the physical presence and the operation of hydropower dams and reservoirs, as well as the relevant measures to ensure the safety of such infrastructures.

4.2.1 *Hazards Related to Project Design*

Amongst the various aspects that must be considered prior to initiating construction work for a hydropower project, three may become important safety hazards if not studied adequately. These aspects include:

- the proper understanding of the geological structures that constitute the dam's foundation and that support its weight. Insufficient geological data may result, in worst cases, in the collapse of the dam
- the gathering of sufficient hydrological data to build the most representative water flow model which will reduce the risk of an overtopping event
- the gathering of sufficient data on sedimentation (amount and pattern of depositions in the reservoir) to better evaluate the reservoir's life span and to avoid accumulation of sediment on power plant equipment, thus blocking them.

4.2.2 *Hazards Related to Construction Work*

Public safety during construction is essentially related to the safety of construction workers. Workers on hydropower project sites are exposed to various hazardous situations and operate heavy machinery and other potentially dangerous equipment. Accidents during the construction of major infrastructure projects are almost inevitable, but their risk of occurrence can be seriously increased when:

- for various reasons, workers with little or no experience are hired
- governments and companies fail or neglect to implement safety protocols for various types of construction activities, thus neglecting the safety of workers.

4.2.3 *Hazards Related to the Presence of the Dam-Reservoir Complex*

The presence of a dam and reservoir has been found in certain cases to be a source of public safety hazards even if all aspects related to the construction, operation and maintenance of the facilities are well taken care of. Safety issues associated with the presence of dam-reservoir complexes include:

- their contribution to problems linked to flood control
- reservoir induced seismicity (RIS) and earthquakes
- the occurrence of landslides on the banks of reservoirs (water saturation of the reservoir bank's soils and the waves' action amplified by the wind combine to favor the occurrence of landslides which can be dangerous for people installed along the reservoir)
- the risks incurred by greater numbers of people who settle downstream of hydropower projects, as a result of the relative security inspired by regulated river* flows.

Since the beginning of this century, floods have increased in intensity and their effect on human development has proved ever more devastating. Hydropower dams are but one of the numerous infrastructures that are installed on rivers and their tributaries to try and control the devastating effects of yearly flooding. However, the multiplication of flood control structures, hydropower dams and irrigation dams has been found in certain cases to have the opposite

* See Appendix A: Glossary.

effect. This is largely due to the fact that rivers have become more or less channeled by various flood control structures, accelerating total water flows without reducing the total volumes carried. The increased severity of floods is also frequently due to increased deforestation and erosion of upstream watersheds. In certain cases, flooding is also aggravated by the poor floodwater retention and evacuation capabilities of older dams.

Major overtopping of dams and dikes have occurred in previously unsettled flood plains. The problem has become so significant that some US states (ex. Oregon and California) have decided to dismantle existing flood control structures and thus re-open the old flood plains. The concept of working with the flood plains, instead of against them (flood management instead of flood control), appears to be gaining ground (Williams, 1993). Hydropower reservoirs have also been known to induce earthquakes. The first time that seismic activity was imputed to a reservoir was in California in the late 1930’s (Goldsmith and Hildyard, 1984, Vol. 1, p.106).

Seismic events of magnitude 4.0 to 6.5 on the Richter scale have been reported at some 30 dam projects since the relationship between seismic activity was proven for the Hoover dam in 1945 (Helland-Hansen, Holtedahl and Lye, 1995, p. 74).

However, the actual processes that trigger reservoir induced seismicity (RIS) are still not fully known, even if factors such as site-specific geomorphologic conditions and the weight of the water body are well recognized. A recent study of RIS phenomena carried out on 124 reservoirs concluded that *“… RIS triggering conditions are complex, and associated with particular geomorphological conditions, highlighted by a particular risk of occurrence, and the manner of impoundment and operation…”* (Vladut, 1992, cited in Helland-Hansen, Holtedahl and Lye, 1995, p. 74).

4.2.4 Hazards Related to the Operation of Dam Facilities

Operating dams requires continuous input and analysis of information coming from external and internal sources, such as meteorological data, upstream variance in water flows and volumes, regular inspection reports on the structural integrity of the dam, etc. Employees must be adequately trained to be able to react efficiently in times of need, to recognize warning signs foretelling a potential structural failure, and to operate the dam according to its original capacity and design. Regular maintenance and testing of dam and power station equipment and machinery must be carried out, recorded and compiled to promptly identify problems. The consequences of not implementing such basic operational standards can result in drastic and hazardous releases of large volumes of water or, in worst cases, in catastrophic flooding through overtopping and structural failure of the dam.

4.2.5 Mitigation and Compensation Measures

Completely eliminating public safety hazards associated with hydropower projects is in practice very difficult because of overriding cost/benefit considerations. For large dams or dams presenting special design complexities, the World Bank’s Operational Policy on Dam Safety (OP 4.37, Sept. 1996) requires:

- reviews by an independent panel of experts throughout investigation, design, and construction of the dam and the start of operations

- preparation and implementation of detailed plans: a plan for construction supervision and quality assurance, a plan for instrumentation, an operation and maintenance plan, and an emergency preparedness plan
- pre-qualification of bidders during procurement and bid tendering
- periodic safety inspections of the dam after completion.

With respect to RIS, dam construction should be restricted in high risk areas by considering alternative layouts and systems design that distribute impoundment away from a single site and/or limit dam heights. High risk areas are defined both by tectonic analysis and by the numbers of people likely to be affected by a potential dam failure. If development takes place in remote areas where tectonic analysis indicates minimal risks to the area around the dam, structures should be selected and designed with the appropriate earthquake loading factored in (Helland-Hansen, Holtedahl and Lye, 1995, p. 101).

The Saguenay Region's Reservoirs (Canada)
The catastrophic flooding which occurred in the Saguenay region in 1996 as a result of the overtopping of several dams and the structural failure of another dam, has led the provincial authorities to entirely reconsider their approach to dam and reservoir management. One of the main conclusions of the Nicolet Commission (1997) formed by the Government of Québec to review the disaster was the need for strictly enforced legislation concerning regular inspection of dams and the production of public reports on their state, adequate training of personnel responsible for operating dams and closer cooperation between dam owners and regional and local planners to ensure proper implementation of efficient emergency plans. The Commission also observed that such mitigation measures are not likely to be thoroughly implemented and enforced without the long-term commitment of public authorities.
Source: Nicolet Commission (1997).

5 Social Impacts

The considerable modifications to upstream and downstream land use systems introduced by hydropower projects, as well as the varied distribution of project benefits and costs among various stakeholders, have a wide range of social consequences. These consequences are summarized below under the following headings: demographic and institutional impacts; impacts on community traditions and ways-of-life; class or gender related impacts; impacts on vulnerable minority groups; impacts on human heritage and landscapes; and geopolitical impacts.

5.1 Demographic and Institutional Impacts

Large-scale development projects, such as hydropower dams and reservoirs, have direct and indirect influences on population migrations. These include direct demographic impacts on local communities associated with construction activities (boomtown effects), as well as indirect and induced demographic impacts related to the arrival of migrant populations and the development of new urban communities around the reservoirs and downstream of hydropower dams. In turn, such population migrations may cause land use conflicts and significantly increased demands on local services and infrastructure.

5.1.1 Boomtown Effects

Hydropower projects generally result in the transfer to the project site of large numbers of construction workers with their families over a period of five to ten years. Typically, a large hydropower dam will require a work force of more than 2,000 workers. This work force will diminish rapidly after construction and be replaced by a small number of operation and maintenance personnel.

The Missouri Basin Power Project (United States)
The construction of the 1,500 MW Laramie River Power Station was carried out as part of the Missouri Basin Power Project (MBPP) between 1974 and 1982. The project required a peak force of 2,600 workers, with a subsequent permanent workforce of 200 and a related population of 750. When plans were announced for the project, nearby Wheatland, the largest incorporated town in Platte County in the state of Wyoming, had a largely rural population estimated at 2,800.
Source: Missouri Basin Power Project (1983).

The sudden inflow and subsequent departure of a large contingent of workers and related groups within small, often traditional communities, frequently causes a variety of social, health, economic and cultural problems at the local community level which are collectively summarized under the term boomtown effects. Such destabilizing effects can be even more severe in developing countries, where the construction of large dams may require larger numbers of workers to compensate for the lack of adapted machinery and of specialized workers.

5.1.2 Migrations and Land Use Conflicts

As mentioned earlier in the section on land use, in densely populated areas in the tropics, the shores of new reservoirs are resettled by displaced populations and colonized by newly arrived migrant populations looking for work, fertile land or access to productive fisheries. Conflicts often arise between local populations forcibly displaced away from the impoundment zone, local host communities that must absorb resettled populations and migrant populations attracted by the opportunities offered by newly created reservoirs.

Downstream of reservoirs, regulated rivers strongly encourage local populations to settle closer to the downstream riverbed or within the limits of the flood plain. The presence of permanent water and regulated river flows often supports the development of a variety of new economic activities. In turn, these activities attract influxes of migrants from outside the watershed and frequently lead to greater downstream population densities and to the growth of new urban communities.

5.1.3 Effects of Population Shifts on Institutions and Services

The sudden arrival within small, often traditional communities, of large numbers of in-migrating workers and family members, as well as of migrant populations looking for better opportunities, generally results in increased demands on local services and infrastructure, difficult fiscal challenges for local governments, and greater problems of social assimilation.

> …In the case of small, unprepared communities, local authorities often face very difficult choices; if they build facilities to meet the population-related requirements of the project's construction phase, they face the possibility of having substantial excess capacity just a few years later. On the other hand, failure to provide needed facilities and services can lead to severe problems during the peak of the construction-phase population influx. (Leistritz and Murdock, 1986, p. 33).

