GOOD PRACTICE NOTE

Environmental, Health, and Safety Approaches for Hydropower Projects

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Acknowledgments

This IFC Good Practice Note on Environmental, Health, and Safety Approaches for Hydropower Projects (2018) is part of the Good Practice Series, which provides guidance from the Environment, Social and Governance Sustainability Advice & Solutions Department of the International Finance Corporation (IFC). The Good Practice Series seeks to share information about private sector approaches to addressing a range of environmental and social issues that IFC believes demonstrate one or more elements of good practice in these areas.

The drafting of this document originated many years ago. Since then, many people have contributed to this project. Although it is impossible to acknowledge all these contributions, we, the authors, would like to mention those whose assistance was direct and vital to the completion of this work.

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Foreword

IFC prides itself on contributing to the continuing evolution in environmental and social risk and impact management practices in the private sector, as reflected in our Policy and Performance Standards (PSs) on Environmental and Social Sustainability, the World Bank Group (WBG) Environmental, Health, and Safety (EHS) Guidelines, and our regular publications of good practice guidance.

Hydropower has a well-established role in the energy sector and support for further deve lopment of this energy resource is very important, especially in developing countries. Hydropower is a vital renewable energy resource and, for many countries, has the potential to expand access to electricity to large populations. But hydropower development poses complex challenges and risks. Each hydropower project is unique and presents a complex range of EHS risks, varying widely depending on many factors.

It is my pleasure to present this IFC Good Practice Note on Environmental, Health, and Safety Approaches for Hydropower Projects. This note is intended to be used in conjunction with the EHS General and as relevant other Guidelines and IFC's PSs to identify, avoid, mitigate, and manage EHS risks and impacts in hydropower projects. It is not intended to replace official IFC guidance documents. Instead, it is an effort to capture sector-specific knowledge and experience gained through the extensive engagement of IFC staff and clients in hydropower development, while offering sector-specific guidance to help implement EHS-related requirements contained in the PSs.

We hope that the knowledge presented in this publication assists private-sector companies in emerging markets and guides them in the effective design and implementation of measures to assess and manage EHS risks related to hydropower projects and contributes to the sustainable and well-executed development of valuable hydropower resources.

Morgan Landy
Director
Environment, Social, and Governance Sustainability Advice
and Solutions Department, IFC

List of Abbreviations and Acronyms

ACGIH	American Conference of Governmental Industrial Hygienists
ARD	Acid Rock Drainage
ANCOLD	Australian National Committee on Large Dams
ARM	Adaptive Resource Management
AZE	Alliance for Zero Extinction Sites
BEIs	Biological Exposure Indices
CIA	cumulative impact assessment
CIAM	cumulative impacts assessment and management
CDM	Clean Development Mechanism
CO	carbon monoxide
dBA	A-weighted decibels
DO	dissolved oxygen
DRIFT	Downstream Response to Imposed Flow Transformations
EAP	Emergency Action Plan
EFlow	environmental flow
EHS	Environmental, Health, and Safety
ELOHA	Ecological Limits of Hydrologic Alteration
EMF	electric and magnetic fields
EMP	environmental management plan
ESIA	Environmental and Social Impact Assessment
GHz	gigahertz
GLOF	glacial lake outburst flood
GIIP	Good International Industry Practice
GHG	greenhouse gas
GPN	Good Practice Note
HACCP	Hazard Analysis Critical Control Point
H_2S	hydrogen sulfide
IBA	Important Bird Areas
ICNIRP	International Commission on Non-Ionizing Radiation Protection
ICOLD	International Commission on Large Dams

IEEE	Institute of Electrical and Electronics Engineers
IFIM	Instream Flow Incremental Methodology
IHA	International Hydropower Association
IPA	Important Plant Areas
IRS	indoor residual spraying
IUCN	International Union for the Conservation of Nature
NIOSH	National Institute for Occupational Health and Safety
OP	operational policy
OHS	occupational health and safety
OSHA	Occupational Safety and Health Administration of the United States
PAG	Potentially-Acid-Generating
PEL	Permissible Exposure Limits
PHABISM	Physical Habitat Simulation System
TDG	Total Dissolved Gases
TGP	total gas pressure
TLV	Threshold Limit Value
TSS	total suspended solids
UK EA	United Kingdom Environment Agency
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
VEC	Valued Environmental Component

Introduction

This IFC Good Practice Note on Environmental, Health, and Safety Approaches for Hydropower Projects is a technical reference document with industry-specific examples of Good International Industry Practice (GIIP).[1] This publication applies to environmental, health and safety (EHS) aspects of run-of-river diversion, run-of-river reservoir, storage reservoir, and pumped storage types of facilities (as defined in Annex A). If a hydropower project requires development of reservoirs, use of such reservoirs for purposes other than hydropower production are not covered in this document. Because of the EHS complexity of some hydropower projects, users of this publication may also consult the **General EHS Guidelines,**[2] which provides guidance on common EHS issues potentially applicable to all industry sectors, as well as sector-specific EHS Guidelines including those for **Electric Power Transmission and Distribution, Construction Materials Extraction, and Toll Roads.**

This document is composed of four sections. Section 1 looks at industry-specific impacts and management, while Section 2 covers performance indicators and monitoring. Sections 3 and 4 provide additional resources with a reference list and useful annexes.

[1] Defined as the exercise of professional skill, diligence, prudence, and foresight that would reasonably be expected from skilled and experienced professionals engaged in the same type of undertaking under the same or similar circumstances globally or regionally. The circumstances that skilled and experienced professionals may find when evaluating the range of pollution prevention and control techniques available to a project may include, but are not limited to, varying levels of environmental degradation and environmental assimilative capacity, as well as varying levels of financial and technical feasibility.

[2] The **Environmental, Health and Safety (EHS) Guidelines** (www.ifc.org/ehsguidelines) contain the performance levels and measures that are generally considered to be achievable in new facilities using existing technology at reasonable costs. Application of the EHS Guidelines to existing facilities may involve establishing site-specific targets, based on environmental assessments or environmental audits as appropriate, with an appropriate timetable for achieving them. Users should tailor the applicability of the EHS Guidelines to the hazards and risks established for each project based on the results of an environmental assessment in which site-specific variables, such as host country context, assimilative capacity of the environment, and other project factors, are taken into account. The applicability of specific technical recommendations should be based on the professional opinion of qualified and experienced persons. When host country regulations differ from the levels and measures presented in the EHS Guidelines, projects are expected to achieve whichever is more stringent. If less stringent levels or measures than those provided in these EHS Guidelines are appropriate, in view of specific project circumstances, a full and detailed justification for any proposed alternatives is needed as part of the site-specific environmental assessment. This justification should demonstrate that the choice for any alternate performance levels protects human health and the environment.

1. Industry-Specific Impacts and Management

This section summarizes EHS[3] issues associated with hydropower activities that may occur during the development, construction, and operational phases, along with recommendations for their management. The **General EHS Guidelines**[4] provide recommendations for managing EHS issues common to most large industrial and infrastructure activities, including those which occur during the construction phase of projects.

1.1 Environment

Potential environmental issues typically associated with hydropower projects depend heavily on the size, type, operating mode[5] and location of the project and may include management of:

- General management of environmental risks and impacts
- Watershed management aspects
- Conversion of aquatic and terrestrial habitats
- Changes in in-stream flows, including water, sediment and aquatic biota flows
- Connectivity and fish entrainment

CLIMATE CHANGE RISKS

Hydropower production will likely be affected by changes in climate. Direct and indirect climate-related adverse effects may impact a hydropower project during its life-cycle. Increased variability of precipitation as well as changes in the timing and extent of glacier and snow-cover melting are likely to have substantial impacts on hydropower production. Droughts and extended dry periods can reduce river flows, deplete reservoirs and significantly decrease hydropower output, dramatically reducing national energy supplies and leading to shortages and blackout periods. Competition for water resources, especially in areas under water stress, will further constrain hydropower water supply.

These impacts will be more severe when coupled with increased electricity demands and higher peak requirements in summers. Furthermore, more intense and frequent heavy rainfall may put greater stress on dams that were not designed to take account of future climate change and may increase their risk of failure. Facilities may be at higher risk of being flooded. Increased water sedimentation because of greater runoff may erode turbines and affect their performance.

While it is becoming more common to perform a Climate Risk Assessment when designing new hydropower projects, this is not yet a well-established practice. As this is a relatively new and evolving science, there are no methodologies widely accepted and applied that are considered as the recommended good international industry practice.

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[3] Social impacts—including physical and economic displacement, impacts on indigenous peoples, stakeholder grievances, and so on—not directly related to occupational and community health and safety are outside of the scope of this document and of the EHS Guidelines in general. However, when one or more members of the World Bank Group are involved in investments in these sector, social aspects are addressed through application of the World Bank's Environmental and Social Standards and/or IFC's Performance Standards.

[4] Available at www.ifc.org/ehsguidelines.

[5] See Annex A.

- Stream morphology and sediment management
- General pollution prevention and control and reservoir management, which covers water quality and reservoir erosion, slope stability and sedimentation

1.1.1 General Principles for Identification and Management of Environmental Risks and Impacts

The effective anticipation and avoidance, minimization or compensation/offsets of environmental risks and impacts in hydropower development depend on a number of key aspects:

- Implementation of a comprehensive screening process that involves detailed scoping of issues using participatory stakeholder approaches so that environmental assessments are targeted to address the substantive issues that are relevant and considered to be priorities in a specific context.
- Early consideration of the scale and context of the development, including the size of the hydropower development and the hydropower resources being developed, the presence of other hydropower developments upstream or downstream of the development, the conservation and human and biodiversity value of the resource being developed, national or other strategies, and plans for hydropower and energy development for river basins of concern.
- Early consideration of the potential area of influence of the project, which may extend far upstream and downstream of the project and will include the means by which electricity will be evacuated to the national grid or other users, sources of construction materials, access and site roads, laydown areas and work camps, and other ancillary facilities and operations.
- Inclusion of strategic considerations into project site selection and evaluation of project alternatives. Evaluation of project alternatives should consider relevant technical, economic, financial, environmental and social issues, risks, and opportunities, including issues of optimization and efficiency in the use of the hydrologic potential of the river system, as well as cumulative impacts.[6] Examples of site selection alternatives include:
  - Avoiding impacts to areas with high biodiversity values (such as critical habitats, International Union for the Conservation of Nature (IUCN) Protected Area Management Categories,[7] United Nations Educational, Scientific and Cultural Organization (UNESCO) Natural World Heritage sites, Key Biodiversity Areas,[8] High Conservation Value areas identified using internationally recognized standards, other areas based on systematic conservation techniques carried out by governmental bodies and other organizations), areas of high social value (such as culturally significant), areas of high aesthetic value (such as important landscapes) as well as avoiding or minimizing physical or economic displacement of population, displacement of economic activities (such as agricultural lands) and public health and safety risk, among others;[9]

[6] International Hydropower Association (IHA) 2010.

[7] Guidelines for Applying Protected Area Management Categories. IUCN. 2008.

[8] For example, these can encompass such areas as Ramsar Sites, Important Bird Areas (IBA), Important Plant Areas (IPA), and Alliance for Zero Extinction Sites (AZE).

[9] IHA 2010.

- Where technically and financially feasible, considering locations that will affect shorter or less biodiverse river reaches, and which do not require any water storage (that is, run-of-river diversion projects);[10]
- Siting of multiple hydropower projects in rivers in cascades, while preserving other rivers in the same region;[11] and
- Designing the operating regime to consider biodiversity, ecosystem services,[12] community health and safety, river bed and sediment load dynamics, and other factors.

- Assessment of potential environmental risks and impacts as early as possible in the project life cycle to effectively apply the mitigation hierarchy and maximize the range of options available to anticipate and avoid, or where avoidance is not possible, minimize, and, where residual impacts remain, compensate or offset potential negative impacts (see Annex B for examples of issues that may be considered in this process). The assessment of risks and impacts should be based on a thorough understanding of the operating principles of potentially applicable hydropower technologies, as well as the way the power plant is expected to be constructed, commissioned, and operated (see Annex A), including an assessment of alternative approaches. Baseline assessments should include seasonally representative information (such as hydrologic regimes, aquatic, or terrestrial ecology), following internationally accepted practices for the assessment of environmental impacts.[13]
- Inclusion of operational flexibility into project design, particularly where there is uncertainty associated with the extent of baseline information and potential impacts, to provide a wider range of options as part of Adaptive Resource Management (ARM) strategies. This in turn may imply the inclusion of an appropriate level of uncertainty into operational and financial modeling.

1.1.2 *Watershed Management*

Watersheds provide hydropower projects with essential ecosystem services including regulation of hydrologic regimes, regulation of stream sediment loads, and regulation of nutrient inputs into storage reservoirs. In this sense, hydropower projects directly depend on the maintenance of such services. Although often beyond the control of hydropower project operators, poor environmental management of catchment areas by third parties, such as deforestation or unsustainable agricultural practices, can compromise the operational efficacy of hydropower projects. The project should consider these aspects during its design phase and when evaluating the project site selection and alternatives.

> ". . . poor environmental management of catchment areas by third parties, such as deforestation or unsustainable agricultural practices, can compromise the operational efficacy of hydropower projects."

Hydro-project developers are recommended to address these concerns by exploring opportunities to collaborate with private and public-sector institutions, as well as catchment area landowners, in the development of watershed management programs that aim to reduce soil erosion and reservoir sedimentation rates.[14]

Potential catchment-level management strategies might include:

- Conservation measures to maintain catchment vegetation cover (including forests);
- Catchment restoration and reforestation;

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[10] The projects with the greatest environmental impacts are projects on main stems of large rivers that create large storage reservoirs that have the capacity to alter water releases downstream on daily, weekly, or monthly time scales although, even run-of-river diversion and run-of-river storage projects modify natural river flows and may have potentially significant impacts to downstream users (Ledec and Quintero, 2003). On the other hand, it must be kept in mind that hydropower schemes in upper sections of a watershed usually involve longer diversions and therefore have the potential to create long dry/low flow dewatered sections.

[11] Many nations have designated specific waterways as "working rivers" and have limited development of hydropower to these systems. This approach has the advantage of synchronizing power operations on "working rivers" and allows for the maintenance of other rivers in their natural state, "pristine rivers."

[12] Ecosystem services are the benefits that people, including businesses, derive from ecosystems. See IFC Performance Standard 6: Biodiversity Conservation and Sustainable Management of Living Natural Resources (2012), paragraph 2.

[13] Refer to Annex A for a summary of key types of hydropower projects and their principal operating principles and to Annex B for a summary of key aspects that should be covered in an environmental and social impact assessment for hydropower projects.

[14] In catchments where sediments are fine and quickly transported into rivers and streams, watershed management has the greatest likelihood of achieving measurable reductions in sediment inputs.

- Catchment terracing;
- Upstream check structures;
- Land use changes or crop substitution (such as, cattle ranching or annual crops to fruit trees or timber); and
- Measures to minimize impacts related to road construction, mining, agriculture, or other land uses.

The effectiveness of alternate watershed management measures should be quantified to identify the economically optimal option taking into account the cost of reservoir and hydropower facility maintenance.

Watersheds also provide local communities and wider populations with essential ecosystem services, including potable water, industrial water, groundwater recharge, water for religious or ceremonial purposes, recreation, dilution of sanitary and industrial discharges, and flood attenuation. It is essential to gain a detailed understanding of these services so that projects can be located, designed, and operated in such a way that they do not cause unacceptable impacts over ecosystem services.

> "Watersheds also provide local communities and wider populations with essential ecosystem services. . . ."

Recommended approaches to ensure ecosystem services are not unduly compromised include:

- Providing alternative sources of water;
- Assuring provision of adequate environmental flows (EFlows);[15]
- Modifying operating regimes to ensure timely provision of critical services;
- Watershed management measures;
- Providing fish passages/ladders and supporting fish hatcheries to ensure fishing livelihoods and fish populations are maintained; and
- Consulting with those who benefit from ecosystem services.

[15] EFlows are defined as the quantity, frequency, timing, and quality of water and sediment flows necessary to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems.

1.1.3 *Habitat Conversion*

> "Depending on the type and location of the proposed hydropower project, habitat degradation and conversion may be significant threats to aquatic and terrestrial biodiversity."

Depending on the type and location of the proposed hydropower project, habitat degradation and conversion may be significant threats to aquatic and terrestrial biodiversity. Habitat degradation and conversion may occur as a result of reservoir creation, changes in hydrologic flow regime, dewatering river reaches, interbasin transfer of water, development of access routes and transportation corridors, construction material extraction, or development of transmission line corridors. Habitat conversion may also result from temporary construction-related activities, such as storage/disposal sites, and establishment of temporary work camps and permanent structures. The most cost-effective time to consider these threats is early on during the siting and design of project as part of the project's alternative analysis.

Management approaches should consider:

- Habitat conversion in the design of reservoir size and location, in the development of the operating regime, and in all other decisions regarding design, construction, and operation;
- Environmental and social impacts in selection of transport routes, transmission line corridors, and temporary and permanent project infrastructure;
- Consultation with key stakeholders (such as government, civil society, and potentially affected communities) to understand any conflicting land or water use demands and communities' dependence on natural resources or conservation requirements that may exist in the area;
- Identification of high biodiversity values regardless of habitat type and level of disturbance;
- Existing threats to biodiversity that could be exacerbated by project-related impacts, especially through indirect impacts caused by induced access, wildlife poaching, and in-migration;
- Minimization of habitat fragmentation, especially in recognized biological corridors, caused by the creation of the reservoir, dewatered reaches, and related linear infrastructure;
- Measures to minimize or adjust the size of the reservoir based on the identified high biodiversity (for example, micro-sitting of access roads, bridges, river-crossings, and temporary work camps);
- In instances where large reservoirs are created, measures to rescue and translocate flora and fauna with significant conservation value is key, especially during reservoir filling and plant commissioning process; and
- Partnerships with internationally recognized conservation organizations (for example, to develop biodiversity monitoring and evaluation programs, design and manage offsets, and create local capacity to monitor and maintenance programs).