Increased demands on community services and infrastructure include:

- the leasing or acquisition of available housing and land and requests for new housing (with associated upward pressures on real estate and leasing values)
- requests for extensions of local utilities (water, sewage treatment, telephone, power, etc.)
- requirements for upgraded local and regional public services (justice, police, fire protection, ambulance and postal services, etc.)
- increased enrollment in local schools
- requirements for additional health and social services
- requests for additional recreational opportunities.

5.1.4 Mitigation and Compensation Measures

Mitigating project-related boomtown effects on surrounding communities can be approached in three manners: a) by isolating the project site from vulnerable communities located in the vicinity of the project; b) by reducing the numbers of migrant workers (and dependents) living on or close to the construction site; or c) by revising development schedules or project design in order to minimize peak requirements for large numbers of workers.

Finding a feasible dam and reservoir site that is sufficiently remote from any existing communities to eliminate boomtown effects is quite often an impossible task, particularly in densely populated countries. However, in certain cases, it may be possible to design access roads and regulate the use of such roads in such a manner as to minimize impacts upon surrounding communities. Workers from outside the project site can also settle directly on the construction site by providing adequate housing and community services minimizing pressure on local communities.

Increasing local hiring can reduce to a certain extent the numbers of migrant workers (and dependents) living on or close to the construction site. Establishing local hiring preferences and training programs for local unemployed or unqualified workers can be an effective way of increasing the percentage of economic benefits accruing to surrounding communities. It can enhance workforce stability and may reduce recruitment costs. However, local-hiring policies can be viewed as discriminatory and their success depends on the local availability of relatively qualified workers. Training programs often require a long lead-time to be successful and, for a variety of reasons, do not ensure that newly trained local workers will ultimately participate in the project.

Lengthening construction schedules can be a means to minimizing peak requirements for large numbers of migrant workers. However, such an approach runs the risk of significantly increasing project costs or of conflicting with energy sector or other priorities. In certain cases, project design can be adapted in order to facilitate off-site component fabrication or the scheduling of multiple units when several projects or project phases are planned for within the same area (Leistritz and Murdock, 1986).

5.2 Impacts on Community Traditions and Ways-of-Life

5.2.1 Changes to Community Traditions and Ways-of-Life

Cultural distinctions and social relationships within a community are a fundamental part of social life and play an important role in balancing the forces of social conflict and of social cohesion. Cultural distinctions and social relationships at the community level are related to a series of factors: physical proximity, age and length of residence, kinship, ethnicity, religion, social class, work and gender.

Changes brought about by hydropower projects to the physical, economic and social conditions in which local populations live may have far-reaching cultural and social effects at the community level. Such changes may vary considerably from one project to another. For instance, the opening up of access roads to previously isolated areas for the construction of a hydropower dam can enable populations and goods to move more easily, offering new opportunities to exchange with other communities and a greater diversity and quality of available goods and services. On the other hand, improved access to the outside world can also lead to a loosening of social bonds and solidarity within the community, and to increased risks of competition or conflicts with outsiders for available resources.

5.2.2 Mitigation and Compensation Measures

Compensation for changes to community traditions and ways-of-life can be achieved to a certain extent through improved housing, education, social services and health care. Ensuring the long-term financial support of activities that define local cultures can also help to minimize changes to community traditions and ways-of-life brought about by a hydropower project.

The James Bay Reservoirs (Canada)
Within the context of the James Bay hydropower projects, the James Bay and Northern Québec Agreement signed in 1975 guaranteed exclusive hunting, trapping and fishing rights to local Cree and Inuit communities. It also provided an Income Security Program (ISP) for hunters and trappers. This program helps community members continue practicing a traditional lifestyle. These benefits are granted according to the length of time spent hunting, fishing and trapping as well as the annual earnings of the unit and the size of family. The effects of the ISP on indigenous James Bay Cree communities have been studied by several social scientists. All of the studies indicate that the ISP has enabled these communities to maintain their traditional ways-of-life, or at least to slow the decline in the practice of such activities that had been observed before the projects, when compared to other indigenous communities that have not benefited from the ISP.
Sources: Salisbury (1986), Scott and Feit (1992), Proulx (1992), and Simard, et al. (1996).

5.3 Class or Gender Related Impacts

5.3.1 Changes to the Relative Status of Population Groups Within Communities

In rural or resource-based communities, the transition from traditional types of work such as rain-fed subsistence agriculture, animal husbandry, fishing, or hunting and trapping, to more intensive or modern production and service industries frequently results in significant changes to the relative social status of population groups within such communities.

The James Bay Reservoirs (Canada)
In indigenous hunting and trapping societies such as the James Bay Cree in Northern Québec, increased government transfers and financial compensations obtained within the scope of the James Bay hydropower projects have led to the development of modern well-equipped communities. The creation of new public services within these communities has led in turn to numerous relatively well paid clerical jobs for local residents. Consequently, a few social scientists have evoked the possibility that the social differentiation brought about by the emergence of indigenous white-collar elite in such communities could eventually threaten the status of traditional master trappers or tallymen.
Sources: Berkes and Cuciurean (1987), Proulx (1992) and Simard, et al. (1996)

In hydropower projects with an irrigation component, concentrations of irrigated land may occur. Dispossessed small holders often become farm workers dependent on seasonal wages. Otherwise, to compensate for increased prices of relatively rarer staple foods, they are forced to occupy less productive land in order to continue practicing increasingly precarious subsistence farming (Goldsmith and Hildyard, Vol.1, 1984, pp. 188-196). In Third World countries, women are frequently the hardest hit by worsened agricultural conditions for the poor.

The Manantali Dam (Senegal)
In the Senegal River Basin: "…Although women are the leading productive force, they lack access to the resources generated by the project and do not enjoy its benefits. They are practically solely responsible for subsistence farming, as well as for all household tasks; they do not have access to land ownership or to agricultural credit. To become land holders, they must associate with other women, and in such cases, they usually receive less productive land. They are also confronted with the challenge of marketing their products."
Source: Ly (1995).

5.3.2 Mitigation and Compensation Measures

Irrigation schemes developed within the context of hydropower projects can be designed in such a manner that local family farmers are assured of becoming project beneficiaries. In similar fashion to new reservoir fisheries, such an objective requires clear rights to project-affected people, and in particular of affected women, during the early years of a new irrigation scheme. An upper limit can be set and strictly enforced on the size of land holdings that may receive subsidized water. Provisions can also be made to ensure that appropriate training and technical support is provided and that agricultural credit is extended to small holders and to women's associations.

5.4 Impacts on Vulnerable Minority Groups

The World Bank describes indigenous peoples and ethnic minorities as *"…social groups with a social and cultural identity distinct from the dominant society that makes them vulnerable to being disadvantaged in the development process…"* (Operational Directive OD 4.20, Indigenous Peoples, 1991).

5.4.1 Cultural Impacts in Vulnerable Communities

Hydropower development projects in indigenous or traditional resource based areas frequently lead to the imposition of distinct cultural values by outside agencies upon local communities. The world view of a large number of traditional rural, agricultural or indigenous communities is built around the moral significance of their environment and the resources upon which they depend to live. In such communities, landscapes are often invested with special significance: "… *Thus the landscape is dynamic, every part is living, functional, has meaning and moral value…"* (Goldsmith and Hildyard, 1984, Vol. 1, p. 28).

The extent to which a particular development project can be the source of conflicting cultural values within such communities is difficult to ascertain, considering the number of outside influences to which they often are already subjected (radio, television, travel, schools, commercial exchanges, etc.). Nevertheless, communities for whom major transformations to their physical environment run contrary to their fundamental beliefs often perceive such projects as being destructive to their culture. Even in instances where such communities benefit economically from the introduction of a hydropower project, they may perceive the project as an implicit rejection of their cultural values.

The sociological and anthropological literature on the impacts of development projects abounds with examples of the effects of the introduction of conflicting world views into such communities. These effects are variously described as:

- cultural shock associated with the pace of social change which is often beyond local capacities to adapt
- a sense of cultural invasion associated with a fear of outsiders
- cultural disintegration or anomie linked to a sense of fatality, of loss of control over indigenous development (increased dependence upon outsiders)
- diminished authority and loss of credibility of elders and traditional leaders, and the subsequent rejection of traditional values or political structures by younger generations
- progressive replacement of community-based values and practices by individualistic values and activities
- conflicts arising between so called modernists and traditionalists which often exacerbate existing social tensions within communities and can, in certain cases, split communities apart
- younger generations often suffer from a sense of loss of cultural identity.

In turn, such effects frequently contribute to increased community health problems (depression, substance abuse, marital and family violence, juvenile delinquency or apathy, suicide, etc.).

5.4.2 Mitigation and Compensation Measures

It is very difficult to mitigate or fully compensate the social impacts of large hydropower projects on indigenous or other culturally vulnerable communities. Minimizing such impacts requires that local communities be willing partners in the development of a hydropower project, rather than perceiving it as a development imposed by an outside agency with conflicting values. It also requires that local communities be given sufficient lead time to assimilate or think through the consequences of such a project and to define on a consensual basis the conditions in which they would be prepared to proceed with the proposed development. These conditions are not always easy to fulfill for outside development agencies. Thus, they are often tempted to press forward with project design for overriding national purposes, before obtaining the approval of locally affected communities.

The early involvement in project planning of respected members of affected communities is therefore essential to identify the communities' concerns and to work out locally beneficial solutions. For instance, such solutions may include proposals to compensate for losses of land and alternatives to existing sources of income that may be jeopardized by the project. In developing countries where local titles to land (particularly for indigenous peoples) are rarely available, legal protections can be granted by local governments so that affected communities retain exclusive rights to the remainder of their traditional lands and to new lands obtained as compensation.

The Sainte-Marguerite-3 Project (Canada)
In the case of the Sainte-Marguerite-3 hydropower project, indigenous Innu (or Montagnais) communities negotiated an agreement in which they receive substantial funding over a fifty year period to support their economic development and maintain traditional ways-of-life through an Economic and Community Development Fund, an Environmental Remedial Fund and the Innu Aitun Fund set up to support traditional hunting and trapping activities.
Source: (Uashat Mak Mani-Utenam and Hydro-Québec Agreement – 1994).

Supporting the development of local economic activities in project-affected communities can also be financed by the allocation of a fraction of the hydropower project's income. Approaches involving new economic partnerships between developers and local communities, in addition to compensation for losses or damages, should be explored further in future projects.

5.5 Impacts on Human Heritage and Landscapes

Human (or cultural) heritage can be simply defined as: *"…the present manifestation of the human past. It refers to sites, structures and remains of archaeological, historical, religious, cultural and aesthetic value."* (World Bank, 1994a). It also includes oral and written history and traditions.

The conservation of human heritage aims to affirm the significance of past artistic, scientific or cultural achievements. As a legacy from forbears to future generations, it represents a contribution to our understanding of human history, to intergenerational equity and, thereby, to sustainable development.

Heritage sites such as burial grounds play an important role in demonstrating a community's cultural continuity and long-term survival. They include, among others, sacred sites, archaeological sites, monumental sculptures or paintings, monumental architecture, indigenous or vernacular architecture, historic settlements and town centers, cultural landscapes, historic gardens and parks, as well as trade route monuments and remains (World Bank, 1994a).

Exceptional natural landscapes or physical features of our environment also form an important part of human heritage. Landscapes are endowed with a variety of meanings: they constitute assemblages of natural and human ecosystems; they exist as visible representations; they also exist as symbolic representations or reflections of human values. Recognition of the need for landscape architecture considerations in connection with hydropower projects has gathered momentum since the beginning of the 1960's. New approaches to landscape planning for such projects, based on aesthetic, psychological, geographic and ecological principles, have been developed (Hillestad, 1992 and Hydro-Québec, 1993).

The preservation and interpretation of human heritage and exceptional landscapes are of increasing economic importance as a productive activity. Tourism, a multi-billion dollar industry, is heavily dependent upon the conservation and promotion of human heritage and valued landscapes.

5.5.1 Impacts on Heritage Resources

Impacts on heritage resources or historical relics may occur at the design, construction or operation stages of a hydropower project. At the project planning stage, unless handled with care, early public announcements concerning the impoundment zone can result in plundering of unprotected cultural sites that are likely to be submerged by the flooding of the reservoir. Construction activities may alter or destroy heritage sites if nothing has been planned to ensure the protection of such resources. Following construction, new roads to the construction sites may facilitate access to previously remote heritage sites, thereby putting their integrity at risk.

The Three Gorges Project (China)
Even if several historic or archeological treasures will be removed from the impoundment zone, the Three Gorges hydropower project in China is expected to flood thousands of archeological sites and burial grounds along the Yangtze River, as well as scenic landscapes which play a significant role in Chinese cultural traditions.
Source: Zich (1997).

5.5.2 Impacts on Valued Landscapes

The flooding of hydropower reservoirs may lead to the irreversible modification or disappearance of valued or exceptional landscapes, such as spectacular waterfalls and canyons. Long-term landscape modifications can also be incurred by soil erosion, sedimentation and the presence of power transmission lines, as well as by seasonal fluctuations of water levels in reservoir drawdown areas and in rivers downstream of the dam. Prior to the rainy season in the tropics or the spring melting of snow in northern regions, the reservoir has to be partly emptied, exposing barren areas along the shorelines. The same phenomenon frequently occurs in rivers downstream during the dry season, when water releases are at a minimum. Other potential construction-related impacts of hydropower projects on landscapes include the scars left by quarries, gravel pits, spoil areas, temporary roads, the cutting or submergence of trees, garbage disposal and wastewater problems.

5.5.3 Mitigation and Compensation Measures

In many cases, impacts upon valued landscapes in the impoundment zone cannot be avoided other than by reducing reservoir impoundment levels. Therefore, the planning stage of a hydropower dam project is the most effective moment to minimize impacts upon valued landscapes and human heritage resources. An extensive and systematic inventory and assessment of heritage sites in the impoundment zone is required previous to completing project design. Project design documents must include clear specifications with respect to the protection of such sites. Measures taken to protect heritage sites in the impoundment zone should also be implemented or at least initiated before the official announcement of the project. Local oral history should also be collected to maintain collective memory. During construction, human heritage or archeological specialists should supervise all major construction activities to ensure that any site discovered is not irretrievably damaged. If required, particular care should also be taken to limit public access to sensitive heritage sites following project construction.

Many of the considerations regarding the mitigation of impacts of hydropower dams on landscapes are related to whether the planning of such projects should favor visual contrasts through original design or favor blending into the rest of the landscape. If visual contrast is selected as the better-adapted solution to the qualities of the landscape, it is the design of the dam and of its powerhouse that will require particular attention.

Inversely, a focus on blending the infrastructure into the surrounding landscape will lead to significant efforts at landscape design around the dam, the reservoir and required access roads.

5.6 Geopolitical Impacts

Major hydropower projects may have an important geopolitical dimension because of their size, their visibility and the fact that they use and modify resources that are frequently shared by various countries. The development of international river basin institutions has not always resulted in agreements on the sharing and development of international waters. The increased economic potential of land uses near the reservoir and downstream of the dam also sometimes lead to political conflicts between local inhabitants and newly entitled landholders from outside.

5.6.1 Institutional Limitations of International River Basin Organizations

Several international river basin institutions have been set up to manage water resources that are shared by riparian countries. Some of these have proven unsatisfactory for a variety of reasons. In some cases, political considerations play a major role in decisions to proceed with or expand hydropower projects within a given river basin. In other cases, politically motivated decisions hinder rather than expedite the development of such projects, especially where they forestall legal agreements on the sharing and development of international waters and on the formation of appropriate planning, implementation, management and monitoring institutions. There are many instances where riparian states have been unable to reach agreement or form institutions.

The Sardar Sarovar Dam (India)
The development of the Narmada River in India, and specifically the Sardar Sarovar Dam, illustrates the political and institutional challenges associated with river basin management involving several riparian states: "…Initially the three states involved were unable to decide how to share hydropower and other benefits that would accrue from the development. …. That problem was finally resolved after an independent tribunal mediated the dispute and made recommendations that the states accepted…"
Source: Morse and Berger (1992).

5.6.2 *Geopolitical Impacts of Multinational Hydropower Projects*

Building a hydropower dam upstream of a river that crosses various states or countries often results in political tensions and conflicts that are difficult to settle or to arbitrate. International negotiations for strategically sensitive hydropower projects can significantly delay or even jeopardize their implementation. In such cases, negotiations can also be tied up with other sensitive considerations.

The Ataturk Dam (Turkey)
An agreement in 1987 between Turkey and Syria concerning the development of the Upper Euphrate river ensured Syria of a volume of water of 500 m^3/s per month during the filling of the Ataturk dam, on the condition that Syria no longer support Kurdish guerrillas fighting for independence.
Source: Conac (1995), p. 56.

The Senegal River Basin case also illustrates how political elites may take advantage of new opportunities arising from dam construction at the expense of riverine inhabitants: Customary forms of land tenure along the river were ignored when the Mauritanian government passed a land registration act that favored individual tenure by those who had capital resources. The resulting land grab eventually caused the eviction of many ethnically different riverine villagers. This led to retaliation against Bidans in Senegal and almost caused a war between the two nations (Scudder, 1994, pp. 109-110).

The Manantali Dam (Senegal)
"…Because of the racial/class segmentation between the ruling Bidans (White Moors of Mauritania), now suddenly interested in agriculture, and the subordinated black farmers, the farmers have had no legitimate recourse, no way of protecting their lands from seizure. Such protests as were attempted by blacks – mainly by educated children from farming families who put their names to pamphlets – were summarily suppressed: protesters were imprisoned en masse, and most, those who are still alive, remained confined (or expelled from the country). Mauritania has ignored all appeals on behalf of these prisoners of conscience.
Source: Horowitz (1991) p. 170.

6 Resettlement and Rehabilitation

The most sensitive socioeconomic issue surrounding hydropower development revolves around resettlement and rehabilitation, which consists of two closely related yet distinct processes: displacing people (resettlement) and rebuilding their livelihood (rehabilitation or community development).

6.1 Historical Trends in Resettlement

Where involuntary population displacement occurs, the severity of impacts is often considerable in terms of the numbers of people adversely affected, the vulnerability of such populations to resettlement, and the suffering caused both before and after removal from the impoundment zone. Sadly, the proper management of these impacts has until recently been largely neglected by national and international development agencies because of inadequate regulatory frameworks, insufficient financing and biased design and planning methodologies.

According to the World Bank, which has put considerable effort into developing guidelines for the proper management of involuntary resettlement:

> "…Bank experience indicates that, unless appropriate measures are carefully planned and carried out, involuntary resettlement under development projects generally gives rise to severe economic, social, and environmental problems: production systems are dismantled; people are impoverished when their productive assets or income sources are lost; people relocate to environments where their productive skills may be less applicable and the competition for resources greater; community institutions and social networks are weakened; kin groups are dispersed; and cultural identity, traditional authority, and the potential for mutual help are diminished…" (Draft Operational Policy (OP) and Bank Policy (BP) 4.12, Involuntary Resettlement, Jan. 1998, p. 1).

According to a bank-wide review of projects involving involuntary resettlement between 1986 and 1993:

> "…The scale of development-related population displacement in developing countries has grown rapidly in the past decades, due to the accelerated provision of infrastructure and growing population densities. The annual displacement toll of the 300 large dams that, on average, enter into construction every year is estimated to be above 4 million people. Over the past decade, it is estimated that about 80 to 90 million people have been resettled as a result of infrastructure programs for dam construction, and urban and transportation development…" (World Bank, 1994b, p. i).