1.1.4 *Changes in Instream Flow*

Hydropower plants can substantially modify river ecosystems instream from the dam or diversion scheme by changing water flow (volumes and timing), water quality (such as temperature, turbidity, or chemistry), morphology of the river channel and floodplains, and hydrologic connections between upstream and downstream and between a river and its floodplains/river banks.[16]

By their nature, hydropower projects cause long-term modifications of river hydrology with varying degrees of significance depending on the type of hydropower project and river resource.[17] In some cases, the impacts of changing flow regimes can extend beyond rivers to groundwater, estuaries, and even coastal areas.[18] The more similar the downstream flow releases are to natural pre-project conditions in volume, quality, predictability, seasonality, duration, and timing,

[16] Krchnak et al. 2009.

[17] The causes of changes in river flow can also be broader than just the abstraction or storage of water and the regulation of flow by infrastructure; climate change, upstream land-use changes due to forestry, agriculture, and urbanization can also significantly affect flows.

[18] Hirji and Davis 2009.

the less damaging the potential environmental and social impacts are likely to be.[19] (See Annex C for more details on assessment and provision of EFlows and good practice guidance developed by the World Bank Group on this topic.[20])

Approaches to establishing EFlow regimes range from near-constant flows based on percentages of annual average or minimum flows to variable regimes that mimic seasonal patterns although with reduced volumes, to sophisticated data-intensive models. In general, there must be a detailed understanding of the natural and human resources at risk (that is, baseline conditions must be understood) to establish an "environmental flow" or "sanitary flow" that avoids unacceptable impacts. Many countries accept or mandate the adoption of an environmental flow based on 10 percent or some other percentage of average or minimum annual flows, although this approach is no longer considered to be good industry practice. The ultimate EFlow regime must be based on site-specific factors that take into consideration hydrologic, biologic, social, and economic factors.

Recommended measures to minimize impacts associated with changes in hydrologic regimes include the following:

- Project planning activities should include a detailed evaluation of existing flow regimes and upstream and downstream water uses in consultation with potentially affected communities. Flow regimes maintained over seasonal or and even smaller periods (for example, monthly) should be evaluated, not only annual flows. The influence of existing flow regimes on ecosystem services should also be considered. In instances where the project is planned above or below a known or potential hydropower or flow regulation facility, the operational parameters of that facility should be considered, both in terms of its effect on the proposed project and vice versa, as well as potential cumulative impacts to people and the environment.
- Establish EFlows based on a detailed, site-specific analysis of existing conditions and potential impacts during the assessment of design and operational project alternatives. As a general approach, determination of EFlows should focus on the provision of flows, including volumes, timings, and quality to achieve specific objectives. Depending

[19] Generally speaking, run-of-river or small reservoir schemes may better mimic natural river flow dynamics and, therefore, are often preferred over large hydropower plants with large reservoirs. Hydropower generation plants with large reservoirs disrupt—and typically invert—the natural stream hydrograph as they are designed to store water during the raining/wet/freshet season when the natural river flows would be greater, and therefore the downstream release tend to be less than those that would naturally occur. Conversely, during the dry or winter season when drought or low flows are naturally expected, hydropower facilities with large storage capacities continue to release water downstream, typically at higher flows than would be experienced naturally. Plants designed for peaking generation have highly variable downstream releases over much shorter time periods. Diversion schemes, whether large or small, create "dewatered" segments with reduced water in downstream reaches on a daily, seasonal, or annual basis, and introduce higher flows in river reaches below the powerhouse.

[20] IFC. 2018. Good Practice Handbook on Environmental Flows in Hydropower Projects (forthcoming).

on the use of the river upstream and downstream of the hydropower facility, these objectives could include the following:

  - Maintain instream aquatic and riparian ecosystems with the objective of achieving No Net Loss of biodiversity, where feasible, in natural habitats or net positive gains in critical habitat. Habitats would include all those affected, including terrestrial and aquatic and both upstream and downstream. There may be instances when aquatic or terrestrial offsets may be required to achieve these goals.
  - Provide ecosystem services to affected communities, including domestic and industrial water, groundwater recharge, food sources for fish and invertebrates, water for recreation or religious or ceremonial purposes, opportunities for harvesting fuelwood, grazing, cropping on riverine corridors and floodplains, irrigation, flood protection, navigation and transportation, dilution of sanitary and industrial discharges, and purification via removal of wastes through biogeochemical processes.[21]
  - Manage safety risks that may be caused by rapid changes in flow levels (that is, potential risk of drowning for people who use the river for recreation, fishing, washing, sand/gravel, mining, navigation/transportation, or for other purposes).

- Develop and implement procedures to address potential downstream impacts related to community safety, erosion, water quality, habitat suitability, temperature, or fish stranding because of short-term changes to downstream flow patterns from commissioning flow tests[22] and from peaking discharge patterns.
- Develop and implement adaptive resource management (ARM) strategies to optimize system performance by monitoring to verify predicted project impacts and modifying operations as needed to avoid unacceptable impacts.[23]

Regulated flows downstream of dams and within diversions may affect instream and bankside habitat availability and suitability due to alteration of aquatic habitat and biological composition, biological community assemblages, and associated biodiversity. Habitat inside channels and river deltas suitable for spawning and rearing may be substantially decreased when flows are reduced or regulated. For rivers dammed above large deltas, the total freshwater area in the delta can decline considerably, eliminating productive aquatic habitats that are essential for the maintenance of the riverine and estuarine ecosystems and their productivity.

Furthermore, lower flow can create physical barriers, increase competition that may favor invasive species, and generally create drought-like conditions that conc entrate aquatic biota in reduced areas and decrease resource availability.[24]

Hydropower projects may also alter downstream flow and sediment volumes, timing, predictability, and flow change rates, which, together with temperature, water clarity, and other water quality changes, can alter species composition and relative abundance, and can disrupt flow-related cues that trigger important fish life history milestones such as migration or spawning. These changes may benefit some species and have adverse effects on others. The relevance and significance of these potential impacts depend on the type of ecosystem and species occurring in the project area, and is especially important for IUCN Red-Listed, endemic, or migratory fish species. Changes in flow, and resultant potential changes in aquatic and riparian biodiversity, should be understood and accounted for in hydropower design and operation.

Recommended measures to mitigate ecological impacts caused by changes to instream flows include:

- Establish and maintain sufficient flow releases to mitigate adverse impacts and maintain productive ecosystems, based on an understanding of the natural range of flows in a river and the relationship between stream flow and all competing water uses in that river. Several internationally accepted methods are available to calculate EFlows, including hydrologic, hydraulic, habitat simulation, and holistic approaches as well as interactive approaches such as Downstream Response to Imposed Flow Transformations (DRIFT) and Instream Flow Incremental Methodology

[21] Hirji and Davis 2009.

[22] Commissioning tests may include load rejection tests, emergency shutdown and start-up procedures; turbine alterations; irregular release; full load, and load increase testing, among others.

[23] The concept of ARM needs to be incorporated into the project design to allow for the potentially needed operational flexibility. There should also be adequate provision for modifications to hydropower generation because of changes in flow regimes must also be recognized in operational and financial modeling.

[24] Anderson et al. 2006.

(IFIM; see Annex C for discussion of methodologies to determine EFlows). These and other methods can be used independently or collectively to generate instream flow recommendations, if calibrated to the site or area studied.[25, 26] Establishing flow rates based on a percentage of annual average or low hydrological flows is no longer consider good industry practice. EFlow rates should be based on site-specific characteristics of habitat, riverbed and sediment load dynamics, biodiversity, and ecosystem services at risk.

- At certain times of the year or during critical fish reproductive cycles, provide additional flows over and above minimum flow as necessary to protect or facilitate spawning, egg incubation, and migration. These fish flows often involve providing stable flows during the spawning period and then stable or increasing flows throughout the egg incubation period to prevent dewatering of eggs. In some rivers, flow releases from dams are increased during the out-migration period to facilitate transport of young anadromous or adult spawning catadromous species to the estuary or the ocean. In general, flows that follow natural patterns, even at reduced volumes, are preferred over a constant flow regime.
- Avoid rapid increases or decreases in flow rates that can adversely affect downstream ecosystems. This is particularly important during plant commissioning and in schemes which operate in peaking mode. In general, fast ramping rates can result in the stranding of fish and invertebrates or scouring of riverbeds. The use of very short-term flow reductions prior to the main reduction (conditioning flows) may help to decrease stranding rates. Sudden flow increases can result in the disruption of spawning activity and the displacement of young fish, fish eggs, and invertebrates, as well as scouring. In general, the slower the ramping rate, the lesser the impact, but appropriate site-specific rates should be developed based on local river conditions. Overall, extended ramp-up and ramp-down periods are preferred over abrupt changes.
- Consider use of re-regulating reservoirs to attenuate rapidly fluctuating flow releases from power stations and stabilize the downstream flows.
- Prepare a comprehensive water use plan that manages the extent and timing of drawdown to minimize adverse ecosystem and ecosystem services impacts without significantly compromising hydropower generation operations.
- Consider designs with base-load facilities located downstream of peaking facilities so that the reservoirs of the downstream facility re-regulate the flows from the peaking plant and provide a more stable or natural flow regime downstream, or releasing water from storage systems upstream in a coordinated fashion to dampen the effect of rapid flow releases from the powerhouse.

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[25] IUCN, 2003; Hirji and Davis, 2009; Estes and Orsborn 1986; Lewis et al. 2004, Jowett 1996; Grecco, 2005.

[26] Additional information is also available at the IUCN's Global Environmental Flows Network: https://www.iucn.org/theme/water/our-work/environmental-flows.

- In areas where ice buildup may occur, consider design and operation solutions such as development of flow release conditions that permit a quick freeze and prevent frazil and anchor ice formation.[27]
- Develop a long-term, aquatic, multi-taxa, biodiversity evaluation and monitoring program that includes the benthic, in-stream and riparian habitats. Baseline data should be collected prior to project-related impacts and monitoring should continue as part of an adaptive management program.

1.1.5 *Connectivity and Fish Entrainment*

Construction of dams or certain run-of-river water retention, diversion, and intake structures (see Annex A) may physically obstruct upstream and downstream movements of fish and other aquatic organisms, causing a loss of connectivity between upstream and downstream components of the riverine ecosystem. In addition to these man-made physical structures/barriers, reduced flows can also generate physical barriers for upstream, downstream, and within-stream lateral movements depending on the river bed and severity of the reduced flows. These can have significant negative effects on aquatic fauna that require annual or periodic in-river migrations upstream or downstream past the dam to habitats that are essential for the maintenance of the species or stock. Lower or altered flows can also impair within-stream lateral connectivity between deeper and shallower areas of the river bed and river banks that may provide distinctive habitats that are essential for foraging, breeding, cover, resting, or hiding places for different mammals, fish, amphibians, reptiles, and invertebrates and may also provide core habitat for plant species.

> "Construction of dams or certain run-of-river water retention, diversion, and intake structures (see Annex A) may physically obstruct upstream and downstream movements of fish and other aquatic organisms. . ."

In some cases, recreationally or commercially desirable fish species may concentrate below a dam for feeding or during attempts to migrate upstream. This situation may result in forming a tailwater fishery, but if not properly regulated, these fisheries can result in the collapse of some stocks or the extirpation of a species from the river.

Reservoir impoundments may support viable fisheries, often of species not previously found in the flowing river, or not found in sufficient numbers to support a fishery. Establishment of reservoirs will also lead to changes in species composition, and often introducing conditions favorable to nonnative species. When this could threaten populations of native species of conservation concern, monitoring programs should be used to guide development of programs to ensure No Net Loss of native species, or Net Gain, if necessary.

Entrainment of fish into hydropower facilities can adversely affect fish populations both upstream and downstream from the dam. Fish entrainment can cause high mortality rates (up to 20 percent at some facilities). Mortality rates vary among sites and are influenced by dam height, turbine type, fish species, and fish size. Deep draw-downs of storage reservoirs combined with high-flow releases may significantly reduce reservoir-based populations. The downstream migration of anadromous and catadromous fish species, such as salmon or mountain mullet, can suffer significant losses during downstream passage through turbines, particularly in river systems with multiple dams between spawning and foraging.

> "Entrainment of fish into hydropower facilities can adversely affect fish populations both upstream and downstream from the dam."

Mitigation options to reduce fish losses at hydropower facilities have been developed for some economically important and ecologically migratory

[27] ICOLD 1987; Environment Canada 1989.

species, such as salmon, sea trout, eel, and shad. Depending on the presence and type of fish species,[28] the following measures can help mitigate the obstruction to fish movements and the potential consequent destruction of natural fish stock:

- Identify migratory fish species, whether anadromous, catadromous, and potadromous, that will require passage past the dam or diversion structure to fulfill their life cycle requirements, and consider fish passage during the site selection and design stages of the project. Special attention should be paid to regionally or locally important fish stocks or IUCN Red-listed fish species whose long-term sustainability may depend on upstream or downstream passage.[29]
- Research life histories and habitat use of fish species potentially impacted by the hydropower project, particularly in tropical areas where species diversity and endemism are high, and information is limited.
- Ensure consideration of impacts of water storage (reservoir) and peaking operation on fish populations both upstream and downstream of the hydropower project in mitigation planning.
- Provide appropriate mechanisms for upstream fish passage, such as fish ladders, mechanical or hydraulic fish lifts, and trap and transport programs.[30]
- Use appropriate mechanisms for downstream fish passage, such as increased spill (provided that dissolved gas concentrations do not become excessive), bypass channel, and trap and transport programs.
- Provide appropriate fish exclusion or guidance devices for both upstream and downstream passage that will prevent entry of fish into dangerous areas and guide them into bypass facilities. Such fish screens can be a physical mesh or a behavioral screen that uses a deterrent stimulus (such as electrical barriers, strobe lights, bubble curtains, or acoustics). These techniques often divert native nonmigratory species as well, but typically have not been specifically designed to do so.[31]
- Consider use of "fish friendly" turbine technology or construction of bypass structures to reduce fish mortality and injury from passage through turbines or over spillways, especially where large-scale downstream fish migrations occur. Typically, Kaplan turbines are more "fish friendly" than Francis units[32] Several manufacturing companies are starting to offer greater diversity on design of fish friendly turbines (such as Alden turbines[33]).
- Identify species, life stage, and loss rates of fish[34] and replace losses either directly (such as hatcheries or spawning channels) or indirectly (such as fertilization or stream enhancement).
- Assess critical depths and velocity needed for upstream and downstream movements of indicator species based on fish swimming abilities to assure availability of such characteristics at key stages of the migration cycles.
- Provide lateral river-flood zone movement connectivity through the physical modification of the river bed, the creation of downstream wetlands and shallow areas, and through intentional flood or nonregular ecological flow releases.
- Ensure adequate EFlows within any low-flow segments downstream of the dam to maintain fish habitat and allow fish to access the fish passage.
- Quantify losses and predict gains in fish populations when required to demonstrate No Net Loss or Net Gains of biodiversity.[35]

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[28] Gough et al. 2012.

[29] IHA 2004.

[30] For an overview of the general types of fish passes used refer to Larinier and Marmulla, 2003.

[31] Turnpenny et al. 1998; Coutant 2001.

[32] Cook et al. 2000.

[33] A type of turbine using a runner that is designed to reduce blade strike mortality through several modifications (such as reduced number of blades, special blade leading edge geometries, or slower rotation speed than conventional turbines).

[34] See EPRI 1992 and FERC 1995 for a description of entrainment impacts and assessment techniques.

[35] For example, to comply with IFC's Performance Standard 6.

1.1.6 Stream Morphology and Sediment Management

> "The reduction in sediment transport below a dam can lead to "sediment-hungry" rivers, which can cause riverbed deepening and modification of the hyporheic exchanges (up/downwelling)."

Operation of dams and other water diversion and retention structures holds back suspended sediments and bedload that would naturally replenish downstream ecosystems. The reduction in sediment transport below a dam can lead to "sediment-hungry" rivers, which can cause riverbed deepening and modification of the hyporheic exchanges (up/downwelling),[36] potentially affecting riparian vegetation and aquatic habitat and altering hyporheic recharge into side channels, sloughs, and marshes adjacent to the river. Diversion projects can reduce the amount of sediment transported through the diverted reach which, combined with the scouring effect of water released from discharge works, can threaten the structural integrity of in-stream infrastructure, such as bridge foundations, and irrigation channel intakes.

Sediments that are transported beyond the dam and not flushed out by natural variation in stream flow can fill the interstitial spaces of gravel and cobble stream bottoms (armoring), greatly decreasing the spawning areas for many fish species and the habitat for macroinvertebrates. Rivers with distinctive seasonal flow regimes may experience significant changes in the seasonal transport of sediments, which in turn can disrupt the natural life cycles of aquatic species.

Recommended measures to mitigate the negative impacts of sediment load changes downstream of hydropower developments may include:

- Understanding and carefully considering the potential impacts of sediment load modifications on downstream aquatic habitats, riparian vegetation, civil works built on the stream bed, and stream morphology, including changes to natural seasonal cycles of sediment transport;[37]
- Avoiding or minimizing sudden disposal of large volumes of sediment from dredging, silt flushing, or similar occasional activities to remove sediment buildup in reservoirs and diversion structures which can result in the short-term transport of large volumes of sediment into the downstream river, and can adversely affect the ecosystem by smothering the river bed;[38]
- Conducting more frequent flushing or dredging of small reservoirs, de-sanders and sediment traps to prevent sudden sediment load modifications in the stream in run-of-river or small reservoir schemes;[39]
- Releasing periodic flushing flows to prevent armoring of river beds downstream from dams;[40]
- Using river training works and bank revetments to mitigate the effects of increased scour and river bed erosion (these works can involve dredging, bed vanes, spur dikes, groynes, barrages, and weirs),[41] and where possible, avoiding the need for engineered works—using them only when less intrusive methods are not feasible;
- For hydropower peaking plants, using re-regulation storages to dampen rapid daily fluctuations that can exacerbate and accelerate shoreline erosion leading to increased sediment input to the system; and
- Physically modifying sections of the downstream river channel to optimize flows and re-establish a functional relationship between the revised hydraulic regime, the river channel, and the floodplain.[42] As applicable, improve riparian cover to increase shaded river segments.