Funding and managing involuntary resettlement is difficult for developing country governments, particularly in low-income countries with land scarcity, competing needs and limited resources, as well as severe constraints on institutional capacity. Restoring previous standards of living in developing countries is therefore a formidable task in practice. Nevertheless, multilateral and bilateral developing agencies have long been reluctant to fund project-related resettlement activities, judging that they remain largely under the responsibility of local governments.

Historically, indigenous peoples, ethnic minorities and pastoral groups have composed, more often than not, a large share of the populations displaced by hydropower dams in developing countries. This can be explained by the fact that such communities often live in remote areas that are considered as non-productive by mainstream society. In the past, when planners of a hydropower project were confronted with the presence of indigenous peoples or other vulnerable minority groups, these populations were simply forced to move to new territories. The populations involved were relatively helpless to defend their rights.

The appearance of international and local NGO's focusing on human rights abuses associated with development projects in the 1970's, and the subsequent development and implementation of guidelines on involuntary resettlement by international financing agencies in the 1980's, have in most cases changed the manner in which indigenous or other vulnerable rural populations displaced by development projects are treated.

However, new approaches to involuntary resettlement have as yet met with little success in terms of long-term human development (World Bank, 1997; Scudder, 1997). Whether considered under the angle of human rights, of environmental protection or of economic development, such shortcomings are not justified. Strictly in terms of human rights, project-affected populations should be the primary beneficiaries of any public works project. From an environmental viewpoint, rural populations dispossessed by a public works project are more likely to overuse other locally available environmental resources or to migrate to urban areas that are incapable of supporting their needs. On an economic basis, the important costs of involuntary resettlement require that displaced populations contribute to the long-term stream of economic benefits derived from such projects, rather than continuing to be a long-term cost (Scudder, 1995, pp. 255 and 265; Pearce, 1993).

6.2 Challenges for Future Hydropower Development

Follow-up studies of populations resettled within the context of large public works projects reveal a number of common points among the reactions of those who have been displaced. Such dislocations generally involve rural populations with low incomes who are closely tied to their land and who often have limited title to their land. Two major phases can be distinguished during resettlement: the actual resettlement phase and subsequent development.

➢ Resettlement Phase

The resettlement phase, which may last several years before and after the commissioning of the project, engenders the greatest stress and tension among people to be displaced and among host populations who live in the resettlement zone.

Before the project begins, most of those who will have to relocate are apprehensive about leaving their homes, land and familiar surroundings. They are even more apprehensive when project related benefits accrue to other population groups. Because resettlement is involuntary and because moving to new communities with new neighbors and production systems takes much time and energy, relocation is the source of a great deal of psychological and socio-cultural stress. This is even truer when the planned resettlement area is located in a very different environment. The cumulative effects of such stresses can tear apart the social fabric and local economy, thereby leading to impoverishment through landlessness, joblessness, food insecurity, deteriorating health or the loss of access to community assets (World Bank, 1994b).

Such high levels of stress are generally manifested through very conservative attitudes among persons to be displaced. During the first years after resettlement, they tend to remain attached to their former production techniques and to seek out social groups that are familiar to them. Experience shows that most prefer to stay as close as possible to their former homes and to maintain the cohesion of their social groups.

Under such conditions, it is quite unrealistic to expect that forcibly displaced people will adapt quickly to new production systems in unfamiliar soil and climatic conditions, and even more so when they must change professional occupations. The more familiar the new physical, social and cultural setting, and the more support measures are provided that take into account the sources of stress related to the resettlement program, the shorter the transition to development will be.

➢ Development phase

Throughout the world, few resettled populations have experienced subsequent development. In most cases, such populations are frequently poor, politically powerless, and suffer from a lesser standard of living than neighboring non-resettled populations. The principle causes of such failures are insufficient allocation of long-term resources, inadequate planning and poor coordination of resettlement efforts.

On the other hand, studies of a few successful resettlement programs have observed that many displaced people have proven to be dynamic entrepreneurs that are prepared to take risks in their new environment. In such cases, development is usually supported by the introduction of cash crops, livestock breeding or fish farming, the acquisition and development of new land and the establishment of small agro-industrial companies. The development phase must lead to the complete incorporation of the resettled communities into the regional economy. This ultimately implies the dismantling of the agencies responsible for carrying out and supporting resettlement.

Social research undertaken since the 1960's (Scudder and Colson, 1982; World Bank, 1988) on communities displaced by hydropower projects indicates that such events have a considerable (if rarely realized) potential to improve the quality of life of the majority of project-affected people, once they have got beyond the difficult transition stage between the resettlement and development phases. The various reasons invoked for such a hypothesis include the fact that:

- resettlement offers communities new economic possibilities associated with their incorporation into a larger polity
- once adapted to their new environment, communities tend to break away from a risk-avoidance strategy in favor of a risk-taking strategy (this can be explained in part by reduced socio-cultural constraints linked for instance to land tenure and social stratification)
- well managed economic development programs during resettlement can multiply new possibilities.

6.3 Principles for Successful Resettlement

According to the World Bank's review of its projects involving involuntary resettlement between 1986 and 1993, the major common factors which contribute to the success of resettlement are:

- political commitment by the borrower, expressed in law, official policies, and resource allocations
- systematic implementation by the borrower and the bank of established guidelines

- sound social analysis, reliable demographic assessments, and technical expertise in planning for development-oriented resettlement
- accurate cost assessments and commensurate financing, with resettlement timetables tied to civil works construction
- effective executing organizations that respond to local development needs, opportunities and constraints, and
- public participation in setting resettlement objectives, identifying reestablishment solutions and in implementing them (World Bank, 1994b).

The Arenal Hydroelectric Project (Costa Rica)
The involuntary resettlement component of the Arenal Project entailed relocating about 2,500 people (some 500 families) from the reservoir area. Ex-post evaluation produced evidence that the Arenal resettlement succeeded in improving the standards of living of project-affected populations and returning the settlers control over their own lives in a period of five years after their transfer. The resettlement program was carried out under the responsibility of the project proponent (ICE, Instituto Costarricense de Electricidad). The planning of resettlement was delegated to an Inter-Institutional Task Force composed of the ICE Office of Architectural Design, the Institute of Municipal Development, the Departments of Anthropology and Architecture of the University of Costa Rica, and the National Census and Statistics Bureau.
Resettlement preparation activities began in 1973, two years before multilateral financing was secured and the construction of the dam was begun (1975). The population was resettled two years after the start-up of construction (1976 and 1977). Preparation activities took place took place in 11 phases spread out between 1973 and 1975. The first two to three years in the two new resettlement communities (Nueva Tronadera and Nueva Arenal) were difficult. The settlers were fully engaged in subsistence activities for the most part, based on traditional slash-and-burn techniques. The transition stage appears to have ended and the development stage started between 1979 and 1981. The change is indicated by successful experiments and innovations taken by settlers, with assistance from ICE, to intensify agricultural and livestock production. Innovations involved especially adapted varieties of coffee and cut-fodder for grazing. These successes were obtained through careful planning and rigorous implementation of the resettlement action plan.
Source Partridge (1993).

7 Conclusion

In the preceding section, the description of socioeconomic impacts and relevant mitigation and compensation measures* typically associated with hydropower projects has been grouped under four headings: land use, economic impacts, social impacts and resettlement. The main conclusions regarding each of these issues are briefly summarized below.

* See Appendix A: Glossary.

➢ Land Use

By their very nature, hydropower projects generate a significant amount of long term impacts on existing and future land uses. They usually lead to the disappearance of valuable resources and land uses in reservoir impoundment zones and to widespread modifications to existing land uses, both upstream and downstream of the power plants. Changes to land uses are generally a consequence of the submergence of large areas in river valleys, modifications to upstream and downstream water levels and water flows and induced development associated with the regulation of water flows and the creation of large reservoirs.

➢ Economic Impacts

Because of their long-term structural impact, there is no doubt that well-sited and designed hydropower projects generate significant economic regional and national benefits. It is difficult to overstate the economic importance of hydropower and irrigation dams in countries affected by scarce water resources for agriculture and industry, limited access to indigenous sources of oil, gas or coal, and frequent shortages of electricity.

➢ Health and Safety Impacts

Modifications to upstream and downstream land use systems introduced by hydropower projects may lead to a wide range of consequences on public health and safety. These can, for the most part, be adequately mitigated and compensated. Of particular concern, however, are impacts on human health near tropical reservoirs and irrigation schemes.

➢ Social Impacts

Modifications to upstream and downstream land use systems introduced by hydropower projects, as well as the varied distribution of project benefits and costs among various stakeholders, may also result in a wide range of social consequences. These typically include:

- demographic and institutional impacts
- impacts on community traditions and ways-of-life
- class or gender-related impacts
- impacts on vulnerable minority groups
- impacts on human heritage and landscapes
- geopolitical impacts.

The majority of social impacts caused by hydropower projects can be adequately mitigated and compensated. Of particular concern, however, are impacts upon vulnerable indigenous or ethnic minorities in remote resource-based communities.

➢ Resettlement and Rehabilitation

As with most other public infrastructure projects in developing countries, the most sensitive socioeconomic issue surrounding hydropower development is resettlement. The World Bank review of projects involving resettlement showed that *"…inadequate resettlement induces local resistance, increases political tensions, entails extensive project delays and postpones project benefits for all those concerned; the benefits lost because of such avoidable project delays sometimes far exceed the marginal cost of a good resettlement package…"* (World

Bank, 1994b). Although the review confirmed that there were significant improvements in the Bank's portfolio of resettlement operations, outcomes were not consistent with the standards defined and demanded by the Bank's policy in a number of projects.

As mentioned in section 6.3, above, the major common factors which contribute to the success of resettlement are well identified and applicable.

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Appendix G

CUMULATIVE IMPACTS

APPENDIX G
CUMULATIVE IMPACTS

Main Author:
Karin Seelos

As the adequate assessment of cumulative impacts remains a complex issue, this text will first pinpoint current problems related to this evolving field. Then the analytical framework will be briefly discussed, presenting basic concepts and procedural elements. Finally this text will close on specific questions related to hydropower developments.

Current problems

- Only a few EA's addresses cumulative or induced impacts in any detail.
  World Bank – Second EA Review (1992 - 1996)
- Workable methodologies for predicting and improving cumulative effects have not yet been fully developed.
  Husain Sadar (1995)
- Minimal guidance is available on a variety of substantive issues like processes of accumulation or types of cumulative impacts, defining spatial boundaries, defining temporal boundaries, use of methodologies and the monitoring of predicted impacts.
  Cooper and Canter (1997)
- A common problem with cumulative impacts in environmental assessment is that in many cases no evidence or analysis is presented to support conclusions of no significant impact.
  Lance McCold (1995)
- Assessment of cumulative impacts for some but not other affected resources is a common weakness of EAs that addresses cumulative impacts.
  McCold and Saulsbury (1996)
- Also, cumulative effects on a given resource, ecosystem, and human community are rarely aligned with political or administrative boundaries, which makes their appraisal as well as their management and monitoring complex. CEQ (1997)

Basic concepts

Broadly, cumulative impacts (CIs) refer to the accumulation of human-induced changes on valued environmental components over time and across space in an additive or interactive manner. Cumulative impacts, cumulative effects, and cumulative environmental changes are generally interchangeable terms.
The idea of cumulative impacts reflects a broadened perspective on the nature of human-environment interactions. This perspective acknowledges:

1. Sources of cumulative impacts
Environmental changes may originate not only from *single* projects, but also from interactions of *multiple* projects, similar or different in kind.

2. Pathways of accumulation
Environmental changes may accumulate through *additive* or *interactive* processes. Additive processes are summative in that one unit of environmental change may be added, or subtracted, from a previous unit. Processes are interactive (synergistic) when net accumulation is more, or less, than the sum of all environmental changes.

3. Types of cumulative impacts
Resulting environmental changes may be differentiated, generally according to temporal and spatial attributes. The following types of cumulative impacts. have been characterized in literature:

- **additive impacts** of projects that individually have an insignificant impact but in total have a significant impact
- **synergistic impacts** where several projects' total impacts exceed the sum of their individual impacts
- **threshold/saturation impacts** where the environment may be resilient up to a certain level and then become rapidly degraded
- **induced impacts** where one project may trigger secondary development
- **time- or space-crowded impacts** where the environment does not have the time to recover from one impact before it is subject to the next one
- **indirect impacts** where the impact is triggered at some time or distance away from where it ultimately occurs.

In fact, "cumulative impacts are the total effects, including both direct and indirect effects, on a given resource, ecosystem, and human community of all past, present and reasonably foreseeable future actions, no matter who (federal, nonfederal or private) has taken, takes or will take the actions."(CEQ, 1997:8). "These may occur over a certain period of time and distance." (FEARO, 1994:135).

However, such a definition is so broad, that it is excessively difficult to translate into applicable working methods and procedures.

➢ Procedural Elements

Evaluating the cumulative effects on the environment does not necessarily involve thoroughly changing the environmental assessment, but rather broadening the existing analytical framework for impact studies. However, to keep it realistic and manageable, the assessment procedure should focus as soon as possible on the most important problems and effects. Therefore a sound scoping[*] procedure is essential to identify issues and to set appropriate assessment boundaries. As the broadened spatial and temporal scales required for cumulative impact assessment (CIA) usually go far beyond the proponents authority and administrative limits, it is helpful to implement a process of consultation between the proponent, government departments, professional organizations and local communities at all stages of the assessment, particularly in the preparation of EA guidelines.

Basically, the process of analyzing cumulative impacts can be thought of as enhancing the traditional components of an environmental impact assessment*, where the key elements are (1) scoping, (2) description of the affected environment and (3) determining the environmental consequences. Nevertheless, there are 4 major steps[1] in analyzing CIs:

1- identify the issues / stakes
2- select the valued environmental components as to the *ecosystem*s and to the cultural aspects
3- establish the boundaries (spatial and temporal limits)
4- determine the other influencing activities.

[*] See Appendix A: Glossary

[1] CEAA (1997), p.14

One major challenge in the CIA is determining impact significance. Even if legal frameworks usually establish who will decide whether an impact is significant or not, the matter about how to do so is less obvious, as it involves probabilities, such as the probability of occurrence as well as the degree of scientific certitude that can be associated to the assessment results. In order to state about potential cumulative impacts the following factors may provide indications about significance:

- exceeding a threshold
- the efficiency of mitigation measures
- the size of the investigation area / study zone
- the rarity of a species
- the importance of local effects
- the magnitude of change in relation to the variability of the natural environment
- the engendering of inducted effects.

CIs may be assessed at the project level as well as at the policy level, namely in the context of regional or sectoral policies. As CIA requires broadened spatial and temporal scales, the most suitable levels for considering cumulative impacts are at the strategic, sectoral and regional planning levels.

Assessing cumulative impacts at the project level may supply first inputs, but an overview can only be obtained in a perspective going beyond site inventories and local boundaries. Thus cumulative effects should be addressed by strategic, sectoral or regional environmental assessment* , which should streamline project planning. In contexts where policies are not yet environmentally assessed, the proposal of a large scale project may be a trigger for adopting a global strategy of environmental management. In this cases, CIA may occur after the project assessments in order to take advantage of those first inputs.

➢ CIA and its specific challenges for hydropower projects

Assessing cumulative impacts at the energy policy level allows for a comparison of energy options – hydropower, coal, gas and other electricity production alternatives- over issues such as global warming, acid rains, deforestation, biodiversity loss, depletion of the ozone layer, etc. Another appropriate level for CIA constitutes regional planning, where cumulative effects will be assessed in relation to a specific territory.

Addressing CIs, such as greenhouse gases or acid rain, at the energy policy level would help to minimize the analysis of CIs for a specific project.

In more general fashion, the question remains whether the proponents of a hydropower project is the best organization to address cumulative impacts of multiple economic activities occurring over a large region beyond the scope of a project.

* See Appendix A: Glossary.

Finally, some useful questions to ask in assessing CIs are:

- What are the valued environmental components[2] that might be affected ?
- How does the proposed project combined with other existing and planned activities affect the condition of these valued environmental components ?
- What is the probability that these effects may occur ?
- Are the resulting effects unacceptable ?
- Are these effects permanent ? If not, how long will it take before recovery ?
- What is the probable extent as well as the probable duration of these effect ?
- What additional accumulation of effects the valued environmental components can tolerate before they may undergo an irreversible alteration of their conditions ?
- What degree of certitude can be related to the estimates concerning the occurrence and the magnitude of these anticipated effects ?
- And finally, what are the cumulative impacts of the next best alternative to the project?

[2] Definition: Any element of the environment considered as important by the proponent, the public, the scientists and the governments taking part in the assessment process. Cultural values as well as scientific preoccupations can serve as criteria in order to determine the importance accorded to those elements. (CEAA, 1997)

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Appendix H

REVIEW OF LITERATURE CONCERNING THE ASSESSMENT OF ENVIRONMENTAL IMPACT ASSESSMENT PROCESSES (HARD LAW)

APPENDIX H
REVIEW OF LITERATURE CONCERNING THE ASSESSMENT OF ENVIRONMENTAL IMPACT ASSESSMENT PROCESSES (HARD LAW)

Main Author:
Gilles G. Bérubé

Organizations

An *Analysis of Environmental Impact Assessment Practice and Procedures in Other Countries*[1] was carried out for the Commonwealth Environment Protection Agency in May 1994. The study aimed to identify processes, practices and procedures that could maximize the effectiveness and efficiency of an EIA. The study analyzed scope (including social, economic, cultural and physical factors and cumulative impacts) and the cultural and political context. The study also looked at the implementation of EIAs, the decision-making process, the substantive and procedural review and its enforcement, monitoring results and extra-territorial application. The areas studied were Indonesia, Canada (at the federal level), Ontario (at the provincial level), the United States and Europe.[2] The analysis shows that the principles underlying EIAs are based on ethical considerations such as fairness, prudence, control and stewardship.

Authors

Sadler: Barry Sadler has written extensively on the effectiveness and efficiency of EIA processes. In a final report submitted within a series of international studies on EIA efficiency and effectiveness, Mr. Sadler defined 14 criteria to promote effectiveness.[3] He says that to be effective, an EIA should: be vested in law (clear mandate and provisions); have explicit goals; enforce procedures uniformly and consistently; include an appropriate level of assessment; use a relevant scope of consideration; adopt a flexible problem-solving approach; use an open and facilitative procedure; ensure necessary support and guidance; have standards of best practice; provide for efficient and predictable implementation; demonstrate a decision-oriented process; be related to condition-setting; include a follow-up and feedback mechanism; and aim at a cost-effective outcome.

Mr. Sadler developed this list after thoroughly analyzing documents on environmental assessment in different countries. Since his criteria are founded on ethical considerations,[4]

1 Commonwealth Environment Protection Agency, Review of Commonwealth Environmental Impact Assessment, 1994.

2 The final recommendations of the study concerned modifications to be made to the Australian EIA system.

3 Barry SADLER, International Studies on Efficiency and Effectiveness of Environmental Assessment: *Final Report – Environmental Assessment in a World in Evolution*, 1994.

4 For example, an open and facilitative procedure encouraging public participation during different phases of assessment refers to the ethical principle of participatory decision-making. In addition, clear mandate and provisions require that the EIA process establish the responsibility and obligations of all parties that meet the ethical principle of stewardship.

his research serves as a useful guide for assessing legal mechanisms used at the national or territorial level.