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36 United Kingdom Environment Agency (UK EA) handbook on hyporheic zone and other references on surface-groundwater interactions con be found at https://www.gov.uk/government/publications/the-hyporheic-handbook-groundwater-surface-water-interface-and-hyporheic-zone-for-environment-managers

37 Sediment transport models may be required to help predict changes in sediment transport rates.

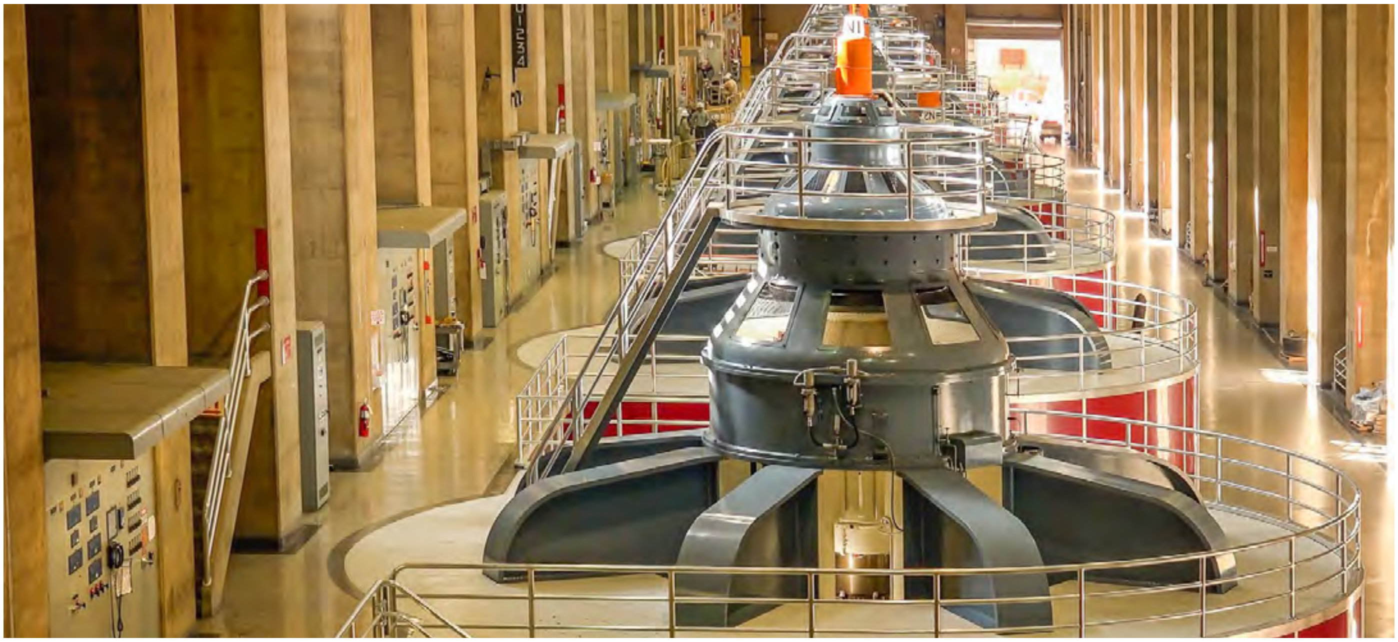
38 In some cases, the sediment may have a beneficial use for riparian habitat development, to improve marginal soils for agriculture or forestry, or for construction.

39 Smaller reservoirs and ancillary structures can also be flushed and/or dredged as often as every two weeks depending on design and natural sediment load.

40 These high-discharge events mimic small floods and scour fine sediments from the substrate and transport them downstream. These flood events can be provided at multiyear intervals, depending on the compaction rate of the riverbed and the availability of sufficient flow, and should be designed to minimize disruption of spawning and other key periods in fish life cycles. Because these minor flood events should be designed to inundate portions of the floodplain, there is a need to ensure that post-dam development within the floodplain does not preclude use of this technique. In smaller river systems, physical disturbance of the riverbed using mechanical or hydraulic "rakes" to break up the armor layer and flush out fines can be used.

41 Przedwojski et al. 1995.

42 Ibid.



Reservoir Erosion, Slope Stability, and Sedimentation

Accelerated accumulation of sediments in aquatic ecosystems can lead to changes in surface water quality and biodiversity.[43] Sedimentation within the reservoir can also decrease generating capacity. Reservoirs can flood soils that were not previously saturated, changing groundwater levels and the loads on reservoir slopes. This can cause increased sediment deposition within the reservoir, increased sediment input from denuded shoreline areas, and river-bank failures. Measures to mitigate impacts associated with erosion and sedimentation in reservoirs include the following:

- Implement a life cycle management approach to sediment management, especially in situations where hydropower facilities will be constructed on river systems with high suspended sediment loads or where high volumes of bedload transport are expected.[44] This involves siting, designing, constructing, operating, and maintaining the infrastructure in a manner that will ensure the project remains viable and sustainable over the planned operational life of the project.
- Perform reservoir bathymetry at the onset of operations, and continue to monitor it to assess significant modifications that may need to be managed to assure optimal reservoir functionality and useful life.
- Conduct surveys of soils and geologic conditions at future reservoir margins to identify erosion- and landslide-prone formations and area, and stabilization of those areas as needed to maximize slope stability and minimize erosion and landslides (this may require some adjustments to reservoir operating parameters to limit wet-dry cycles on potentially unstable slopes).
- Implement additional measures as needed to reduce sediment inputs to the reservoir, such as upstream check structures, by-pass systems, and off-channel storage.[45]
- If actions to reduce sediment from entering reservoirs are insufficient, use operational management practices to control or remove sedimentation within reservoirs, especially sediment deposition that affects either crucial structures or important habitats. Models can be used to evaluate changes in flow and water level that can influence where sediment is deposited[46] and how much sediment is transported through the reservoir.

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[43] Henley et al. 2000.

[44] Palmieri et al. 2003.

[45] Upstream check structures involve debris dams that are generally used on high-gradient mountain tributaries where coarse-grained sediments predominate, and slope failures are common. Reservoir by-pass structures are designed to divert sediment laden flood flows around the main reservoir.

[46] The selection of reservoir levels during the flood period has a direct influence on the volume of sediment deposited in the upper, middle and lower portions of the reservoir. Typically, if reservoir levels are kept high during the flood season, sediment deposition will occur in the river-reservoir interface area at the upper end of the reservoir. At low reservoir levels, sediment is transported further downstream and deposited nearer the dam in the dead storage zone.

- Give preference, if feasible, to sediment transport methods that use a more natural hydrograph pattern to manage sediment infilling. These methods typically involve passage of more natural flow volume, which also can provide beneficial effects to the aquatic ecosystem.
- For larger reservoirs, use the most common methods to manage the inflow of sediments sluicing, flushing, or density current venting:[47]
  - Sluicing involves taking advantage of heavy rains or freshet flow by operating the reservoir at a lower than normal level and passing a sufficient portion of the flood peak to maintain sediment transport capacity, thus avoiding further accumulation of sediment in the reservoir. Reservoir filling can then be achieved in the latter part of the freshet or wet season period when flows are clearer.[48]
  - Flushing is similar to sluicing but involves either a complete or partial drawdown of the reservoir water levels to recreate river-like conditions in the reservoir and mobilize deposited sediments either further downstream in the reservoir (typically the case with the partial drawdown option) or out of the reservoir (as generally occurs during a complete drawdown) via low-level gates that have been designed as part of the dam. Sluicing and flushing are often used together, but the effectiveness of both techniques depends on the availability of excess flows during the freshet or wet season (that is, sufficient flow volumes to provide a period of sediment transport with sufficient remaining flow to fill the reservoir), the types of sediment (more effective with fine than coarse sediment), and reservoir morphometry (more effective in relatively shallow, short, and narrow reservoirs).
  - Density current venting involves selective discharge of deeper, sediment-laden water. When a cold or turbid inflow encounters clear or warm surface waters of a reservoir, the inflows will often have a greater density and will descend under the surface waters. This can facilitate the down-reservoir transport of sediment, and in reservoirs where strong density currents occur, the provision of low-level gates at the dam can be used to discharge this higher density layer of elevated sediment laden water through the dam. Density current venting does not require lowering of water levels or excess flows.
- Consider mechanical removal of sediments in cases with very high sediment inflows or where flow-assisted sediment transport options in reservoirs are not feasible. These typically involve dredging, dry excavation, or hydrosuction removal.[49]
- Implement operations to address shoreline erosion in reservoirs, such as water management measures (such as ramp-down rules, constraints on time spent at particular operating levels, operating to maintain the stabilizing characteristics of existing or planted vegetation); and direct intervention techniques (such as rip-rap, bank protection works, and planting stabilizing vegetation).[50]

1.1.7 General Pollution Prevention and Control and Reservoir Management

Construction Environmental Aspects

A main issue associated with construction of hydropower projects is the physical land disturbance that typically involves the excavation of large quantities of soil and rock, and sometimes the drilling and blasting of tunnels and channels. Construction activities often entail the construction of temporary workers' camps, as well as temporary and permanent site access roads. More specific environmental aspects associated with construction activities of hydropower works may include:

- **Dust:** due to earth movement and construction materials extraction activities, as well as construction vehicle movement on unpaved access roads.
- **Noise and vibrations:** mainly associated with materials extraction activities, excavation, blasting, materials crushing, stockpiling, and construction vehicle transit.

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[47] Palmieri et al. 2003 for a detailed description of these methods.

[48] Sluicing may also be used for run-of-river reservoirs.

[49] Dredging is typically expensive and therefore, is often localized (tactical dredging). Dry excavation involves removal of sediments during periods of low reservoir levels by using earth moving equipment. Excavation and disposal costs can be high, and this method is usually used only in small impoundments or in debris dams of larger impoundments. Hydrosuction removal is a variation of traditional dredging that uses the hydraulic head of the dam for dredging. Environmental issues and the potential costs of mitigation actions related to the downstream discharge of these sediments can be high and need to be considered in the development of this option.

[50] IHA 2010.

- **Solid waste:** in volume, mainly associated with rock waste and removed topsoil-overburden, but also construction debris, as well as domestic waste from work camps.
- **Wastewater discharges:** sources may include stormwater runoff from disturbed areas, which is typically high in suspended sediments, and effluents from worker camp operations.
- **Tunneling discharges:** tunneling works generate effluents that are typically high in suspended sediments and can have pH significantly different from receiving surface water bodies (for example, tunneling discharges can be strongly basic because of alkaline soils or the use of standard cement or "shotcrete" in tunnel grouting activities; or strongly acidic because of the presence of acid generating rock, termed Acid Rock Drainage or ARD). The introduction of fine cement particles from cement grouting and shotcreting used to seal the walls of tunnels can result in extremely high pH in the tunnel effluent and receiving water body. Recommended measures to mitigate impacts caused by tunneling water discharges include:
    - Flush the tunnels at specified times of the year to avoid fish migration or spawning periods.
    - Use well-maintained compensation and sedimentation ponds and booms to control sediments from tunneling and cement management activities, and to introduce online buffering solutions when required.
    - Closely monitor pH and suspended solids of tunnel wastewater discharges, as well as in the receiving body of water 100 meters upstream and downstream of the point of discharge, and have clear procedures to halt tunnel discharges or take corrective measures (for example, pH adjustment or routing through a settling pond) if wastewater or process water discharges are out of specification.

Specific guidance applicable to prevent and control the environmental impacts associated with hydropower construction activities is available in the **General EHS Guidelines** (particularly Section 1.3 Wastewater and Ambient Water Quality and Section 4.0 Construction and Decommissioning)[51] and the **EHS Guidelines for Construction Materials Extraction.**[52]

Commissioning and Operation Environmental Aspects

The most significant and permanent environmental impacts associated with hydropower development occur during the process of commissioning and then continue during operations. Commissioning is when the project reservoirs are filled, resulting in terrestrial habitats being permanently flooded and the flooded reach of the river being converted from a free-flowing environment to a lake. This is also when impacts on downstream river flow regimes start to occur and when both terrestrial, riparian, and aquatic habitat connectivity is either blocked or impaired. More general pollution prevention and control aspects associated with commissioning and operations of hydropower may include the following.

Water Quality

Depending on their type and design characteristics, hydropower projects will have varying effects on water quality. Except for run-of-river diversion hydropower schemes, most hydropower projects include the construction of some type of reservoir, even if it is just a daily regulation pond with limited storage (see Annex A). Creation of a reservoir may alter water quality within and downstream of the reservoir compared with the undisturbed upstream river environment. Together with the changes to the hydrologic regime, changes to water quality are among the most major aspects associated with hydropower projects, potentially affecting the water reservoir and downstream. Small hydropower projects that essentially pass available flows typically have the least effects. Projects that involve the creation of large reservoirs that flood substantial areas of land and modify the free-flowing lotic ecosystem into a lentic slow flowing water body have the greatest effects.

> "Depending on their type and design characteristics, hydropower projects will have varying effects on water quality."

[51] See http://www.ifc.org/ehsguidelines

[52] Ibid.

Water quality may be changed depending on the specific characteristics and operational mode of the hydropower project, the morphology of the affected river, and the quantity and dynamics of the downstream releases. For instance, a reduced flow in a riverbed with a wide floodplain will sever habitat connectivity with the former river bank, riparian areas, and side channels, along with altering sediment transport regimes. These changes in turn can alter turbidity, water temperatures, and dissolved oxygen, as well as modifying instream and riparian habitat.

Within the reservoir, the nature and extent of water quality changes are influenced by a variety of factors: water residence time; bathymetry; climate; presence of inundated biomass; catchment geomorphic characteristics; the level of industrial, agriculture, and resource extraction activities; and how the hydropower system is operated.[53] The degree and significance of water quality changes will also be governed by the nature and use of the water in the impoundment, and downstream of the water diversion or dam structure (that is, the presence of ecologically, economically, or socially significant aquatic species, recreation, irrigation, and potable water supply, among others. This should be carefully evaluated in the impact assessment phase of the project based on the collection of seasonally representative baseline data.

Water Temperature

Water temperature is a key determinant of aquatic habitat productivity and can be instrumental in providing migration cues for some aquatic species. Reservoirs may affect water temperature by increasing the surface area of the water body, which alters the heating and cooling rate of the surface waters. Larger, deeper reservoirs with longer water retention times may result in thermal stratification, with warmer waters near the surface (epilimnion) and cooler water at depth (hypolimnion) in the summer. Dams with deep water (hypolimnetic) outlets produce colder water temperatures in the downstream river than would have occurred naturally. Conversely, near-surface withdrawals can result in warmer downstream conditions. Therefore, the type of reservoir created, the type of dam outlet structures, and the operating parameters may substantially alter the downstream temperature regime and affect fish and other aquatic organisms.

Temperature changes can also occur in smaller reservoirs in tropical areas, in reservoirs with large surface areas but shallow depths, or in instances where several smaller reservoirs are present in series on a river system.

In diversion schemes, downstream temperature changes can be very significant in the dewatered river reach between the water diversion scheme and the tailrace, especially when this river reach is subject to minimum flow release.

Special attention should be given to the potential abrupt daily changes in temperature associated with facilities that operate for daily or periodic peak generation. These systems can prevent the reservoir and downstream receiving environment from ever reaching a steady-state.[54]

[53] ICOLD 1994.

[54] Anderson et al. 2006.

Recommended measures to mitigate adverse impacts caused by changes in the natural river temperature include the following:

- Consider sites that allow smaller reservoirs with short water retention times and relatively shallow depths, as they allow mixing and remain isothermal (similar temperature at surface and at depth). Such reservoirs typically experience minor changes in water temperature relative to inflows or in comparison to pre-project conditions in the downstream system.
- Avoid, as much as possible, long dewatered sections of the downstream waterbody that will be subjected to low flows. This can be achieved through such measures as reducing the distance between the diversion and the powerhouse and siting the project so the diversion section receives input from perennial tributaries.
- Include dam design options to mitigate predicted temperature changes for storage reservoirs, such as multi-level withdrawal structures (to allow withdrawal of water from selected volumes depths and mixing of these waters to produce a target temperature for downstream releases), temperature curtains (structures deployed within the reservoir near the dam to reduce the withdrawal of surface waters), or submerged weirs (to reduce the withdrawal of cooler water at depth).
- Use air injection/diffusers or mechanical systems that move water vertically and mix bottom and surface waters to minimize temperature stratification (this is, generally practical only in smaller reservoirs).
- Optimize operating parameters to maintain acceptable water temperatures in the reservoir and in downstream habitats.[55]

Dissolved Oxygen[56]

Reduction in dissolved oxygen (DO) levels of aquatic habitats can negatively impact overall aquatic habitat composition and productivity in the reservoir and downstream. The creation of reservoirs may negatively affect natural stream DO by reducing the transport rate of water and the degree of mixing between bottom and surface waters and by microbial decomposition of flooded vegetation and other organic matter that may accumulate in the bottom of the reservoir, consuming available oxygen.[57] Additionally, the continued decomposition of flooded biomass under anaerobic conditions may result in the generation and emission of methane and other toxic and corrosive gases, such as hydrogen sulfide (H_2S). This situation can produce foul odors and poor water taste and adversely affect people and aquatic and terrestrial flora and fauna.

> "Reduction in dissolved oxygen (DO) levels of aquatic habitats can negatively impact overall aquatic habitat composition and productivity in the reservoir and downstream."