Shpyth : Another interesting study was carried out by Albert A. Shpyth of the Faculty of Environmental Studies at York University in Ontario in 1991.[5] The study examines in detail the criteria for fairness,[6] efficiency[7] and effectiveness[8] during and after an EIA process. His assessment is based explicitly on the ethical principles of fairness, prudence, control, optimality and stewardship.

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5 Albert A. SHPYTH, The Effectiveness, Efficiency and Fairness of Environmental Impact Assessment in Alberta and Saskatchewan: A Case Study of the Old Man and Rafferty Dams, 1991, Faculty of Environmental Studies, York University, Ontario, Canada.

6 In his study, Shpyth identifies eight elements of a fair assessment: ensure openness; eliminate bias or pre-decision; provide flexibility and a broad scope; make policy assumptions explicit; address procedural fairness directly; grant funding to public participants; place time limits on proceedings; and require written decisions by assessment agencies. He also concludes that assessments must not only be fair, they must also be *perceived* as fair.

7 Studying the efficiency of an environmental process involves evaluating the time and effort involved, where effort is linked to the costs of the environmental impact process. Mr. Shpyth mentions the importance of aiming for a speedy, cost-effective process but says that this should not be achieved by giving insufficient weight to legitimate values or ignoring long-term environmental damage or the concerns of affected parties.

8 Studying the effectiveness of an environmental process involves evaluating whether the EIA has produced the intended result. It is essential to ensure that all relevant impacts associated with a proposed activity have been adequately identified, assessed and fully taken into account in the decision-making process.

Appendix I

PRINCIPLES OF INTERNATIONAL ENVIRONMENTAL LAW AND SUSTAINABLE DEVELOPMENT (SOFT LAW)

APPENDIX I
PRINCIPLES OF INTERNATIONAL ENVIRONMENTAL LAW AND SUSTAINABLE DEVELOPMENT (SOFT LAW)

Main Author:
Gilles G. Bérubé

Authors

Owen J. Lynch and Greg Maggio of the Center for International Environmental Law in Washington surmise that conflicts on human rights, economic development and the environment have increased worldwide over the past few years.[1] They cite that sources of hydroelectricity are often located in areas that are especially valuable for conserving biological diversity or inhabited by resource-dependent communities, including indigenous people and other long-term occupants.

Developing natural resources in such areas is a multidimensional issue, they say, since any analysis must explore the link between human rights, environmental protection and economic development as complementary goals rather than unrelated disciplines.[2] Note that Mr. Lynch and Mr. Maggio regard as "human rights" the interests of local communities that depend directly on natural resources. This definition encompasses aboriginal or native rights in particular. As the result of aboriginal rights, the political authorities in developing or emerging countries where projects are often proposed may indeed face legitimacy problems.[3]

Mr. Lynch and Mr. Maggio's analysis is based on the ethical considerations that ensue from the relationship between the three types of universal rights: human, environmental and economic. Their ethical considerations are founded on international law (soft law). On the basis of these considerations, they have developed five yardsticks to reconcile international environmental law, human rights and economic development.

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1 Owen J. LYNCH and Greg MAGGIO, *Human Rights, Environment and Economic Development: Existing and Emerging Standards in International Law in Global Society*, 1997, Center for International Environmental Law Papers and Publications, Washington, D.C.

2 Various authors have examined the relationship between international human rights, economic development and environmental protection. (See Edith Brown WEISS, *Environmental Changes and International Law: New Challenges and Dimensions*, United Nations University, 1992, and Laurence BOISSON DE CHAZOURNES, Richard DESGAGNÉ and Cesare ROMANO, *Protection internationale de l'environnement*, Paris, Éditions A. Pedone, 1998.)

3 One example is the case of the Banyano Kuna Indians who protested strongly against the Banyano Dam project in Panama, which resulted in the loss of 80 per cent of their territory. (Katherine M. WEIST, *Indigenous Peoples Resistance to Development Projects*, Development Induced Displacement and Impoverishment Conference, Wadham College, Oxford University, January 3 to 7, 1995.) In the Philippines, the Chico River Dam, whose construction was partially cancelled because of the strong opposition from the Bontoc and Kalinga groups, also illustrates the kind of problem that hydropower proponents may face when their projects raise issues of aboriginal rights. (Charles DRUCKER, "Dam the Chico: Hydropower Development and Tribal Resistance" in *Tribal People and Development Issues*, edited by John H. Bodley, Mountain View, CA: Mayfield.)

These are:

- inter- and intra-generational equity[4]
- common but differentiated responsibilities[5]
- equitable sharing[6]
- a state's right to permanent sovereignty over its natural resources and the concomitant duty not to harm areas beyond its national jurisdiction[7]
- and finally the precautionary principle.[8]

Development and environmental issues involve questions of human rights and economic rights, especially in the case of hydropower projects. Therefore, ethical considerations that arise from international law pertaining to the environment, the economy and human rights are especially relevant for our purposes.

Increasingly, authors agree on the interrelation between these categories of rights. Jean-Marc Lavieille mentions that international environmental law contributes to creating and enforcing the right to the environment, which is one of the three solidarity rights (the third generation of rights).[9] Interestingly enough, the other two rights in this third generation are the right to peace and the right to development. Again, a connection can easily be made between development, human rights and the environment.

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4 **Intergenerational and intragenerational** equity are part of customary international law. Intergenerational equity indicates that the international community has come to recognize the use of natural resources in an intertemporal context. It calls for fairness in the use of resources between generations, past, present and future. Intragenerational equity refers to fairness in allocating resources among the members of present generations, both domestically and globally.

5 **Common but differentiated responsibilities** imply that all states are responsible for protecting, preserving and enhancing the environment for present and future generations. Yet standards that are valid for the most developed countries may be inappropriate for developing countries in light of the social costs. Such a concept therefore promotes fairness and justice given that each country's needs and financial means are taken into account. Hence, recommendations must offer a range of expectations according to different contexts. The common but differentiated sharing of responsibilities is described in Principle 23 of the Stockholm Declaration.

6 There are two accepted meanings of **equitable sharing**. The first refers to an equitable sharing of natural resources among countries. The second pertains to a fair economic return to all state and non-state parties from which the resource is obtained. With respect to sharing with non-state players, references are made (in Agenda 21 in the context of biological diversity) to the importance of sharing benefits with affected groups such as indigenous people.

7 Case law from the International Court of Justice, as well as general practice, confirms that the principle of the **state's right to sovereignty over its natural resources** is part of customary international law. This principle is set out in Principle 21 of the Stockholm Declaration.

8 The **precautionary principle** is another instrument used to balance economic considerations with equity and environmental protection when promoting sustainable development. According to Principle 15 of the Rio Declaration, states must apply the precautionary approach widely according to their capabilities. When serious or irreversible damage is threatened, lack of full scientific certainty is not a sufficient reason to postpone cost-effective measures to prevent environmental degradation. The precautionary principle ensures that potential environmental harm is considered even when scientific evidence proving this potential is not fully available.

9 Jean-Marc LAVIEILLE, *Droit international de l'environnement*, Collection ellipses, édition Marketing S.A., Paris, 1998, p. 22-23.

Organizations

The United Nations Conference on Environment and Development (UNCED) received a report on international law principles and sustainable development in 1996.[10] The report by the United Nations Expert Group describes various principles in greater detail than in Mr. Lynch and Mr. Maggio's paper. However, these principles are essentially the same. The report identifies the following principles: the right to a healthy environment; equity; sustainable use of natural resources; prevention of environmental harm; the precautionary principle; the principle of international co-operation; participatory decision-making and transparency; and monitoring and compliance.

10 United Nations, Department for Policy Coordination and Sustainable Development, Report of the Expert Group Meeting on Identification of Principles of International Law for Sustainable Development, 1996.

Appendix J

THE INTEGRATION OF ETHICAL PRINCIPLES IN INTERNATIONAL LAW

APPENDIX J
THE INTEGRATION OF ETHICAL PRINCIPLES IN INTERNATIONAL LAW

Main Author:
Gilles G. Bérubé

Many international environmental conventions and agreements show that there is in fact an international consensus on basic ethical principles, such as optimality, stewardship, fairness & justice, participatory decision-making and prudence and control. Both universal and regional conventions reflect such a consensus.

International Conventions

Among all ethical principles, the ethical principle of **participatory decision-making** is the one that is mentioned most frequently. Basically all international conventions and other international instruments regarding environment mention this principle.

For instance, the Espoo *Convention on Environmental Impact Assessment in a Transboundary Context* (February 25, 1991), as well as the *Convention on Biological Diversity* (1992) and the Basel *Convention on the Control of Transboundary Hazardous Wastes and Their Disposal* (1989) all contain provisions regarding the need for public information and participation. In addition, the Convention on Access to Information, Public Participation in Decision Making and Access to Justice in Environmental Matters was signed by 39 countries in June 1998 in Denmark and is set to come into force in the year 2000.

As for other ethical principles recognised at the international level, we should mention the **prudence and control** principle which is cited in the preamble of both the *Geneva Convention on Long-range Transboundary Air Pollution* (1979) and the *Vienna Convention on the Protection of the Ozone Layer* (1985).

Principle 23 of the *Stockholm Declaration* describes the **common but differentiated responsibilities** principle which implies that all states are responsible for protecting, preserving and enhancing the environment for present and future generations. Yet standards that are valid for the most developed countries may be inappropriate for developing countries in light of their social costs. Such a concept therefore promotes **fairness** and **justice** while taking into account each country’s needs and financial means.

The ethical principle of **stewardship,** as well as **fairness and justice** can be identified through other principles, such as equitable sharing. With respect to sharing with non-governmental stakeholders, references are made in *Agenda 21* of the United Nations *Convention on the Environment and Development* (1994) to the importance of sharing benefits with affected groups such as indigenous people in the context of biological diversity.

Regional Conventions and tools

Regional conventions or other binding instruments developed at a regional level reflect the integration of ethical principles in international law.

The example of the European Union Directive and Guidelines

Directive 85/337/EEC of June 27th 1985, recently amended by Directive 97/11/EC which came into force on March 14th 1999, imposes on member states, among others, to develop procedures for **public participation** in order to promote transparent decision-making processes.

In addition, Directive 90/313/ECE on freedom of access to information concerning the environment requires that information which is normally held by publicly accountable bodies be made available on request to the public.

Other tools have been developed in Europe in order to promote directly or indirectly many ethical principles:

The European Commission issued in May 1996 a “Guidance on screening” which aims at **optimality** by suggesting a six step methodology to conduct the screening process.

In the same light, Directorate General XI of the European Union issued in 1996 guidelines for scoping which aim at **optimality** by including all factors that must be taken into account while conducting the scoping process. These guidelines also promote **public participation** by proposing different methods of public consultation in order to adjust to the realites of each member country.

Another example: North-America

There are also certain legal instruments that reflect ethical principles to be found in American conventions or other agreements.

For instance, the *North American Agreement on Environmental Co-operation,* binding the United States, Canada and Mexico, contains provisions concerning **public access to information** (e.g., art 6 and 7), as well as co-operation actions aiming at **optimality** (e.g., art 5).

Also, even if it has not yet come into force, the *Draft North American Agreement on Transboundary Environmental Impact Assessment,* in its preamble, reflects in many ways the importance of some ethical principles, such as the **precautionary principle**, **public participation** and **optimality** through legal and administrative provisions.

Appendix K

PROJECT STAGES

APPENDIX K
PROJECT STAGES

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The table below outlines project planning and implementation stages, tools for environmental management, and the types of impacts associated with each stage. Project stages may differ from one country to another according to the specific EA and licensing processes. For instance in some countries EA is part of the licensing process, while in some others the EA precedes licensing.

Hydropower Project Stages and Impact Management

Project Planning and Implementation Stage	Project Planning and Implementation Stage	Environmental Focus
Policy Context National strategies for sustainable development • Energy policy • Water policy • Land use policy	• Strategic environmental assessment (SEA) • Sectoral environmental assessment • Cross-sectoral environmental assessment • Regional environmental assessment (REA)	Transboundary/cumulative impacts[1] Cumulative impacts Precautionary principle
Project Planning • *Inventory Study* Objective: identify river basins or reaches • *Prefeasibility Study* Objective: select potential projects within a river basin for study • *Feasibility Study* Objective: study alternatives and recommend one project	• Screening of potential impacts • Preliminary EA study • Terms of reference and scoping • EIA study[2] including environmental management plan and contingency plan	Impact avoidance Potential impacts Anticipated impacts Design impact mitigation
Project Implementation • Detailed design/engineering • Tendering and contracting • Construction	• Environmental design criteria • Integration of mitigation and compensation measures identified in the EA study • Environmental management systems (e.g., ISO 14001) • Environmental site monitoring, audits • Environmental contingency plans • Environmental mitigation measures • Environmental follow-up studies	Impact avoidance Impact mitigation Temporary impacts management
Project Operation	• Integrated resources management plan • Environmental management system (including monitoring and auditing)	Real (observed) impact management; impact monitoring and follow-up.
Project Upgrading and Relicensing	• EA according to the magnitude of the project • Site monitoring	Residual and incremental impacts
Project Decommissioning	• EA study to determine social and environmental impacts • Site monitoring of the works • Ex post inspections	Residual and temporary impact mitigation and monitoring

1 Examples of cumulative impacts at the national level: greenhouse gas emissions, acid rain, degradation of biodiversity, deforestation, depletion of ozone layer, climate changes and nuclear waste disposal.

2 Compare alternatives, impact significance, trade-off between benefits and costs, social impact assessment.

Hydropower projects are multigenerational investments. They may last a century or longer and hence more than four generations (see the following table). Planning such projects requires a long-term view and flexible management since ecological balances, land use and people's concerns about a power plant will evolve over time.

Typical Life Cycle of a Hydropower Project

	construction				**upgrading/relicensing**					**decommissioning**
planning	←		**operation**		→	←		**operation**		→
0 years	10	20	30	40	50	60	70	80	90	100 years

Large hydropower projects often take a long time to design, engineer, finance, license and build. Decades may pass before the first kilowatt-hour is produced. Hydropower projects evolve throughout the design and construction stages. Project design is an iterative process, and the EA and/or licensing processes must reflect this fact.

1 Policy Level

The policy level refers to the policy framework for hydropower: It may include national policies on energy, water or land use, for example. The policy context is sometimes overlooked in studies that review EA efficiency. Yet policies shape the context and influence the EA process before the project has been initiated by a proponent.

Recently, several countries have created mechanisms, such as strategic, sectoral or regional environmental assessments of their policies, programs and plans in various sectors[3].

1.1 Description

When it comes to classifying the different environmental assessment tools used at the policy level, different perspectives exist. Some authors consider strategic environmental assessment (SEA) to be a generic term for all environmental assessments at the policy level. Thereafter, different types of SEA can be identified such as regional environmental assessments and sectoral environmental assessments. Others consider that regional environmental assessments or sectoral environmental assessments are distinct from an SEA. One thing is sure nevertheless: authors agree that SEA, REA or Sectoral EA are all mechanisms for environmental assessment at the policy level.

The aim of this section is to describe the various assessment categories used at the policy level. These descriptions are theoretical given that the definitions are not mutually exclusive. Also, it is important to remember that there is no systematic implementation of these mechanisms in national systems of law. In some jurisdictions, one or more of these instruments will be commonly applied to a specific sector (such as energy policy, without

3 This need for impact assessment at the policy level is becoming increasingly popular. Many authors consider SEAs an improvement over the EA process, which lacks a strategic view and cannot address the cumulative, indirect and synergistic effects of projects. (See Riki THERIVEL, Elizabeth WILSON, Stewart THOMPSON, Donna HEALEY and David PRITCHARD, *Strategic Environmental Assessment*, Earthscan Publications Ltd., London, 1992.

considering water management policy). This will affect the content of other types of assessments, and especially subsequent assessments such as site-specific EAs.

Since this debate is mainly theoretical, we do not wish to elaborate further on this matter, except to say that for the purposes of this report, we analyzed the existing assessment tools at the policy level, namely strategic, sectoral, cross-sectoral and regional environment assessments.

Before presenting them, we should point out that certain of these assessments may be conducted in part through public consultations in order to determine the orientations and goals of the different policies, while in other cases they may not. It is generally recognized that public participation must be included in the process as early as possible.[4]

1.2 Strategic Environmental Assessment (SEA)

An SEA provides the general framework in which individual EIAs for specific projects are developed. An SEA addresses more general issues (sustainability, cumulative effects, resource management and conservation, global trends concerning environmental goals and commitments), while project-specific EIAs deal only with local effects. This difference is recognized and established for example in the Convention on Biological Diversity, in which a clear distinction is made between EIA and SEA in section 4.[5] The SEA concept also appears in section 4 of the United Nations Framework Convention on Climate Change.[6]

Global and regional issues such as climate change, acidification and biodiversity are, for obvious reasons, best addressed within the SEA framework. Indeed, a SEA provides an integrated approach to decision-making, especially for public development policies. Integrating environmental considerations and objectives into broader decisions is therefore helpful.

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4 The European Commission mentioned in one of its report on SEA that specific methods should be to increase participation. (European Commission: Case Studies on Strategic Environmental Assessment, February 1997.

5 Section 4 reads: “Each contracting party, as far as possible and appropriate, shall:

a) Introduce appropriate procedures requiring environmental impact assessment of its proposed projects that are likely to have significant adverse affects on biological diversity with a view to avoiding or minimizing such effects and, where appropriate, allow for public participation in such procedures.

b) Introduce appropriate arrangements to ensure that the environmental consequences of its programs and policies that are likely to have significant adverse impacts on biological diversity are duly taken into account.”

6 Section 4 reads: “All parties, taking into account their common but differentiated responsibilities and their specific national and regional development priorities, objectives and circumstances shall:

f) Take climate change considerations into account, to the extent feasible, in their relevant social, economic, and environmental policies and actions, and employ appropriate methods, for example impact assessment, formulated and determined nationally, with a view to minimizing adverse effects on the economy, on public health and on the quality of the environment, of projects or measures undertaken to them to mitigate or adapt to climate change.”

1.3 Sectoral Environmental Assessment

Sectoral environmental assessment addresses sector-wide - energy, water,.. - environmental issues.

A country's energy policy identifies and promotes specific means and strategies to satisfy the energy needs of populations while considering other fundamental needs such as health, economic growth and fresh air / water. Energy policies may support specific electricity production technologies (such as thermal, nuclear, solar, hydropower or wind) to meet the anticipated demand. Energy policies also enable alternative policies, plans and programs for a particular sector to be considered[7]. An energy policy could help a project proponent decide whether to pursue a project that is at the early planning stage.

Governments may adopt a comprehensive water policy incorporating the principles — protection, use, distribution and implementation measures — that guide the management of water resources. Water policy may have significant implications for hydropower and other water uses. Such a policy can clarify the context for hydropower developments by recognizing the categories of water users, their needs and the applicable rules. It may also identify river basins suitable for development or conservation. Again, this could contribute to better predictability at later stages of a project. Consider the case of watersheds: competition for water uses may be addressed at the regional policy level in order to clarify the situation for any potential hydropower project.

The Master Planning policy in Norway illustrates this kind of general sectoral strategy for the hydropower development sector. The plan includes a mapping of possible hydropower projects for all rivers and a study of each project's conflicts with environmental and other interests. Protection Plans have also been adopted in order to protect certain river systems from hydropower development.