Recommended measures to maintain adequate DO concentrations in the reservoir include:

- Designing the project to minimize the area and vegetative biomass to be flooded through siting selection and other project design modifications that reduce the reservoir footprint;
- Removing readily decomposable vegetation from the proposed impoundment area through a combination of one or more of the following practices:
  - Harvesting of merchantable standing timber and removal of logging by-products
  - Controlled burning of herbaceous vegetation in the hypolimnion
- Timing the clearing of vegetation and reservoir flooding to prevent the establishment of secondary growth vegetation in cleared areas potentially leading to a greater proportion of flooded biomass than was originally present; and
- Implementing a long-term debris management program for reservoirs that receive substantial inputs of organic debris from forested upstream catchments (see waste management section in the following pages).

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[55] A model-based decision support system can be used to predict temperature and incorporate temperature objectives into daily operations.

[56] Although dissolved oxygen issues are mainly associated with the creation of storage or run-of-river reservoirs, because of temperature changes they may also occur in the "dewatered" segment of run-of-river diversion schemes depending on the riverbed morphology of the segment of the river subject to reduced flow releases.

[57] Both flooded soils and vegetation can release significant quantities of oxygen-consuming materials and plant nutrients (Gunnison et al 1984).

The following are recommendations for storage reservoirs:

- Use mechanical methods to mix surface and bottom layers.
- Aerate the hypolimnion during or after initial reservoir filling (typically only feasible in smaller reservoirs).
- In shallow reservoirs, use baffles to direct circulation and ensure adequate water flow-through and mixing.
- Minimize the development of anoxic zones in the reservoir through reservoir operating strategies that limit the development of anoxic zones in the reservoir and the release of these waters into the downstream river environment (such as reducing the residence time for hypolimnetic waters by operation of sluice gates), especially where clearing of biomass is incomplete.[58]
- Use penstock air injection or diffusion systems to aerate the water before it passes through the turbine, including installation of surface pumps near the dam intakes that pump oxygenated surface waters down to depths where it can be drawn into the penstock.
- Operate the sluice or spillway to add surface flows with higher dissolved oxygen levels and add oxygen through entrainment of air bubbles. Spill volumes should be sufficient to achieve target levels of dissolved oxygen while avoiding total dissolved gas supersaturation (see Total Dissolved Gases, below).
- Use selective water withdrawal structures to modify the temperature of outflow and allow mixing of waters with low and high dissolved oxygen.
- Use turbine venting to re-aerate the water released downstream. This can be accomplished at some sites by supplying air to openings in the turbine where the pressure is subatmospheric (turbine venting, auto-venting turbines), and at other sites by application of blowers or compressors (forced air systems).[59]
- Aerate the outflows using submerged tailrace diffusers, surface aerators, side stream aerators, or aerating weirs.

Total Dissolved Gases (TDG)[60]

Elevated total gas pressure (TGP) may result from discharge over dam spillways, entraining air bubbles into the plunge pool where the higher hydrostatic pressure of the water forces the bubbles into solution causing supersaturation (that is, more than 100 percent saturation) of gases. Elevated dissolved gas levels can also occasionally result from air entrained during water releases from low-level dam outlets or from turbines that are operated in synchronous condense mode (free-spinning turbines to provide reactive power for voltage support to a transmission system). High levels of TGP can produce gas bubble trauma, a condition in fish caused by the formation of nitrogen bubbles in the vascular system.[61] In addition to siting and design considerations, recommended measures to prevent excessive TGP include the following:

- Use low-level dam outlets to pass excess water.
- Use spillway structures that direct flows horizontally and eliminate bubbles being carried to depth.
- Use spillway gates to produce the lowest levels of dissolved gas.
- Avoid operation of generators in synchronous condense mode.

Salinity

Dissolved salts can enter a reservoir via river or stream inflows, groundwater, or surface runoff. The geology of the drained soils mainly determines salinity in reservoirs and salinity tends to become a problem in lowland reservoirs, largely because of inputs from returned irrigation water.

[58] Mathematical water quality models can be used to assist in development of reservoir operating strategies.

[59] This technique is a passive system, often requiring only valves and piping to implement, and installation and maintenance costs are relatively small compared to other alternatives. Disadvantages of this system include (i) absorption of nitrogen from aspirated air bubbles may cause gas supersaturation and adversely affect fish downstream (see Total Dissolved Gases), and (ii) venting may reduce generating efficiency and capacity.

[60] Total dissolved gas (TDG) is a measure of the percent of atmospheric gases that are in solution within the water column and is often expressed as total gas pressure (TGP).

[61] Fidler and Miller 1997.

In addition to siting and design considerations, the following recommended measures can prevent and control buildup of salinity:

- Minimize evaporative losses during water storage, which may be significant for reservoirs with a large surface area to depth ratio,[62] for example by holding water in deeper upstream reservoirs during periods of high evaporation rates.
- Use first-flush releases, whereby most of the water containing the highest salt concentrations (typically in the onset of the rainy season) is passed through the reservoir.
- Minimize saline intrusion, for example, by extracting saline groundwater before it flows into the reservoir.
- Limit addition of salts during domestic and industrial use of water in the catchment area.
- Promote use of irrigation systems and practices that reduce water use and leaching of salts from soil.
- Divert saline irrigation flows away from streams.

Contaminants

The extent to which a reservoir or downstream reaches become contaminated by nuisance or toxic substances depends upon many factors, including the type and extent of soils flooded, inputs from the surrounding area (particularly in developed areas), differences in adsorption, absorption, and desorption of substances associated with the substrate and their transport and deposition through sediments,[63] and the potential presence of un-remediated contaminated sites or other sources of pollutants prior to or during flooding and operations.[64] In the reservoir, anaerobic conditions can liberate contaminants, such as sulfides, selenium, ferrous and manganese ions, and organic mercury from the sediments. These substances can be toxic to aquatic life and water fowl, and may be of concern when the dilution capacity of the reservoir[65] is not sufficient to limit the direct and indirect exposure pathways and consequent detrimental effects of these and other pollutants on aquatic and riparian ecosystems. Lower volumes typical of dewater river reaches can often result in increased concentration of contaminants, especially if they are subjected to uncontrolled wastewater discharges.

Mercury may bioaccumulate in the reservoir food chain, particularly if biomethylation occurs. In reservoirs located in temperate zones, the accumulation of mercury in fish is often highest following the creation of the reservoir, when the highest levels of accumulated mercury in the soils and flooded vegetation are released. The release of mercury in reservoirs located in temperate regions tends to be exacerbated because of raising and lowering of the reservoir during the winter, which results in the weight of the ice squeezing the flooded vegetation or soil, particularly peat. Mercury levels typically decline to natural levels after the reservoir has aged for 10 to 30 years.[66] In general, mitigation of contaminants and their effects can be achieved by minimizing or eliminating the source of the substance or changing the reservoir conditions to favor less toxic or less mobile forms of the substance. Recommended measures to minimize contaminant concentrations in reservoirs include the following:

- Identify potentially significant point and nonpoint sources of natural and anthropogenic contaminants within the reservoir basin full pool, adjacent areas of the catchment basin, and in the dewatered reaches through a land-use inventory program.[67]
- Implement remedial actions to prevent or minimize the release of identified contaminants into the aquatic environment.

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[62] Hydroelectric generation can be a significant water consumer through evaporation and more than climate the key factor is the area flooded per unit of installed capacity. Mekonnen & Hoekstra (2011) at (http://www.waterfootprint.org/Reports/Mekonnen-Hoekstra-2012-WaterFootprint-Hydroelectricity.pdf) and Mekonnen, M.M. and Hoekstra, A.Y. (2011) The water footprint of electricity from hydropower, Value of Water Research Report Series No.51, UNESCO-IHE at http://waterfootprint.org/media/downloads/Report51-WaterFootprintHydropower_1.pdf.

[63] ICOLD 1994.

[64] Additional contaminant point sources that may contribute contaminants during or following reservoir flooding include abandoned mining operations, industrial sites, settlements, or their associated infrastructure. Nonpoint sources can include flooded agricultural lands that have been sprayed with pesticides or herbicides.

[65] Depends on the contaminant loads and physicochemical characteristics, and volume and water residence of the reservoir.

[66] Lucotte et al. 1999.

[67] Examples of activities to be identified in this survey include contaminated industrial sites, old mine shafts or pits and tailings deposits from abandoned mine excavations or ore processing, landfills, and sewage collection, transport, and treatment systems or other facilities that may become flooded by creation of the reservoir or may discharge wastewater along the dewatered reaches of the river.

- To avoid contaminant bleaching or squeezing from flooded vegetation or soil, when contamination is suspected or known, consider removing contaminated layer of soil and clearing vegetation to the extent feasible prior to filling of the reservoir.
- Implement methods to prevent stratification of the reservoir to avoid anoxic conditions (see the section on dissolved oxygen above).

Nutrients and Minerals

The main sources of nutrients and minerals in a reservoir and downstream reaches derive from river and stream inflows with loadings that originate from natural and anthropogenic sources, such as human settlements along the reservoir margins and the downstream floodplain, with potentially increased inputs of agricultural, industrial, and domestic waste.[68]

The initial flooding of a reservoir often results in a substantial, but temporary, increase in aquatic productivity because of the decomposition of flooded biomass that releases nutrients (primarily phosphorous and nitrogen) and minerals. In systems with low productivity, this often results in the formation of productive fisheries within a few years of reservoir formation. However, these fisheries typically decline or collapse completely after a few years as the nutrients released from the vegetation naturally decrease as they lack sufficient sources of replenishment, among other factors. In systems with higher initial productivity, this initial surge in productivity can result in the proliferation of vascular plants or algae, taste and odor problems, and the depletion of dissolved oxygen.[69] Recommended measures to mitigate adverse impacts caused by excessive nutrients and minerals include the following:

- Use limnological models in the planning stage to predict the nutrient transport and uptake cycles within a proposed reservoir to identify whether the impoundment will tend toward eutrophic or oligotrophic conditions.
- Minimize eutrophication by, for example, watershed management practices that reduce inputs from soil transport (erosion) or runoff, reservoir flushing, chemical immobilization of sediment phosphorus, and food web manipulation.[70]
- Adopt operational methods, such as increased flow-through rates, diffused air systems, surface aeration, paddlewheels, hypolimnetic aerators, or propeller-aspirator aerators, which help reverse eutrophication and prevent algal blooms by duplicating the natural turnover of a water supply.
- Control nuisance growths of invasive algae and aquatic macrophytes to the extent necessary as part of an overall management strategy that minimizes adverse impacts on the environment and aquatic habitat. Control options include the following:
    - Physical barriers to prevent passage and spread of invasive species.
    - Mechanical removal, such as hand pulling, cutting and harvesting, rototilling, and hydro-raking.[71]
    - Dredging to physically remove sediment and associated plants.
    - Reservoir drawdowns during periods that will kill exposed algae and macrophytes.
    - Introduction of sterile or noninvasive herbivorous fish species.
    - Application of herbicides, based on an integrated pest management approach.[72]

Turbidity

The clarity or transparency of water governs light penetration and, accordingly, the extent of the productive photic zone where most of the primary productivity occurs. Typically, the reduction in water flow caused by river impoundment results in reduced turbidity and thus an increase in water clarity in both the reservoir and downstream river. This change

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[68] ICOLD 1994.

[69] This is generally a greater problem in small, shallow reservoirs and in warmer climates, and in severe cases can result in an acceleration of the eutrophication process. In tropical areas, high water temperatures (greater than 35° C) and thermal energy inputs can result in eutrophication in a very short time, even with low nutrient loading (ICOLD 1994).

[70] Carpenter 2005.

[71] Nonchemical methods of algae control include application of barley straw to the reservoir to control algae growth; fungal decomposition of the straw results in exudates with algistatic properties.

[72] Algaecides can be used to rapidly clear a water body when implemented as part of an overall management system, recognizing that the effects are only temporary, and some algae can become resistant to herbicides if they are used too often.

in water clarity can benefit visual predators; however, species adapted to turbid waters may be adversely affected to the point where they become endangered or extirpated. Conversely, there are also cases where large quantities of very fine suspended particles either enter the reservoir during high flow periods or are re-suspended during reservoir filling. This can affect reservoir and river productivity by limiting light penetration and reducing photosynthetic activity and fish feeding success. Measures to mitigate undesired increases or decreases in water turbidity include the following:

- Reduce reservoir water levels during the rainy or freshet period to allow the initial pulse of first rains or freshet to pass through the reservoir and thereby increase turbidity and nutrient transfer to the downstream river. Increases in reservoir turbidity and downstream transport of sediments in other seasons can be achieved through reductions in reservoir levels and exposure of deposited sediments on the dewatered shoreline to rain and runoff or wave action.
- Use selective withdrawal structures to selectively discharge water of desired turbidity. In instances of undesired increases in reservoir turbidity, the turbid water is often retained in the reservoir as a discreet horizontal layer.[73]
- Alter the rate of reservoir filling, particularly if annual filling of the reservoir creates levels of turbidity above natural levels.
- Install baffles to inhibit wind-induced re-suspension of sediments in shallow reservoirs.

Emissions

Reservoirs, such as natural lakes, emit greenhouse gases because of biochemical processes that take place in organic-rich sediments or the decomposition of vegetation, as well as other organic matter inflows from the catchment basin.[74] Under anoxic hypolimnetic conditions, methane may be produced by the decomposition of impounded organic material in reservoirs and can be emitted through various pathways that mainly include diffusive and bubbling emissions from the reservoir surface and degassing in hydropower dam tailrace and diffusive flux downstream of the dam.[75] The extent and rates of methane generation and emissions from reservoirs are the subject of significant scientific debate, ongoing research, and criticism.[76, 77, 78] Significant progress has been made in the development of qualitative predictive tools to estimate potential greenhouse gas (GHG) emissions from planned reservoirs as well as development of direct reservoir GHG emissions measurement methodologies.[79] However, it is widely accepted that early calculations stating that up to 7 percent of global GHG emission came from reservoirs seem now to reflect a gross overestimation. More recent scientific evidence indicates that this contribution is probably less than 1 percent.[80] Similarly, the initial assumption that methane represented a significant component of the GHG emissions generated from reservoirs is no longer accepted, as it has been determined that most of the methane resulting from anoxic bottom organic matter decomposition is re-oxidized to carbon dioxide as it reaches the reservoir surface.[81] Significant methane contribution will only occur when dealing with anoxic reservoirs, which does not happen often and would imply other and more pressing reservoir management issues (such as water quality or fish kills). Recommended measures to minimize generation and release of methane and other greenhouse gas emissions include the following:

- Site reservoirs in areas with low vegetative biomass taking into consideration site-specific potential for biomass decomposition.[82]
- Set up watershed management measures to reduce contribution of organic matter from the catchment area.

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[73] ICOLD 1981.

[74] World Commission on Dams 2000.

[75] UNESCO, IHA, 2008.

[76] For examples of diverging views see Rosa et al., 2004; Rosa et al., 2006; Fernside, 2004; and Fernside, 2006.

[77] UNESCO, IHA, 2009.

[78] International Rivers Network 2006.

[79] Greenhouse Gases from Reservoirs caused by Biochemical Processes, Interim Guidance Note for the World Bank, 2013. This Interim Guidance Note provides a useful screening logical framework to help EIA practitioners determine when GHG emissions from reservoirs could represent a significant impact.

[80] World Bank 2013.

[81] Ibid.

[82] The United Nations Framework Convention on Climate Change (UNFCCC) Clean Development Mechanism (CDM) Board does not consider hydroelectric power projects with a power density of less than 4 Watts (W) per square meter (m^2) of reservoir surface to be eligible as CDM project activities. This criterion effectively excludes projects with storage reservoirs from the CDM. An exception to this is hydroelectricity power project reservoirs where it can be demonstrated that the greenhouse gas (GHG) emissions from the reservoir are negligible (UNFCCC, 2007). The World Bank has presented a revised methodology to the UNFCCC applicable to projects with power density less than 4 W/m^2 that can demonstrate negligible GHG emissions through direct measurement (World Bank 2010).

- As feasible, clear readily decomposable vegetative matter prior to flooding (see section on dissolved oxygen above).
- Avoid anoxic hypolimentic conditions.

Waste Management

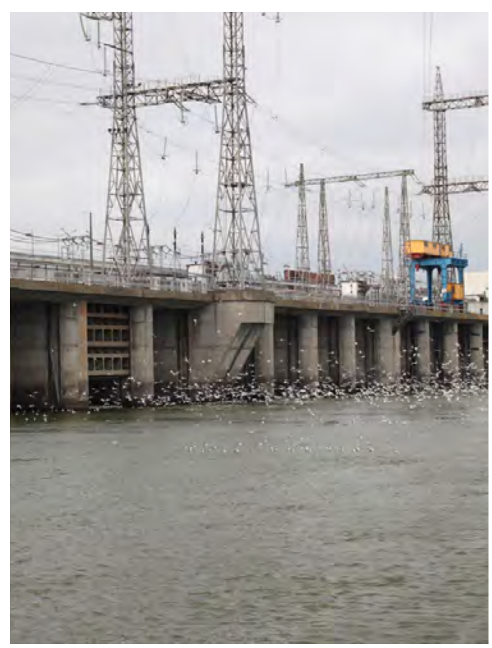
During operation of hydropower projects, hazardous wastes may include turbine and transformer oil, and maintenance materials or chemicals (such as paints, solvents, and abrasives for sand blasting). Nonhazardous wastes may include office waste, packing materials, and domestic waste from workers and work camps.

In some cases, the operation of hydropower power plants may also generate significant amounts of solid waste from floating debris removed through screens in the water intake structures. Debris may consist primarily of woody materials such as tree trunks, branches, and leaves, as well as plastic containers or other solid wastes in river systems located downstream of urban areas.