1.4 Cross-sectoral Environmental Assessment

In some countries, general cross-sectoral strategies for sustainable development define priorities regarding specific environmental issues. Applying EA to public policies can help address global issues such as climate change, acid rain and biodiversity by avoiding undesirable impacts at the source. Such a tool provides a basis for cross-sectoral cooperation (e.g.: energy, transport, urban development) and enhances resource management by avoiding duplication of efforts and policy contradictions between sectoral agencies and ministries.

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7 For example, the World Bank developed guidelines describing the principal steps in a sectoral environmental assessment in the power sector. They are:
1) Describe the current situation in the power sector.
2) Review the country's environmental institutional framework.
3) Review the regulatory framework of power sectors and planning procedures.
4) Analyze strategies for planned and alternative power sectors.
5) Choose an optimal investment strategy.
6) Review the institutional capacity of power sector agencies.
7) Hold public consultations.
8) Develop an action plan (for mitigation, management and monitoring).

1.5 Regional Environmental Assessment

Regional environmental assessment is particularly useful when cumulative or interrelated effects may arise from a project in a region. It provides a local framework that can help avoid the considerable work that must be done during the project-specific EA and/or licensing processes.

Land use policy is a good example for a regional environmental assessment. The goal of a land use policy is to establish guidelines, priorities and objectives for developing a particular territory. In this context, regional environmental assessment helps evaluate a specific region according to its natural resources and ecological and socioeconomic characteristics. The assessment provides an overview of baseline environmental conditions within the study area. The result may be a comprehensive regional development plan identifying investment projects that are environmentally sustainable for the region as a whole. The larger spatial scope of this assessment also allows the consideration of potential cumulative impacts.

2 Hydropower Project Planning Stage

2.1 Description

The project-planning stage proceeds but successive iterations from general inventories and screening of project alternatives down to progressively more detailed data collection and design studies. This stage may include the following steps: data collection studies, pre-feasibility studies, feasibility studies and project licensing. These steps differ from country to country.

2.2 Data Collection or Preliminary Studies[8]

Data collection studies are normally the first step in project planning. Their main goal is to investigate available water resources and identify potential power projects[9] on suitable river basins. The selected reaches will be studied at the pre-feasibility stage.

Although only the main project components are known at this level of investigation, a first cost estimate and an implementation schedule are drawn up, including a preliminary appraisal of environmental and resettlement costs.

2.3 Pre-feasibility Stage

In general, the objective of this stage is to identify reasonable project alternatives to be investigated in-depth during the feasibility stage.

The information gathered in the earlier investigations will help determine alternative scenarios for various sites and configurations during the pre-feasibility activities. At this

8 This process replaces studies usually done at the SEA stage, when applicable. The practice is a good one for proponents when an SEA does not apply

9 SEAs in Nepal and Norway both included identifying the potential power projects. Since this identification is completed at the policy level, it occured prior to the project planning stage.

stage, several project scenarios must be identified in order to select potential projects within a specific river basin.

Two types of considerations mainly influence the identification of a suitable site: physical conditions at the site and the intended purpose of the future facility (including multiple uses of water). The main environmental activity at this stage is the scoping and screening process.

With respect to screening and scoping, the environmental and social issues are usually identified as well as the potential impacts that might be related to a given project configuration. These activities are usually supported by a preliminary environmental assessment study. Such a study encompasses not only investigations on the biophysical sector but also human impact assessment studies, including resettlement and compensation programs if necessary. All these aspects are then considered in order to estimate the costs and an implementation schedule for each alternative. Based on the findings of the preliminary study, the pre-feasibility study compares the costs of assessed alternatives and other power generation options. This stage results in a recommendation of whether to proceed or not with feasibility studies.

2.4 Feasibility Stage

Based on the recommendations of the pre-feasibility study, the feasibility study covers four major components: technical, financial, economic and environmental considerations. At this stage of project planning, comprehensive analysis is directed towards project licensing.

The aim of the feasibility stage is usually to study project alternatives at a given site and recommend one particular scenario. The decision of whether to proceed with a hydropower project depends on its technical feasibility, economic viability, and environmental and social acceptability.

➢ Environmental Feasibility

It is at this stage that a full EIS is carried out. This assessment aims to determine significant impacts and to design appropriate mitigation or compensation measures on the basis of consultations with concerned stakeholders. The assessment usually takes into account the construction of other related infrastructures (e.g., power lines, substations, access roads, airports, and quarries). In addition, it is good practice for proponents to get input from the public (e.g., values, concerns, scope, etc.) and integrate this input as much as they can. It is at this planning stage, prior to the licensing, that impacts may best be avoided.

Following a review of impact assessment and mitigation alternatives, an environmental management plan should be designed in order to mitigate or control significant impacts and optimize positive impacts.

The environmental impact assessment report provides recommendations on environmental management plans; mitigation plans, compensation schemes, contingency plans and monitoring programs that must be incorporated into the project approval documents. It is also essential that responsibilities for implementing all recommended actions contained in the environmental assessment report be clearly allocated.

2.6 Project Licensing

Once the feasibility study is completed, the project is submitted to public authorities for review and licensing. This stage frequently involves, for major projects, public hearings according to the legal and regulatory framework. Additional studies may be required during the review process. The implementation stage starts after project approval by the licensing authorities.

3 Implementation Stage

3.1 Description

Project implementation includes detailed engineering, tendering and construction.

3.2 Final Design and Detailed Engineering

The objective of this stage is to finalize the design of the project and provide the technical basis for the tendering documents.

The Development Assistance Committee of the OECD suggests that during project design, procedures be established for a compliance audit to ensure that recommendations on mitigation, monitoring, resettlement and compensation are fully implemented. To promote environmentally sound hydropower design, Norway has developed criteria for such an audit and included landscape features and proposals for various project components.

3.3 Tendering and Contracting

The aim of this implementation stage is to prepare the contract documents and select contractors. At this stage, environmental performance clauses may be included in pre-qualification documents for contractors. It is essential for environmental mitigation measures to be integrated into the tendering documents and the engineering process. Contractors may need to be certified according to ISO 14001 standards or other EMS (environmental management systems).

3.4 Construction

The goal of the construction stage is to build the project as agreed and as required by the licenses. For major hydropower projects, a large-scale organization is needed to manage the many players involved in field operations, namely contractors and suppliers for the general civil works, the transmission works, the electromechanical equipment and works, the camps, catering and similar services. On the management side, administrative services, quality assurance, construction and contract management, engineering services, supervision of work and supplies, inspection and documentation must all be provided. These major activities result in temporary and permanent impacts, and a code of good environmental practices for construction work is recommended.

The procedures developed to minimize construction impacts are supported by penalties and fines for non-compliance. Thus, monitoring and auditing activities are very important for sound environmental management during this stage because they help identify remedial or corrective actions.

4 Operation Stage

4.1 Description

During the operation stage of a hydropower project, the goal is to optimize the output within the existing technical, environmental, economic and social constraints, which may include multiple water uses.

Many countries are moving toward automation and remote control of power plant operations. Hydropower plants are sometimes unmanned and controlled from remote operation centers.

At this phase, the crucial environmental management issue is monitoring. Environmental monitoring ensures compliance with standards and previous undertakings and determines the success of mitigation. Procedures ensuring regular environmental monitoring and follow-up are implemented. Monitoring and auditing activities determine whether programs need to be modified over time and whether the results are serving a useful purpose. During the operation phase, a contingency plan will provide measures to cope with possible accidents in the plant area.

A useful tool at this phase is an environmental management plan. This plan includes an integrated resource management plan. Transparent and clear operating rules should ensure an equitable share of water to all users. The environmental management plan may be incorporated into a comprehensive environmental management system according to internationally recognized standards.

5 Upgrading, Relicensing and Decommissioning

5.1 Upgrading, Relicensing

The main goal associated with these stages is to extend the useful life of the components in a hydropower project. There are essentially two types of upgrading projects.

- Projects that do not require changes in river water flows.
- Projects that require changes in river water flows (implying a change in water flow downstream and change in water fluctuations and/or water levels in reservoirs).

The environmental issues for the first type are generally much less significant. Environmental studies are designed accordingly, and the solutions to address the impacts are less complex to develop and less costly. However, the environmental issues for the second type of project may be similar to those of a new project.

Project upgrades may trigger public hearings on mitigation and compensation measures for impacts produced by the original project and its operation. In Japan, for example, if the impacts of the base project pose no significant problem, then only the predicted impacts of a refurbishment project will be addressed. If the original project creates negative residual impacts, the impacts of both the base and refurbishment projects will be considered.

Often the relicensing process sparks considerable debate among the supporters of different uses of reservoir water (e.g., irrigation, water supply, recreation, fishing, wildlife). A negotiated agreement between the stakeholders on water flows and water levels may affect the operating parameters of the hydropower plant.

5.2 Decommissioning Stage

This stage is intended to restore the site to negotiated conditions. Over decades of operation, a reservoir and its basin reach a new ecological equilibrium. In addition, human activities develop such as recreation, navigation, industry or farming. In such cases, decommissioning generally involves dismantling the power plant, but often the dam and reservoir are kept intact.

A site investigation must consider current and potential uses made by local populations and fauna to determine to what degree the ecological conditions of the site can be restored. An EA and/or licensing processes could be required to evaluate several decommissioning scenarios and the temporary and residual impacts of each type of dismantling activity.

➢ A sensitive issue at this stage is determining who pays for what.

In addition, before decommissioning begins, electricity generation alternatives to replace the lost power production must be assessed in order to compare their impacts with the impacts of decommissioning the hydropower facility.

Once the decision to decommission is made, the dismantling activities require a monitoring procedure similar to those of the construction and upgrading phases. Depending on the degree of renaturalization implemented, regular inspections of the abandoned site may be necessary to ensure public security after the decommissioning phase.