In addition to guidance pertaining to hazardous and nonhazardous wastes, as well as hazardous materials management described in the **General EHS Guidelines,** additional considerations warrant emphasis relative to hydropower dam sites. Given that wastes generated at hydropower dam sites are in or near water bodies, a key objective should be to prevent waste releases (either solid, liquid, or leachate) to the surrounding environment, especially surface water and groundwater. Recommended measures to minimize and manage wastes at hydropower projects include the following:

- Preferably remove nonearthen wastes from the site for treatment and disposal at an off-site facility operating in accordance with applicable national and local requirements and internationally recognized standards. Organic wastes removed from intake structure screens should be composted, while inorganic wastes should be either recycled or managed at an on-site or off-site waste treatment or disposal facility.
- Where off-site removal is impractical, the location, design, and operation of the on-site waste treatment, storage, or disposal facility should be in accordance with applicable national and local requirements and the **EHS Guidelines for Waste Management Facilities.**
- Explore opportunities to work with upstream communities (such as through awareness campaigns) and relevant government agencies to improve waste management practices and minimize discharges into the river system.

1.2 Occupational Health and Safety



Occupational health and safety (OHS) risks and mitigation measures during construction, commissioning, operation, and decommissioning of hydropower plants are, in some cases, similar to those at other large industrial and infrastructure activities and are addressed in Section 2.0 of the **General EHS Guidelines.** In addition, the following health and safety impacts are of particular concern during construction and operation of hydropower projects:

- Construction OHS aspects:
  - Tunneling
  - Use of explosives
  - Traffic safety
- Snow avalanche management
- Non-ionizing radiation
- Noise
- Confined spaces and working at height
- Electrical hazards

1.2.1 *Construction OHS Aspects*

The most significant occupational health and safety hazards in hydropower projects often occur during the construction phase and include aspects such as physical hazards from over-exertion, slips and falls, work at height, moving machinery, dust, and confined spaces and excavations. These hazards are common to many civil construction activities and are covered in detail in the **General EHS Guidelines** (Section 4.0 Construction and Decommissioning[83]). The following additional construction hazards and mitigation measures are more specific to hydropower project construction.

> "The most significant occupational health and safety hazards in hydropower projects often occur during the construction phase."

Tunneling

Construction of certain run-of-river water retention, diversion, and intake structures may include tunnels and other underground works with potentially significant risks to life and safety because of rock falls or tunnel collapse, poor air quality, and poor lighting, among others. Many of these hazards are covered in detail in Section 1.2 of the **EHS Guidelines for Mining**.[84]

As a general safety rule, a tagging system should be implemented to account for all persons traveling into the tunneling works. Additional recommended mitigation measures for tunneling related hazards include the following:

Geotechnical Safety

- Planning, designing, and implementing tunneling activities should be based on an accurate assessment of the geology of the area, selecting rock support methodologies in accordance with the risks of rock collapse. Rock types or segments where potential collapse is present (that is, fractured rock) typically require the use of rock bolts, shotcrete, and other rock stabilization methods. Highly fractured rock generally needs the use of complete segment rings installed by tunnel boring machines. Additional levels of safety should be applied in active seismic areas and those potentially exposed to extreme climatic events. Systematic monitoring and regular review of geotechnical stability data should be carried out.
- Accurate assessment of worksite safety from rockfall or landslide should be conducted. Particular attention should be given after heavy rainfall, seismic events, and after blasting activities. Risks should be minimized by appropriate bench and pit slope design, blast pattern design, rock scaling, protective berms, and minimizing traffic.

Ventilation

- Ventilation and air cooling systems should be appropriate for the workplace activities and be able to maintain work area temperatures and concentrations of contaminants at safe levels. Ventilation operators and maintenance personnel should undergo adequate training with respect to such issues as explosive atmospheres, products of combustion, dust, and diesel fumes.
- Tunneling works should ensure a safe and clean source of air for all areas expected to be occupied by workers. Recommended management strategies include the following:
  - Ensure surface ventilation units and associated auxiliary equipment are located and managed to eliminate hazards that could jeopardize ventilation equipment performance or ventilation air quality (for example, emissions sources and inflammable or explosive materials should not be stored near air intakes).
  - Operate auxiliary fans to avoid the uncontrolled recirculation of air.
  - Remove all persons from the tunnel, if the main ventilation system is stopped other than for a brief interruption.
  - Barricade all areas that are not being ventilated and post warning signs to prevent inadvertent entry.

[83] See http://www.ifc.org/ehsguidelines.
[84] Ibid.

- Provide personal H_2S and carbon dioxide (CO_2) detectors and response training wherever these gases may accumulate.

- As appropriate, thermal conditions should be monitored to identify when heat and cold stress could adversely affect workers, and protective measures should be implemented. Temperatures should be maintained at levels reasonable and appropriate for the activities undertaken. Other practices should include heat tolerance screening, acclimatization, water breaks, and adoption of suitable work-rest regimens.

Dust

- Over and above the risks associated with dust covered in the **General EHS Guidelines,** dust control should be fully integrated into tunneling procedures, particularly associated with blasting, drilling, and material transport and dumping. Minimization of dust is essential to improve visual clarity in an underground setting and improve workers' health.

Illumination

- Underground illumination should be adequate for the safe performance of all work functions and the safe movement of workers and equipment.
- Separate and independent emergency light sources should be provided at all places where a hazard could be caused by a failure of the normal lighting system. The system should turn on automatically, should be adequate to allow the workers to conduct an emergency shutdown of machinery, and should be tested on a regular basis.
- Underground workers should always have an approved cap lamp in their possession while underground. The peak luminance should be at least 1500 lux at 1.2 meters from the light source throughout the shift.

Use of Explosives

The use of explosives in the hydropower power sector is limited to construction activities, particularly in the development of tunneling works for water diversion and transport and in the quarrying of materials. Recommended explosives management practices include the following:

- Use, handle, and transport explosives in accordance with local and national explosives safety regulations and internationally accepted standards.[85]
- Assign certified blasters or explosives experts to conduct blasts.
- Actively manage blasting activities in terms of loading, priming, and firing explosives, drilling near explosives, misfired shots, and disposal.
- Adopt consistent blasting schedules, minimizing blast-time changes.
- Implement specific warning devices (such as horn signals and flashing lights) and procedures before each blasting activity to alert all workers and third parties in the surrounding areas (for example surrounding communities). Warning procedures may need to include traffic limitation along local roadways and railways.
- Conduct specific personnel training on explosives handling and safety management.
- Implement blasting-permit procedures for all personnel involved with explosives (handling, transport, storage, charging, blasting, and destruction of unused or surplus explosives).
- Ensure that qualified personnel check blasting sites for malfunctions and unexploded blasting agents following the blast and prior to resumption of work.
- Implement specific audited procedures for all activities related to explosives (handling, transport, storage, charging, blasting, and destruction of unused or surplus explosives) in accordance with relevant national or local regulations and internationally recognized fire and safety codes.
- Use qualified security personnel to control transport, storage, and use of explosives on site. Blasting activities may cause accidental explosions and affect surrounding populated areas. In addition to the prevention and control measures described above, the following measures are recommended to address risks to nearby communities:
  - Community awareness and emergency preparedness and response planning should be undertaken, including control of third-party access to blasting areas.
  - Vibrations[86] caused by blasting have potential community impacts. Monitoring (that is, preconstruction surveys of buildings, infrastructure, and structures, including photographic and video image recording) should be implemented to ensure that potential household damages caused by the project activities can be adequately identified and managed.
  - Blasting should be conducted according to a consistent timetable. If changes to the blasting timetable occur, nearby communities should be immediately informed of those changes.

Traffic Safety

Hydropower projects may use vehicle fleets for transport of workers and materials, most notably during the construction phase. Often, hydropower projects are in remote mountainous areas, with precarious road infrastructure; therefore, road traffic accident and fatalities are a major risk. Road traffic safety concerns and mitigation measures at hydropower projects are generally similar to those encountered at other large industrial projects and are addressed in the **General EHS Guidelines.** Additional recommended measures to minimize potential traffic safety hazards specific to hydropower projects include the following:[87]

- Coordinate and control vehicle operation from one central authority during the construction phase.
- Establish procedures and signage, and position traffic safety personnel to achieve separation of light and medium vehicles from heavy vehicles.

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[85] For transport, see UN Recommendations on the Transport of Dangerous Goods—Model Regulations. Twentieth revised edition https://www.unece.org/trans/danger/publi/unrec/rev20/20files_e.html.

[86] Ground vibration levels measured in the closest residential areas should not exceed 0.5 to 2.0 inches/second (US Bureau of Mines, RI8507).

[87] ICOLD 1992a.

- Equip light and medium vehicles with devices (for example, a pole-mounted flag) to improve their visibility to other operators.
- Require defensive driving training for all drivers, including contractors and subcontractors.
- Implement traffic safety procedures to coordinate safe transport of workers to and from the workers' camp.
- Construct and maintain roads, particularly emphasizing major slopes, to ensure slope stability and the safety of heavy vehicle operation.
- Inform affected communities about potential traffic-related safety risks and issues, such as vibration and dust. Implement specific measures to ensure pedestrian safety (that is, define crossing areas and speed limits in populated areas) and use best efforts to avoid heavy traffic during in-and-out school times or during major harvesting events or cultural or religious festivities and gatherings, as well as monitoring of potential impacts (such as, preconstruction surveys of buildings, infrastructure, and structures, including photographic and video image recording).

1.2.2 *Rock Slide and Snow Avalanche Management*

Hydropower dams located in areas that may be subject to rock slides or avalanches should consider the potential safety implication to workers. Even relatively minor rock or snow slides may present significant hazard to workers, especially during the construction phase.

Recommended measures to minimize the potential residual risk to workers from rock slides and avalanches include the following:[88]

- Consider slide risks during planning and siting of the project.
- Include awareness training in the site safety plan (such as assessment of prevailing rock slide or avalanche conditions, worker safety procedures and equipment, and worker and site management emergency preparedness).
- Restrict construction or maintenance work during seasons when avalanche hazard is present or periods when freeze-thaw cycles increase the risks of rock slides.
- Identify high risk areas and implement management activities to reduce hazards in the requisite areas.
- Implement avalanche control and construct snow barriers in strategic locations to deter wind-driven accumulations of snow (such as diminution of cornice formation), deter shifting of snow pack, and deflect or absorb the energy of shifting snow.
- Conduct rock slope stabilization using high scaling, rock bolting, trim blasting, shotcrete and mesh installations.

1.2.3 *Operation OHS Aspects*

Non-ionizing Radiation

Power plant workers may experience higher exposure to electric and magnetic fields (EMF) than the general public because of working in proximity to electric power generators, equipment, and connecting high-voltage transmission lines. Occupational EMF exposure should be prevented or minimized by preparing and implementing an EMF safety program that includes the following components:

- Identify potential exposure levels in the workplace, including surveys of exposure levels in new projects and the use of personal monitors during working activities.
- Train workers in the identification of occupational EMF levels and hazards.
- Establish and identify safety zones to differentiate between work areas with expected elevated EMF levels compared to those acceptable for public exposure and limiting access to properly trained workers.
- Implement action plans to address potential or confirmed exposure levels that exceed reference occupational exposure levels developed by international organizations such as the International Commission on Non-Ionizing Radiation

[88] ICOLD 1992a. The ICNIRP exposure guidelines for Occupational Exposure are listed in Section 2.2 of this Guideline.

Protection (ICNIRP),[89] the Institute of Electrical and Electronics Engineers (IEEE). Personal exposure monitoring equipment should be set to warn of exposure levels that are below occupational exposure reference levels (for example, 50 percent). Action plans to address occupational exposure may include limiting exposure time through work rotation, increasing the distance between the source and the worker, when feasible, or using shielding materials.

The **EHS Guidelines for Electric Power Transmission and Distribution Projects** provide additional guidance on the mitigation of non-ionizing radiation.

Noise

Noise sources in operating hydropower power facilities consist mainly of the turbines and generators, which are typically located in enclosed building structures for protection against the elements, thus significantly attenuating environmental noise. Recommendations to minimize and control occupational noise exposures are discussed in Section 2.3 of the **General EHS Guidelines.** Recommended measures include the following:

- Provide sound-insulated control rooms.
- Identify and mark high noise areas.
- Require that workers always use personal noise protective gear when working in high noise areas (typically areas with noise levels greater than 85 dBA).

Confined Spaces

Specific areas for confined space entry may include turbines and turbine wells, as well as certain parts of generator rooms (during maintenance activities). Recommended confined space entry procedures are discussed in Section 2.8 of the **General EHS Guidelines.**

Electrical Hazards

Energized equipment and power lines can pose electrical hazards for workers at hydropower power plants. Recommended measures to prevent, minimize, and control electrical hazards at hydropower power plants are discussed in Section 2.3 of the **General EHS Guidelines.**

1.3 Community Health and Safety

During plant commissioning, community health and safety are of outmost importance and may set the tone for regular operation safety culture and procedures, and relationship with the affected communities. The **General EHS Guidelines** address potential community health and safety issues and corresponding mitigation measures that are common to many large industrial and infrastructure projects. Additional community health and safety issues that may be associated with hydropower projects are described in more detail below.

- Dam safety and emergency preparedness and response
  - Emergency Planning for ordinary and extraordinary operational releases, as well as dam failure
- Reservoir slope failures
- General health issues
  - Specific vector control in water reservoirs

1.3.1 *Dam Safety and Emergency Preparedness and Response*

In hydropower projects with any type of reservoirs, dam failure (including the potential failure of coffer dams during construction) can lead to extensive downstream flooding with potentially catastrophic consequences, including loss of life and destruction of property, depending on the characteristics of land use downstream of the dam. This is especially

[89] The ICNIRP exposure guidelines for Occupational Exposure are listed in Section 2.2 of this Guideline.

relevant when dams[90] are upstream from significant number of downstream land and water users. Numerous definitions of dam size are available, each based on different criteria for evaluation.[91, 92, 93] The International Commission on Large Dams (ICOLD) World Register[94] defines large dams as those higher than 15 meters from foundation (not from ground surface), or higher than 10 meters but with more than 500 meters of crest length, or more than 1 million cubic meters storage capacity, or more than 2,000 cubic meters per second spilling capacity. Many factors can cause partial or total dam failure, including overtopping because of inadequate spillway design, debris blockage of spillways, or settlement of the dam crest. Foundation defects, including settlement and slope instability, can also lead to dam failures. Seepage can occur around hydraulic structures, such as pipes and spillways, through animal burrows, around roots of woody vegetation, and through cracks in dams, dam appurtenances, and dam foundations. Seepage can speed corrosion of reinforcing steel and promote cracks, as well as erosion in embankment dams. These problems can compromise the structural integrity of the dam. Other causes of dam failures include structural failure of the materials used in dam construction and inadequate maintenance. Dam failure can also be caused by seismic events or sudden upstream releases of water. In high mountainous regions, dams may also be threatened by glacial lake outburst floods (GLOFs), a catastrophic release of water from a glacial lake, triggered by the failure of either a moraine or ice dam, which retains the water in the glacial lake.

> "In hydropower projects with any type of reservoirs, dam failure (including the potential failure of coffer dams during construction) can lead to extensive downstream flooding with potentially catastrophic consequences. . ."

Recommended measures to prevent dam failures include the following:

- Design, operate, and maintain structures according to specifications of ICOLD and Australian National Committee on Large Dams (ANCOLD), or other internationally recognized standards based on a risk assessment strategy. Design should consider the specific risks and hazards associated with geotechnical stability or hydraulic failure and the associated risks to downstream human health and safety, economic assets, and ecosystems. Emergency plans should be commensurate with the nature of the risk, based on an assessment of potential risks and consequences of dam failure, including the following: evaluation of the wave front in case of complete dam rupture; mapping of the flooding areas; training and communication with community and government emergency management entities; and evacuation plans.
- Even though government entities in many countries monitor structural integrity and foundation migration and movement, an appropriate independent review of high risk dams[95] should be undertaken at the design and construction stages with ongoing monitoring of the physical structure during operation.[96] Where structures are located in areas that are at risk of high seismic loadings, the independent review should include a check on the maximum design earthquake assumptions and the stability of the structure.
- In the case of high risk dams and impoundments, qualified experts can base their evaluation of safety on specific risk criteria. Experts can initially refer to national regulations and methodologies. Should such regulations not be available in the country, existing well-developed methodologies promulgated by authorities in countries with

[90] Dam failure statistics show that the likelihood, frequency, and severity of dam failures is greater in smaller structures.

[91] Zankhana Shah and M. Dinesh Kumar. 2008.

[92] The definition followed by the National Inventory of Dams in the USA, is based on a dam's storage capacity: large dams have storage capacities greater than 50 acre-feet (www.coastalatlas.net).

[93] The U.S. Fish and Wild Life Service uses a combination of dam height and the maximum water storage capacity classify the size of a dam: 1) small dams are less than 40 feet high or that impound less than 1,000 acre-feet of water; 2) intermediate dams are 40 to 100 feet high or that impound 1,000 to 50,000 acre-feet; and 3) large dams are more than 100 feet high or that impound more than 50,000 acre-feet (www.fws.gov).

[94] http://www.icold-cigb.org/userfiles/files/DAMS/position_paper.pdf.

[95] High risk dams are those whose failure could result in loss of life in populated areas (because of wave front and flood peaks) or where significant loss of economic assets could occur.

[96] International Commission on Large Dams (ICOLD) available at: http://www.icold-cigb.net, and Australian National Committee on Large Dams (ANCOLD) available at: http://www.ancold.org.au/.

mature dam safety programs can be referred to and adapted as necessary to local conditions. In broad terms, risk assessment criteria can include the following aspects:

- Flood design[97]
- Simulated earthquake (maximum credible event)
- Properties of construction process and properties of construction materials
- Design philosophy
- Foundation conditions
- Height of dam and volume of materials contained
- Quality control during construction
- Management capacity of the client and operator
- Provisions for financial responsibility and closure
- Financial resources for operation and maintenance, including closure when applicable
- Population at risk downstream of the dam
- Economic value of assets at risk in case of dam failure

- Conduct risk assessment (for example, Failure Mode Effects and Criticality Analysis) to identify conceivable failures, as well as their probabilities and consequences (Quantitative Risk Assessment), in accordance with internationally accepted practices.[98] Through this disciplined approach, dam safety programs can identify the elements of the physical infrastructure and the operating procedures that need to be routinely inspected, monitored, and adjusted to achieve the acceptable levels of risk associated within the dam safety program.
- Prepare and follow a dam safety and emergency response management plan that defines the operating procedures and specifications to protect the physical health and safety of people (residents, workers, and visitors) and their socioeconomic regime, the physical environment and its ecological habitats, and the integrity of the hydropower dam and associated project components to ensure sustainable, safe optimal performance.
- Consider the potential for floods caused by outbursts from glacial lakes (GLOFs) when siting and designing hydropower projects in glacial fed rivers, taking into account anticipated evolving climatic conditions over the life of the dam and project. Where a glacial lake exists with potential to create a GLOF hazard, assess feasible options to drain the lake, divert the flows, or otherwise mitigate the risk.

Emergency Planning for Operational Ordinary and Extraordinary Releases as Well as Dam Failure

An emergency potential is assumed to exist whenever people live in an area that could be flooded by ordinary or extraordinary operational releases or by the partial or total failure of a dam. An emergency in terms of dam operation is defined as an impending or actual sudden release of water caused by failure of a dam or other water retaining structure, or the result of an impending flood condition (including flood conditions due to peaking discharges) when the dam is not in danger of failure.

Some mitigation measures include:

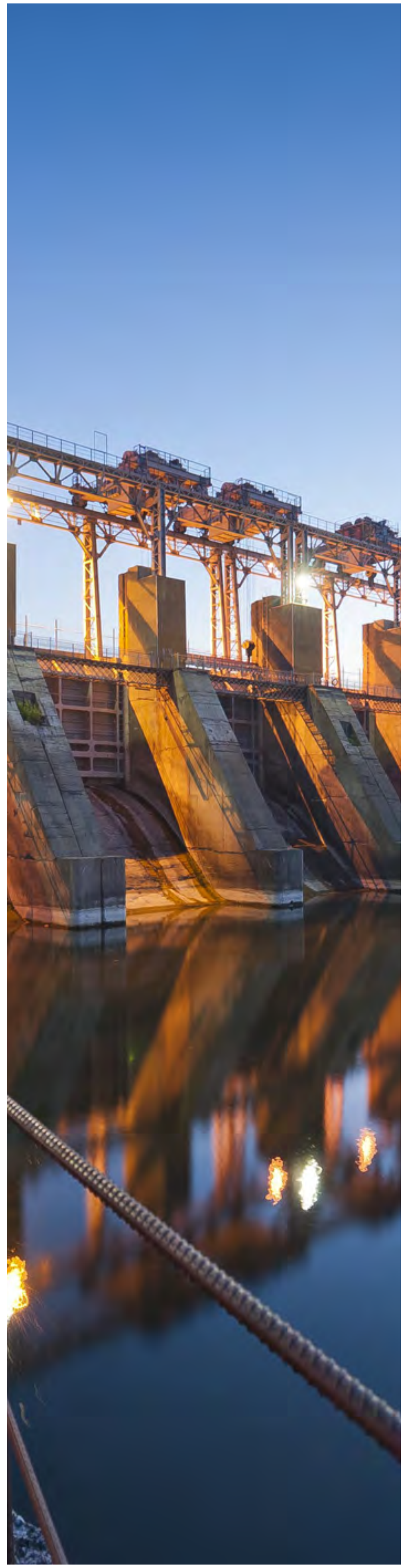
- Continuous education campaigns to sensitize community residents about the risks of drowning in the reservoir, tailrace or downstream river system. These activities involve information and periodic awareness campaigns to potentially affected communities, especially delivered at schools, community centers, and the like;
- Construction of compensation dams downstream of the tailrace; and
- Warning signs and alarm or community warning systems along the tailrace or in downstream areas subjected to sudden water level fluctuation. These alarm systems are especially relevant at the onset of peak generation.

[97] In light of the increasing concerns associated with validity and relevance of historical flow and precipitation data to appropriately account for Climate Change impact on design flows, Climate Risk Assessments are performed more and more frequently when designing new hydropower projects or rehabilitating existing ones. However, there are no methodologies widely accepted and applied that could be consider as the recommended GIIP.

[98] ICOLD 2005.

For projects with emergency potential, the dam owner (the individual dam owner or the operating organization) should prepare a dam Emergency Action Plan (EAP) to identify and define potential emergency conditions at a dam and downstream area of impact. The dam owner should specify preplanned actions that should be taken by the dam owner or others to moderate or alleviate the problems and minimize loss of life and damage to the environment and property. The EAP should be developed in conjunction with potentially affected communities and the competent authorities in charge of emergency preparedness and response, and widely communicated to all relevant stakeholders. It can vary in complexity and detail depending on the risks involved and must be tailored to site-specific conditions. In general, the EAP should contain:

- Installation of meteorological stations and development of catchment retention capacity and flood risks, linked to early warning systems;
- Notification flowchart to show who is to be notified, by whom, and in what priority;
- Emergency detection, evaluation, and classification that establish procedures for reliable and timely classification of an emergency situation to ensure appropriate action is taken based on the urgency of the situation;
- Responsibilities for EAP-related tasks that must be made during the development of the plan (the EAP must clearly specify the dam owner's responsibilities to ensure effective, timely action is taken should an emergency occur at the dam);
- Preparedness actions that are to be taken before any emergency to moderate or alleviate the effects of a dam emergency (such as an operational spillway release);
- Inundation maps to delineate areas that would be flooded as a result of a partial or total dam failure or extraordinary releases as a result of extreme climatic event (these maps greatly facilitate notification by graphically displaying flooded areas and showing travel times for wave front and flood peaks at critical locations for various dam failure or extraordinary release modes); and
- Appendices with information that supports and supplements the material used in the development and maintenance of the EAP.



1.3.2 Reservoir and Infrastructure Safety

Other hazards associated with hydropower power projects include drowning around the project (because of the new reservoirs) or downstream of the project (users of the river). A passerby could also drown because of the water discharging in from the tailrace during normal or emergency events. Other risks are associated with water diversion structures, water intake structures, and other project infrastructure (that is, surge shafts). Prevention strategies that should be evaluated in project design include:

- Education campaigns to sensitize community residents about the risks of drowning in the reservoir, tailrace, or downstream river system;
- Warning signs along the shore of the reservoir;
- Warning signs and alarm or community warning systems along the tailrace or in downstream areas subject to sudden water level fluctuations; and
- Access control (fencing) to prevent access into high risk areas.

1.3.3 Reservoir Slope Failures

Reservoir slope failures (landslides) need to be considered in the context of their cause (that is, the effect that the reservoir may have in destabilizing and increasing the risk of a slope failure in surrounding reservoir slopes), and their effect (that is, impact and consequences of landslide to the reservoir itself and on the surrounding community).[99] This consideration should extend to disposal sites for earthen material excavated during the construction process. Changes in loads on reservoir slope occur during reservoir filling and subsequently during variation in reservoir levels. Reservoir-induced instability of slopes may result from changes in mechanical properties of native slope material and elevated groundwater conditions caused by soil saturation condition because of infiltration of reservoir water. Slope failure can cause total or partial blockage of reservoir, and damage the dam by an impulse wave following slope failure. Notably, a large impulse wave overtopping a dam can cause catastrophic impacts (including loss of life) to people, communities and infrastructure situated downstream.[100] Slope failures can also affect communities and transportation routes situated near the reservoir shores.

Mitigation of reservoir slope failures is based on early identification of slope instabilities and consequent siting to avoid the risk, or implementation methods to improve stability of the slope or release the slope to reduce or eliminate the instability. Measures to identify and reduce potential slope instability in projects where impact assessment studies have identified slope instability as a potential risk include the following:[101]

- Conduct reconnaissance, geotechnical, geomorphological, and hydrogeotechnical studies to map signs of existing instability, prior to reservoir filling.
- Determine slope movement rates, slope strength, mechanical properties, and groundwater pressures, and conduct slope failure modeling.
- Establish reservoir operation and water level management height (filling and drawdown limits and rates) to foster long-term stability per slope failure model predictions (for example, larger freeboard when climatic conditions favor flooding).
- Design the reservoir water level to avoid or mitigate slope failure.
- Construct strategic drainage features to mitigate hydrological pressures (such as tunnels or shafts).

[99] ICOLD 2002.

[100] Ibid.

[101] Ibid.

- Periodically monitor hydraulic pressures and deformations (and use to validate/update slope failure model).
- Stabilize slopes by (i) modifying slope geometry for load reduction; (ii) incorporating drainage and infiltration protection (surface and subsurface drainage); (iii) installing retaining structures, and (iv) providing internal slope reinforcement (such as grouting and anchoring).
- Govern land uses to achieve acceptable risk (for example, Failure Modes Effects and Criticality Assessment and Management).

1.3.4 *General Health Issues*

The nature of some hydropower power projects during the construction phase (such as location in remote areas with long material or product supply chains) requires proactive and sustained interventions to minimize the incidence and transmission of communicable diseases, particularly those diseases associated with the influx of migrant workers.

Project housing and catering facilities and services should be designed and maintained according to internationally accepted standards. Workers' living quarters that are designed and maintained to prevent overcrowding can reduce the transmission of communicable respiratory diseases, which may transfer to local communities. Catering facilities and services that are designed, maintained, and operated according to internationally accepted Hazard Analysis Critical Control Point (HACCP) standards reduce the potential for transmission of food-related illnesses from the project to the community. Operations should also define and understand the potential effect of HIV/AIDS, and design an appropriate management response.

Specific Vector Control in Water Reservoirs

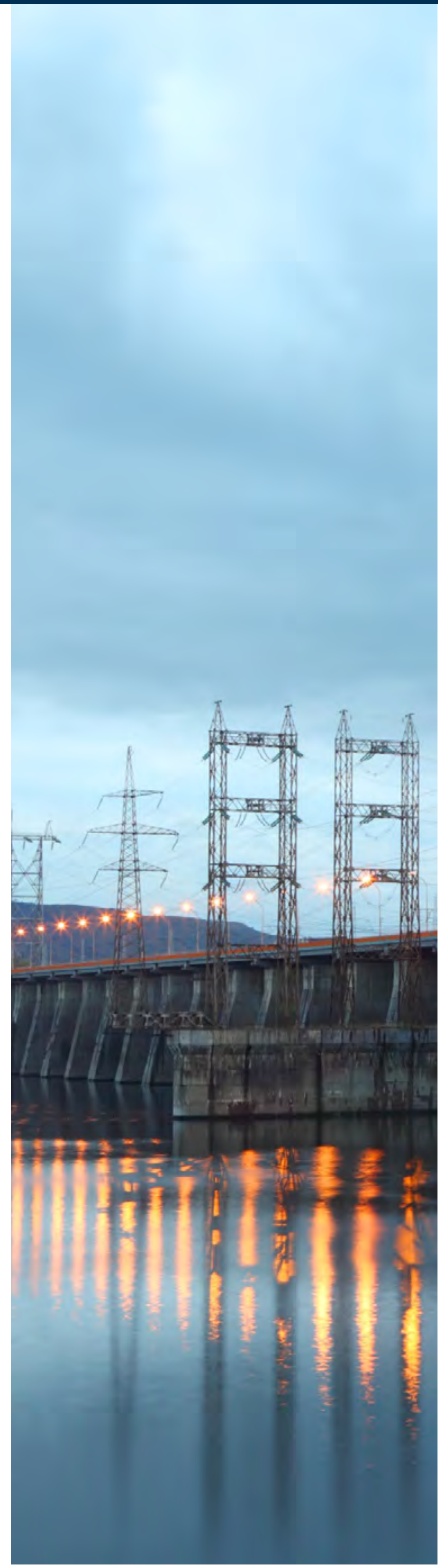
Static or slow-moving water conditions can promote disease vectors that would otherwise not thrive in faster flowing unregulated rivers (such as mosquitoes that cause malaria or snails that cause schistosomiasis). This is especially relevant in large reservoirs flooded around irregular topographies, resulting in fingering shapes and uneven reservoir perimeter. The conversion of flowing conditions to static water bodies exacerbates non vector-based diseases (for example, dysentery, cholera, and hepatitis A).[102] Regulation of natural seasonal variations in river flows can also promote vectors that thrive in moving water (such as the tsetse fly that causes trypanosomiasis). Communicable and water-borne diseases are principally of concern in tropical climates. but they should also be considered in temperate zones (for example, mosquito and avian-based spread of West Nile virus).

Project sponsors, in close collaboration with community health authorities, should implement an ongoing and integrated control strategy for mosquito and other arthropod-borne diseases that should generally involve the following:

- Implement an integrated vector control program.
- Create engineering design reviews, including careful scrutiny of roads, water storage and control facilities and surface water management strategies.
- Collaborate and exchange in-kind services with other control programs in the project area to maximize beneficial effects, particularly distribution of treated bed nets.
- Develop the "A-B-C-D" program for all project workers, where A = awareness, B = bite control, C = chemoprophylaxis for non-immune personnel, and D = diagnosis and treatment.
- Selective use of indoor residual spraying (IRS) for project housing. IRS programs are complex and involve careful design review, particularly a clear understanding of the local mosquito vectors and their pre-existing resistance to available insecticides.
- Develop an effective short and long-term monitoring and evaluation program for both workers and potentially affected communities.

[102] Ledec and Quintero 2003.

2. Performance Indicators and Monitoring



2.1 Environment

2.1.1 *Emissions and Effluent Guidelines*

As described previously in this document, water quality (including aspects such as water temperature, dissolved oxygen, total dissolved gases, contaminants, salinity, nutrients and minerals, and turbidity) should be managed on a project-specific basis according to the water quality objectives of the reservoir and the river system.

For infrastructure facilities' stormwater and sanitary wastewater management, site-specific discharge levels may be established based on the availability and conditions in the use of publicly operated sewage collection and treatment systems or, if discharged directly to surface waters, on the receiving water use classification. Further details are provided in the **General EHS Guidelines.**

Potential atmospheric emissions related to the decomposition of flooded biomass under anaerobic conditions (that is, the generation and emission of GHGs) should be managed also as previously described in this publication.

2.1.2 *Environmental Monitoring*

Environmental monitoring programs for this sector should be implemented to address all activities that have been identified to have potentially significant impacts on the environment, during construction and operational activities. Monitoring frequency should be sufficient to provide representative data for the parameter being monitored. Trained individuals should conduct the monitoring following science-based methods and record-keeping procedures and using properly calibrated and maintained equipment. Monitoring data should be analyzed and reviewed at regular intervals and compared with the operating standards so that any necessary corrective actions can be taken.

Although there is no standard monitoring program for a hydropower project, Table 1 outlines examples of environmental monitoring variables whose applicability should be established through the environmental assessment process and based on environmental management information needs the scope and frequency of which will depend on project-specific circumstances.

The **General EHS Guidelines** provide additional guidance on applicable sampling and analytical methods for emissions and effluents generated during construction or operation.

Table 1 Typical Environmental Monitoring Aspects for Hydropower Projects

Aspects	Monitoring Parameters
Construction-related Issues	• Wastewater discharges—Effluents from worker camp sanitary wastewater • Stormwater runoff—Total suspended solids (TSS) • Rock extraction/tunneling discharges—TSS; pH, acid drainage (also referred to as Acid Rock Drainage (ARD)/metals leaching). Applicability depending on results of pre-construction ARD/metals leaching testing/mapping for the presence of Potentially-Acid-Generating (PAG) materials) • Solid waste—Rock waste and topsoil storage • Biodiversity—Aquatic and terrestrial ecology surveys, vegetation reinstatement (as relevant, aquatic ecology should be assessed upstream and downstream of effluent discharges during construction) • Air quality/emissions—Particulate matter at project boundary; black smoke from construction equipment, visible dust at construction sites • Noise and vibrations at nearest receptor (include preblasting surveys of community infrastructure)
Meteorology	• Rainfall (watershed/reservoir)
Hydrology/Morphology	• Streamflow upstream and downstream (key selected points) • Water consumption (downstream) • Stored water volume (reservoirs) • Flow, velocity, and depth • Exposed/submerged substrate type
Water Quality	• Temperature upstream/downstream (all types of hydropower) • Dissolved oxygen; TSS; water clarity; phosphates/nitrates, in reservoir and downstream
Sediment Transport	• TSS (upstream and downstream); sediment transport and deposition (run-of-river and storage); stream morphology; structural risk to in-stream structures
Instream Infrastructure (bridges and others)	• Foundation integrity
Emissions	• Carbon dioxide, hydrogen sulfide, and methane in reservoir and downstream of dam (storage reservoirs)
Aquatic Ecology	• Fish and invertebrate species/population size (upstream, downstream; and in reservoirs) • Habitat preference by indicator species, considering different life-cycle stages and natural history characteristics (such as spawning, alevins, adults, foraging, breeding, or cover)
Terrestrial Ecology	• Forestation of upstream/reservoir riparian areas • Wildlife (species, distribution, numbers)
Land Use	• Vegetation cover/land use change in watershed
Community Health	• Water-based vectors
Community Safety	• Dam structural safety—Construction and post-construction surveys • Downstream population use of riparian resources

The project should explore opportunities to develop monitoring programs related to water quality, aquatic, and terrestrial biodiversity, and river uses that involve the active participation of affected communities and other relevant stakeholders.[103] This participation can provide additional validation and legitimacy to the assessment process.

To determine the significance of changes in the river hydrological regime and the adequacy of mitigation or compensation options implemented, a robust and scientifically rigorous environmental monitoring program must be designed prior to and during construction to establish an adequate baseline against which the accuracy of impact predictions can be assessed. Monitoring should continue during and after commissioning of the project until sufficient information has been obtained to verify project impacts and determine the efficacy of mitigation or compensation measures.

The monitoring protocol should include key indicator species, as well as basic fish assemblies and invertebrate, aquatic insect, and benthonic assemblies. The spatial scope of the monitoring programs should be sufficiently broad to encompass the project's entire area of influence, both upstream and downstream from the hydropower plant, including transmission lines and other ancillary facilities. The temporal scope of the monitoring program will vary by project, but at a minimum should be designed to include important seasonal biological-flow cycles. Specific and more frequent monitoring should be performed when key species, endangered species, or species expected to be particularly sensitive to the altered flow regime are involved. This is particularly important during commissioning and the first years of operation. The duration of monitoring should not be established at inception but rather should be based on achieving satisfactory conditions over an acceptable period of time.

Developers and practitioners must understand and acknowledge that the environmental consequences of hydropower development and operations cannot be predicted with complete certainty. To be ecologically sustainable, hydropower projects should develop research activities and use appropriate data analysis techniques to address predictive uncertainties and be prepared to develop further mitigation or compensation measures as may be required in the event of unforeseen effects. This program of monitoring, evaluation, and adjustment—commonly referred as Adaptive Resource Management (ARM) strategies or simply adaptive management—should be explicitly integrated into an environmental management plan (EMP).

[103] IFC 2007.

2.2 Occupational Health and Safety Performance

2.2.1 Occupational Health and Safety Guidelines

Monitoring of occupational health and safety performance should cover all workers, including those of the developer, contractors, and subcontractors. Reports of performance should provide summary data, as well as data for individual organizations.

Occupational health and safety performance should be evaluated against internationally published exposure guidelines, of which examples include the Threshold Limit Value (TLV®) occupational exposure guidelines and Biological Exposure Indices (BEIs®) published by American Conference of Governmental Industrial Hygienists (ACGIH),[104] the Pocket Guide to Chemical Hazards published by the United States National Institute for Occupational Health and Safety (NIOSH),[105] Permissible Exposure Limits (PELs) published by the Occupational Safety and Health Administration of the United States (OSHA),[106] Indicative Occupational Exposure Limit Values published by European Union member states,[107] or other similar sources.

Additional indicators specifically applicable to electric power sector activities include the ICNIRP exposure limits for occupational exposure to electric and magnetic fields, listed in the **EHS Guidelines for Electric Power Transmission and Distribution.** Additional applicable indicators such as noise, electrical hazards, air quality, or others are presented in Section 2.0 of the **General EHS Guidelines.**

[104] Available at: http://www.acgih.org/tlv-bei-guidelines/tlv-bei-introduction and http://www.acgih.org/store/

[105] Available at: http://www.cdc.gov/niosh/npg/

[106] Available at: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992

[107] Available at: https://osha.europa.eu/en/legislation/directives/commission-directive-2009-161-eu-indicative-occupational-exposure-limit-values

2.2.2 *Accident and Fatality Rates*

Projects should try to reduce the number of accidents among project workers (whether directly employed or subcontracted) to a rate of zero, especially accidents that could result in lost work time, different levels of disability, or even fatalities. Fatality rates may be benchmarked against the performance of fatalities in this sector in developed countries through consultation with published sources (for example, United States Bureau of Labor Statistics and United Kingdom Health and Safety Executive).[108] There should be a similar target of zero safety impacts on members of communities adjacent to the development.

2.2.3 *Occupational Health and Safety Monitoring*

The working environment should be monitored for occupational hazards relevant to the specific project. Accredited professionals should design and implement monitoring[109] as part of an occupational health and safety monitoring program with recognition for post-closure long-term health concerns. Facilities should also maintain a record of occupational accidents and diseases and dangerous occurrences and accidents. The General EHS Guidelines provide additional guidance on occupational health and safety monitoring programs.

[108] http://www.bls.gov/iif/ and http://www.hse.gov.uk/statistics/index.htm

[109] Accredited professionals may include Certified Industrial Hygienists, Registered Occupational Hygienists, or Certified Safety Professionals or their equivalent.

3. References and Additional Resources

American Rivers. 2002. *The Ecology of Dam Removal. A Summary of Benefits and Impacts.* 15 pp.

Anderson, E., C. Pringle, and M. Rojas. 2006. "Transforming tropical rivers: an environmental perspective on hydropower development in Costa Rica." *Aquatic Conserv: Mar. Freshw. Ecosyst.* 16: 679–693.

BC Environment. 1997. *Ambient Water Quality Criteria for Dissolved Oxygen Overview Report Prepared Pursuant to Section 2(e) of the Environment Management Act*, 1981.

———. 2004. *Instream Flow Thresholds for Fish and Fish Habitat as Guidelines for Reviewing Proposed Water Uses: Synopsis*. Prepared by BC Ministry of Water, Land, and Air Protection and BC Ministry of Sustainable Resource Management. 12 pp and 4 App.

BC Hydro. Water Use Planning web pages. https://www.bchydro.com/about/sustainability/conservation/water_use_planning.html http://www.env.gov.bc.ca/wsd/plan_protect_sustain/water_use_planning/index.html

———. 2007. *Columbia River Project Water Use Plan*. Revised for the acceptance of the Comptroller of Water Rights January 2007. 41 pp.

Beilfuss, R. and Brown, C. 2010. "Assessing environmental flow requirements and tradeoffs for the Lower Zambezi River and Delta, Mozambique." International Journal of River Basin Management, Volume 8. Issue 2: 127–138.

Bergkamp, G., M. McCartney, P. Dugan, J. McNeely, and M. Acreman. 2000. "Dams, Ecosystem Function and Environmental Restoration." WCD Thematic Review Environmental Issues II.1. Cape Town, South Africa.

Bradlow, D., A. Palmieri, and S. Salman. 2002. *Regulatory Frameworks for Dam Safety, A Comparative Study.* Washington, DC: The World Bank.

Carpenter, S.R. 2005. "Eutrophication of Aquatic Ecosystems: Biostability and Soil Phosphorus." Proc. Natl. Acad. Sci. U.S.A., 102(29): 10002–10005.

Cook, T.C., S.A. Cain, P. Fetfatsidis, G.E. Hecker, P.S. Stacy. 2000. *Final Turbine and Test Facility Design Report Alden/NERC Fish Friendly Turbine*. Prepared by Alden Research Laboratories Inc. for U.S. Department of Energy, Idaho Operations Office. 137 pp.

Coutant, C.C. 2001. "Behavioral Technology for Fish Guidance." American Fisheries Society Symposium 26. 193 pp.

Dyson, M., Bergkamp, G. and Scanlon, J., (eds). 2008. *Flow—The Essentials of Environmental Flows,* 2nd Edition. Gland, Switzerland: IUCN.

EDF. 2004. *Framework for Policy & Decision-making on Dam and Hydro Plant Rehabilitation & Upgrading*, Prepared for the World Bank Group by Electricité de France, Project TF050252.

Electric Power Research Institute (EPRI). 1992. *Fish Entrainment and Turbine Mortality Review and Guidelines*. TR-101231 Research Project 2694-01. Prepared by Stone & Webster Environmental Services.

———. 2003. *Survey of Electric and Gas Rights-of-Way Practitioners: Current Practices and Views of Future Transmission Line Siting Issues*. Palo Alto, CA: EPRI. 1009291.

Environment Canada. 1989. *New Brunswick River Ice Manual*. Prepared by the New Brunswick Committee on River Ice. Environment Canada New Brunswick, Inland Waters Directorate, Department of the Environment.

Estes, C.C, and J.F. Orsborn. 1986. "Review and Analysis of Methods for Quantifying Instream Flow Requirements." *Journal of the American Water Resources Association* 22 (3): 389–398.

FAO (Food and Agriculture Organization of the United Nations). Ecosystem: http://www.fao.org/fi/website/FIRetrieveAction.do?dom=topic&fid=13473

Federal Energy Regulatory Commission (FERC). 1995. *Preliminary Assessment of Fish Entrainment at Hydropower Projects*—volume 1 (Paper No. DPR-10). Office of Hydropower Licensing, FERC, Washington, DC.

Fernside, P.M. 2004. "Greenhouse Gas Emissions from Hydroelectric Dams: Controversies Provide a Springboard for Rethinking a Supposedly Clean Energy Source." *Climate Change,* 66: 1–8.

———. 2006. "Greenhouse Gas Emissions from Hydroelectric Dams: Reply to Rosa et.al." *Climate Change,* 75: 103–109.

Fidler, L.E., and S.B. Miller. 1997. *British Columbia water quality guidelines for the protection of aquatic biota from dissolved gas supersaturation—Summary Report*. Prepared by Aspen Applied Sciences Limited for the B.C. Ministry of Environment, Lands and Parks, Environment Canada, and Department of Fisheries and Oceans. Vancouver, B.C. 53 pp.

Goodland, R., A. Juras, and R. Pachauri. 1993. "Can Hydro-Reservoirs in Tropical Moist Forests be Environmentally Sustainable?" *Environmental conservation* Vol. 20. The Foundation for Environmental Conservation, Switzerland.

Gough, P., P. Philipsen, P.P. Schollema & H. Wanningen, 2012. From sea to source; International guidance for the restoration of fish migration highways. Regional Water Authority Hunze en Aa's Postbus 195, 9640 AD Veendam, The Netherlands.

Grecco, A. 2005. Metodologia para la determinacion de los caudales de garantia ambiental. Revista Empresas Publicas de Medellin. Medellin, Colombia. Vol. 15, No. 3: 153–179.

Gunnison, D., J.M. Brannon, R.L. Chen, I. Smith Jr., T.C. Sturgis. 1984. *Richard B. Russell Dam and Reservoir: Potential Water Quality Effects of Initial Filling and Decomposition of Vegetation*. Final Report prepared for the Army Engineering Waterways Experiment Station, Vicksburg MS Environmental Lab.

Hegmann, G., C. Cocklin, R. Creasey, S. Dupuis, A. Kennedy, L. Kingsley, W. Ross, H. Spaling and D. Stalker. 1999. *Cumulative Effects Assessment Practitioners Guide*. Prepared by the CEA Working Group for the Canadian Environmental Assessment Agency, Hull, Quebec.

Henley, W.F., Patterson, M.A., Neves, R.J., Lemly, and A. Dennis. 2000. "Effects of sedimentation and turbidity on lotic food webs: a concise review for natural resource managers." *Reviews in Fisheries Science*. 8(2): 125–139.

Hirji, R. and R. Davis. 2003. Water Resources and Environment—Technical Note C1—Environmental Flows, Concepts and Methods. Washington, DC: The World Bank. 27 pp. http://documents.worldbank.org/curated/en/828931468315285821/Environmental-flows-concepts-and-methods

———. 2009. Environmental Flows in Water Resources Policies, Plans, and Projects—Case Studies. Washington, DC: The World Bank. 181 pp. http://siteresources.worldbank.org/INTWAT/Resources/Env_Flows_Water_v2.pdf

———. 2009. Environmental Flows in Water Resources Policies, Plans, and Projects—Findings and Recommendations. Washington, DC: The World Bank. 212 pp. http://siteresources.worldbank.org/INTWAT/Resources/Env_Flows_Water_v1.pdf

ICOLD. 1981. Dam Projects and Environmental Success—Bulletin 37. International Commission on Large Dams. http://www.icold-cigb.net/

———. 1987. Dam Safety. Guidelines—Bulletin 59. International Commission on Large Dams. http://www.icold-cigb.net/

———. 1988. Dams and Environment. Case Histories—Bulletin 65. International Commission on Large Dams. http://www.icold-cigb.net/

———. 1992a. Dam Construction Sites Accident Prevention—Bulletin 80. International Commission on Large Dams. http://www.icold-cigb.net/

———. 1992b. Dams and Environment. Socio-economic Impacts—Bulletin 86. International Commission on Large Dams. http://www.icold-cigb.net/

———. 1993. Dams and Environment. Geophysical Impacts—Bulletin 90. International Commission on Large Dams. http://www.icold-cigb.net/

———. 1994. Dams and Environment. Water Quality and Climate—Bulletin 96. International Commission on Large Dams. http://www.icold-cigb.net/

———. 1997. Position Paper on Dams and Environment. International Commission on Large Dams. http://www.icold-cigb.net/

———. 2002. Reservoir Landslides: Investigation and Management—Bulletin 124. International Commission on Large Dams. http://www.icold-cigb.net/

———. 2005. Risk Assessment in Dam Safety Management—Bulletin 130. International Commission on Large Dams. http://www.icold-cigb.net/

IFC. 2007. *Stakeholder Engagement: A Good Practice Handbook for Companies Doing Business in Emerging Markets*. Washington, DC: IFC.

———. 2013. *Good Practice Note on Cumulative Impact Assessment and Management for the Private Sector in Emerging Markets*. Washington, DC: IFC. https://www.ifc.org/wps/wcm/connect/3aebf50041c11f8383ba8700caa2aa08/IFC_GoodPracticeHandbook_CumulativeImpactAssessment.pdf?MOD=AJPERES.

———. 2018. *Good Practice Handbook on Environmental Flows in Hydropower Projects*. Washington, DC: IFC.

IHA. 2004. Sustainability Guidelines. International Hydropower Association, February 2004. 24 pp. http://www.hydrosustainability.org/

———. 2010. Hydropower Sustainability Assessment Protocol. International Hydropower Association, November 2010. http://www.hydrosustainability.org/

International Rivers Network. 2006. Fizzy Science, Loosening the Hydro Industry's Grip on Reservoir Greenhouse Gas Emissions Research, International Rivers Network. 24 pp.

Jowett, I.G. 1996. "Instream Flow Methods: A Comparison of Approaches." *Regulated Rivers: Research & Management*. Volume 13, Issue 2: 115–127.

King, J. and Brown, C. 2003. "Water Resources and Environment Technical Note C.2. Environmental Flows: Case Studies." Series Editors: R. Davis and R. Hirji. Washington, DC: World Bank. 25 pp. http://documents.worldbank.org/curated/en/701971469672179365/pdf/261220NWP0REPL1e0C12010Case0Studies.pdf

Krchnak, Karin, Brian Richter, and Gregory Thomas. 2009. "Water Working Notes, No. 22." Washington, DC: World Bank.

Landworks 2005. Aesthetic Assessment and Recommendations for the Proposed VELCO Lamoille County Project Transmission Line and Substation Upgrades Docket No. 7032, VELCO Lamoille County Project Submitted to the State of Vermont, Department of Public Service, Montpelier, VT. Submitted by LandWorks, Middlebury, VT.

Larinier, M. and G. Marmulla. 2003. *Fish Passes: Types, Principles and Geographical Distribution—An Overview.* The Second International Symposium on the Management of Large Rivers for Fisheries, Phnom Penh, Cambodia. http://www.fao.org/docrep/007/ad526e/ad526e0g.htm

Ledec, G. and J.D. Quintero. 2003. *Good Dams and Bad Dams: Environmental Criteria for Site Selection of Hydroelectric Projects*. Prepared for the World Bank—Latin America and Caribbean Region; Sustainable Development Working Paper 16.

Lewis, A., T. Hatfield, B. Chilibeck, C. Roberts. 2004. *Assessment Methods for Aquatic Habitat and Instream Flow Characteristics in Support of Applications to Dam, Divert, or Extract Water from Streams in British Columbia*. Prepared for BC Ministry of Water, Land, and Air Protection and BC Ministry of Sustainable Resource Management. 59 pp plus 2 App.

Lucotte, M., R. Schetagne, N. Thérien, C. Langlois and A. Tremblay. 1999. Mercury in the biogeochemical cycle: Natural environments and hydroelectric reservoirs of northern Québec (Canada). New York: Springer. 334 pp.

Mekonnen, M. and A. Hoekstra. 2011. Value of Water. Delft, the Netherlands: UNESCO-IHE. http://waterfootprint.org/media/downloads/Report51-WaterFootprintHydropower_1.pdf.

Mekonnen, M. and A. Hoekstra. 2012. "The blue water footprint of electricity from hydropower." Hydrol. Earth Syst. Sci., 16, 179–187. http://www.waterfootprint.org/Reports/Mekonnen-Hoekstra-2012-WaterFootprint-Hydroelectricity.pdf.

National Water Quality Management Strategy. 2000. "Australian Guidelines for Water Quality Monitoring and Reporting." No.7. Australian Water Association, Artarmon, NSW.

Palmieri A., F. Shah, G. Annandale, and A. Dinar. 2003. Reservoir Conservation Volume 1 The RESCON Approach. Economic and engineering evaluation of alternative strategies for managing sedimentation in storage reservoirs. The International Bank for Reconstruction and Development. Washington, DC. 101 pp. http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2006/01/18/000160016_20060118174458/Rendered/PDF/349540v10Reservoir0conservation0RESCON.pdf

Pickett, P., H. Rueda, and M. Herold. 2004. *Total Maximum Daily Load for Total Dissolved Gas in the Mid-Columbia River and Lake Roosevelt.* Washington State Department of Ecology Publication 04-03-002. 88 pp.

Poff et al. 2009. The ecological limits of hydrologic alteration (ELOHA): a new framework for developing regional environmental flow standards. http://www.colorado.edu/geography/class_homepages/geog_4501_s10/readings/Poff%20eloha%2009.pdf

Przedwojski, B., Blazejewski, R., Pilarczyk, K.W. 1995. River Training Techniques: Fundamentals, Techniques and Applications. Balkema, The Netherlands. 686 pp. [ISBN 90-5410-196-2]

Rorslett, B. and S.W. Johansen. 1998. Remedial Measures Connected with Aquatic Macrophytes in Norwegian Regulated Rivers and Reservoirs. Norwegian Institute for Water Research in Regulated Rivers: Research and Management, Vol. 12, Issue 4–5, pp. 509–522.

Rosa, L.P.; Santos, M.A.; Matvienko, B.; Santos, E.O.; and Sikar, E. 2004. "Greenhouse Gas Emissions from Hydroelectric Reservoirs in Tropical Regions," *Climate Change* 66: 9–21.

———. 2006. "Scientific Errors in the Fernside Comments on GHG Emissions from Hydroelectric Dams and Response to His Political Claiming." *Climate Change*, 75: 498–510.

Sadler, B., I. Verocai, and F. Vanclay. 2000. Environmental and Social Impact Assessment for Large Dams. WCD Thematic Review V.2 Institutional Processes. Cape Town, South Africa.

Sale, M.J., G.F. Cada, L.H. Chang, S.W. Christensen, S.F. Railsback, J.E. Francfort, B.N. Rinehart, and G.L. Sommers. 1991. "Environmental Mitigation at Hydroelectric Projects." Volume 1. Current Practices for lnstream Now Needs, Dissolved Oxygen, and Fish Passage. DOE/ID-10360, U.S. Department of Energy, Idaho Operations Office, Idaho Falls, ID.

Schindler, E.U., D. Sebastian, and H. Andrusak. 2006. Arrow Lakes Reservoir Fertilization Experiment Summary Report—1999 to 2004. Columbia Basin Fish and Wildlife Compensation Program.

Stanley, E.H, and M.W. Doyle. 2002. "A Geomorphic Perspective on Nutrient Retention Following Dam Removal." *BioScience*. Vol. 52, No. 8: 693–708.

———. 2003. "Trading off: The Ecological Effects of Dam Removal." *Ecol Environ* 2003 1(1): 15–22. http://onlinelibrary.wiley.com/doi/10.1890/1540-9295(2003)001[0015:TOTEEO]2.0.CO;2/full

Turnpenny, A.W.H., G. Struthers, and K.P. Hanson. 1998. *A UK guide to intake fish-screening regulations, policy and best practice with particular reference to hydroelectric power schemes*. Report for the ETSU by Fawley Aquatic Research Laboratories Ltd. and Hydroplan. Report: ETSU H/06/00052/00/00. 127 pp.

UNEP Environmental Due Diligence (EDD) of Renewable Energy Projects—Guidelines for Small-Scale Hydroelectric Energy Systems. http://energy-base.org/wp-content/uploads/2013/11/EDD-Small-scale-Hydroelectric-Energy-Systems.pdf

UNESCO/IHA. 2009. Scoping paper, Assessment of the GHG Status of Freshwater Reservoirs. Working Group on Greenhouse Gas Status of Freshwater Reservoirs. http://unesdoc.unesco.org/images/0018/001831/183167e.pdf

———. 2009. Measurement Specification Guidance for Evaluating the GHG Status of Man-made Freshwater Reservoirs. UNESCO/IHA Greenhouse Gas (GHG) Research Project. http://unesdoc.unesco.org/images/0018/001831/183167e.pdf

UNFCCC. 2007. Guidance on the Eligibility of Hydroelectric Power Plants with Reservoirs as CDM Project Activities. http://cdm.unfccc.int/Reference/Guidclarif/meth/meth_guid25_v01.pdf

US Bureau of Reclamation. Erosion and Sedimentation Manual Chapter 8: Dam Decommissioning and Sediment Management. Pages 8–1 to 8–33. https://www.usbr.gov/research/projects/download_product.cfm?id=69

US EPA (United States Environmental Protection Agency). 1986. Quality Criteria for Water. http://water.epa.gov/scitech/swguidance/standards/criteria/aqlife/upload/2009_01_13_criteria_goldbook.pdf

———. 2009. Quality Criteria for Water. http://water.epa.gov/scitech/swguidance/standards/criteria/current/upload/nrwqc-2009.pdf

UK Environment Agency Good Practices Guidelines for Hydropower Schemes, "technical guidance." http://www.environment-agency.gov.uk/business/topics/water/126575.aspx under

United States Federal Energy Regulatory Commission, Guidelines for Public Safety at Hydropower Projects, 1992 (Updated November 29, 2011). http://www.ferc.gov/industries/hydropower/safety/guidelines/public-safety.pdf

USSD. 2003. White Paper on Planning Processes for the Development of Dams and Reservoirs. Public Involvement and Alternatives Analysis: A Framework for Successful Decision-Making.

USCID and USCOLD. 1993. Proceedings of the Earth Summit Workshop. Responsibilities of US Water Resources Interests in Responding to the Challenges of the Earth Summit. Washington, DC.

Vermeyen, T.B. 1997. Modifying Reservoir Release Temperatures Using Temperature Control Curtains. Proceedings of Theme D: Energy and Water: Sustainable Development, 27th IAHR Congress, San Francisco, CA, August 10–15, 1997.

Waide, J.B. 1986. Environmental and Water Quality Operational Studies. General Guidelines for Monitoring Contaminants in Reservoirs. Army Engineering Waterways Experiment Station, Vicksburg MS Environmental Lab. 174 pp.

World Bank. 2010. Greenhouse Gas Emissions Related to Freshwater Reservoirs: World Bank Report. Washington, DC: World Bank.

World Commission on Dams. 2000. Dams and Development. A New Framework for Decision-Making.

World Health Organization. 1999. Human Health and Dams. Geneva: World Health Organization.

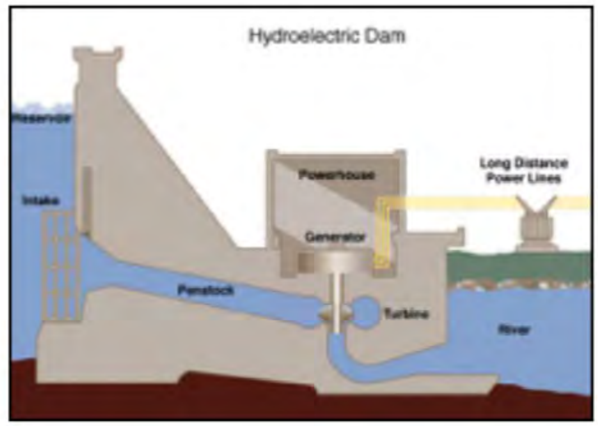
Zimmerman, J.K.H., Letcher, B.H., Nislow, K.H., Lutz, K.A. and Magilligan, F.J. 2009. "Determining the effects of dams on subdaily variation in river flows at a whole-basin scale." *River Research and Applications,* 26: 1246–1260.

Annex A: General Description of Industry Activity

Hydropower Schemes

Hydropower can be generated wherever a flow of water descends from a higher level to a lower level. The difference between the two water surface elevations is referred to as head. Head can exist in nature, for instance, when a stream runs down a steep hillside or when a sharp change in elevation creates a waterfall in a river. It can also be created artificially by constructing a weir or dam, because the weir or dam creates a barrier to water flow, raising the upstream water level to the desired elevation. Because of elevation differences, potential energy is stored in the water; this energy can be exploited by installing turbines and generators. Water flow moves the turbine blades, forcing the generator rotator to spin around the stator, and in this way converting the water's potential energy to mechanical and then electrical energy. Figure A1 depicts this concept in a schematic illustration.

Figure A1 (Source: Tennessee Valley Authority



Hydropower scheme developments must take into consideration the unique natural conditions, local topography, hydrology, and geology characteristics of each development. Each of these conditions can significantly affect the hydropower facility layout; thus, the layout has to be designed to maximize the use of the available head and stream flow in the most efficient manner—technically, economically, and financially—and consider as much as possible foreseeable climate-change factors that could influence the facility's operational regimes in the long run.

- While each hydropower plant is site specific, it is possible to classify all hydropower plant schemes based on the following categories[110] of installed capacity (P) and water head (H) availability:
  - Micro (P < 0.1 MW): Micro hydropower projects can supply electricity for an isolated industry, or small remote community. Usually, micro hydropower plants are stand-alone, that is, they are not connected to the grid, and they are always run-of-river type. Small water storage tanks are sometimes constructed so that hydro generation is guaranteed for a minimum period per day, even during low-water flow conditions.
  - Small (0.1 MW < P < 10 MW): Small hydropower plants usually exploit low discharges. Most small hydropower plants are run-of-river types that are connected to the power grid.
  - Medium (10 MW < P < 100 MW): Medium hydropower schemes are either the run-of-river or storage types and they almost always feed into a grid. Their layout may include a dam to create a head pond.
  - Large (P > 100 MW): Large hydropower schemes are always connected to a large grid; large hydropower plants can be run-of-river or storage type.
  - High head (H > 100 meters), medium head (30 meters < H < 100 meters), or low head (H < 30 meters): Analysis of ICOLD data has shown that the area of land inundated by the reservoir, which can result in the most significant environmental impacts in terms of deforestation and loss of native flora and fauna, is not related to

[110] Opinions vary on the threshold that separates individual categories. The classification in this document is approximate but widely accepted.

the height of the dam, but varies substantially on a site-by-site basis and greatly depends on the topography of the site and the location of the dam.[111]

- Purpose of plant structure: There can be single or multipurpose schemes,[112] including the following: flood protection; drought mitigation; irrigation; water supply; and improved condition of the water body, such as raising or keeping the water level stable, which opens the possibility for tourism, recreational purposes, fishing, navigation, and so on.
- Operation regime: For the purposes of this document, three main types of hydropower projects are described based on the type of power plant constructed and the operational characteristics of the reservoir created. The volume of water impounded by the dam, inflow to the reservoir, and the capacity of the associated hydropower plant dictate the water residence time in the reservoir, which often differentiates the operations of large reservoirs from smaller reservoirs.
  - Run-of-river schemes generate electricity by immediate use of the inflow. As a result, run-of-river hydropower power plants are subject to weather and seasonal variations resulting in variable power generation. Most run-of-river schemes have no storage capacity, or limited storage, which limits peak power operation to a few hours.
  - Storage schemes are characterized by water impoundment upstream of a dam structure to create a reservoir in which water is predominantly stored during high-flow periods and consumed for energy production during low-flow periods. Using stored water for the inflow to generate energy creates some security against natural fluctuations in water availability caused by weather and seasonal variations. Reservoir size determines the level of flow regulation.
  - Pumped storage plants are HPPs that can store water by pumping it from a lower reservoir or a river to a higher reservoir. Water is pumped during off-peak hours (lower power demand/lower priced supply) by reversing turbine operation to make more water available to generate electricity during peak demand periods. This process creates efficiencies of up to 80 percent—the energy that is generated can be up to 80 percent of the energy used to pump water to the high-level reservoir.

Hydropower plants with reservoirs have a greater ability to meet power demand fluctuations, which can be an advantage over run-of-river diversion plants. Although such facilities are usually operated to meet base-load, depending on the market and the regulator, the output of hydropower plants with reservoirs can be quickly adjusted to meet peak power demand on the electrical system. Storage reservoirs can also be used to capture water during wet periods and release the water during dry periods, providing a more consistent energy supply.

Hydropower Plant Components

Each hydropower scheme layout is site-specific based on prevailing geological, topographical, and hydrological conditions. Scheme components vary, but typically will include headworks, waterways, and powerhouse. Headworks create head and divert water into waterways that convey water to the generating units. The powerhouse accommodates the turbine-generator unit and auxiliary equipment. A switchyard with a substation may be required to feed generated electricity into the grid.

"Hydropower plants with reservoirs have a greater ability to meet power demand fluctuations, which can be an advantage over run-of-river diversion plants."

Civil Works

The civil structures that comprise a hydropower plant scheme can be grouped as follows:

- **Headworks:** Typically, headworks comprise a structure (usually a weir or a dam) to raise the water level to the desired elevation and a water intake structure to safely divert water from the river course to the waterway. In

[111] Zankhana Shah and M. Dinesh Kumar 2008.

[112] For more information, see LeCornu, J., Dams and water management, Report of ICOLD Secretary General to the International Conference on Water and Sustainable Development, Paris, France, 1998.

addition, headworks are designed to allow flood discharges to pass without risking structural instability, safe scheme operation, or upstream flooding.

- **Dams:** A dam is a barrier built across a stream or river to obstruct, direct, retard, or store the flow of water. As a basic element of a hydraulic scheme, a dam is used to create a reservoir and perform the following functions: store water, ensure sufficient discharge during dry seasons, develop head by raising the water level, and provide flood protection by accommodating the flood flows and releasing it over a longer period to reduce the damage downstream the dam.
- **Weirs:** A weir is an overflow structure built across an open channel to raise the upstream water level and/or to measure the flow of water. Its main purposes are similar to those of a dam and include diverting water, increasing the water level to develop head, and diverting floodwaters safely. Unlike dams, weirs cannot be used for water storage; they only maintain the upstream water level at the intake. The weir or dam will have a spillway to allow the discharge of flood flows, which may be a simple overflow structure or a gated structure with a carefully designed chute to prevent damage under high flow velocities. Weirs will also have an outlet to allow the pond or reservoir to be emptied or allow flows to be discharged (often for environmental reasons—EFlows) even when the scheme is not generating. Where fish migration is a concern, fish ladders or passways should be an integral component of the weir or dam design. Experts should determine final design, which should be species specific; function for upstream and downstream migration; release adequate water depth, flows, and velocity; and include intermediate resting check-tanks to avoid exhaustion, as well a guiding structures or mechanism at both, ladder entrance and exits, to avoid entrapment during downstream migration or fish being sucked in back into the turbines as soon as they get to the reservoir during their upstream migration.
- **Intakes:** The main function of an intake structure is to divert water into the waterway, which conveys water flow to the power plant in a controlled manner. Intake structures are usually the most maintenance-intensive components of hydropower schemes.

- **Waterway:** The waterway comprises scheme components that convey water from the intake to the powerhouse. The conveyance layout can include either pressure galleries or pipes or a mixed system of free-surface canals and pressurized pipes conveys water to powerhouse. The waterway has additional structures to support a properly functioning hydropower plant scheme; depending on local topographical and geological conditions these structures include some or all of the following:
  - **Sand trap (grit chamber or desander):** The sand trap, typically situated directly downstream of the intake, ensures that sediment suspended in the water is removed before the water flow passes through the turbine. A sand trap is usually omitted in large storage schemes because in reservoirs sediment may have time to settle, depending on water volume. In run-of-river projects, most sediment remains in the water flow up to the turbines, making a sand trap essential in this type of scheme.
  - **Headrace:** The headrace conveys the water safely toward the forebay or the surge tank with minimum head losses
  - **Surge tank (surge chamber):** The surge tank controls pressure variations in the penstock and the headrace, thus eliminating or smoothing water hammer when variations occur because of sudden shutdown of the flow to the powerhouse. The surge tank also regulates water flow to the turbine by providing necessary retarding head.
  - **Pressure pipe (penstock):** The penstock conveys pressurized water from the forebay or surge tank to the turbine. In addition to the pressure caused by static head, the penstock must be able to withstand the pressure rise caused by the so-called water hammer, that is, the pressure rise that occurs because of rapid turbine shutdown in emergencies.
- **Powerhouse:** The powerhouse comprises structures to accommodate electromechanical equipment that converts the water's energy, first into mechanical and then into electrical energy. It hosts the turbine, generator, and auxiliary equipment. Powerhouses can be constructed above or below ground. The layout should allow easy installation of equipment and easy access for inspections and maintenance. Size depends on the types, dimensions, and number of units installed. In general, powerhouses have three primary areas.
- **Tailrace:** Discharges turbine water into a receiving water body such as a river, lake, or ocean.
- **Auxiliary structures:** These structures protect the hydropower plant scheme from potential risks, such as turbine abrasion, sediment deposition in the waterways, and riverbed erosion downstream of the headworks.

Electromechanical Equipment

Hydro turbines can be grouped according to the head that they exploit to harvest hydropower, and their mode of operation. Another common classification of hydro turbines is based on their principle of operation—impulse or reaction type—that describes how the turbine transforms potential water energy into rotational mechanical energy.

- **Reaction turbines** use the water flow to generate hydrodynamic lift forces that propel the runner blades. The runner blades are profiled so that pressure differences across them impose lift forces, just as on aircraft wings, which cause the runner to rotate. Reaction turbines have a runner that always functions within a completely water-filled casing. Reaction turbines have a diffuser known as a "draft tube" below the runner through which the water discharges. The draft tube decelerates the water discharge and reduces static pressure below the runner, thereby increasing effective head. Two main types of reaction turbine are the propeller (with Kaplan variant) and Francis turbines.
- **Impulse turbines** runners operate in air, driven by a jet (or jets) of water. Three main types of impulse turbine are in use: the Pelton, the Turgo, and the Crossflow. Turbine choice is based on the principal site characteristics—available head and flow—including flow variations, that is, if the turbine operates in part-load condition, for example, when available discharge throughout the year is typically lower than the turbine's design discharge. Typically, impulse turbines are more efficient for high heads.

The generator transforms mechanical energy into electrical energy using an excitation system. Typical generator efficiency increases with rated power. For very small units (such as 10 kW) efficiency can be close to 90 percent; for larger capacities (> 1 MW) efficiency approaches 98 percent.

Grid Connection Facilities

The switchyard is the gateway from the generating unit to the distribution network. Before generated energy is transmitted through the grid, step-up transformers increase the voltage to reduce energy losses in the lines.

Annex B: Suggested Aspects of an Environmental Impact Assessment of Hydropower Projects

An Environmental and Social Impact Assessment (ESIA)[113] for new facilities and a combined ESIA and environmental audit for existing facilities should be carried out early in the project cycle in order to incorporate, to the extent feasible, the mitigation requirements (including alternative analysis) into the project design of a new or modified hydropower plant.

Table B1 provides suggested key elements of the ESIA, the scope of which will depend on project-specific circumstances.

Table B1 Suggested Aspects of an ESIA of New Hydropower Projects[114]

Assessment of Baseline Conditions	• Land use • Affected communities and stakeholder mapping • Hydrology and hydro-morphology; historical hydrology dynamics • Water quality • Biodiversity values, including aquatic and terrestrial ecological assemblies as well as ecosystem services • Upstream and downstream river use • Fish stocks, fisheries, and livelihoods • Vector-borne diseases • Climate change risks or vulnerability
Analysis of Alternatives	• Energy demand and supply alternatives • Siting alternatives (that is, location in river, watershed, or region) • Project design alternatives (such as type of hydropower project, EFlows, dam height, inundation area, water intake, and discharge structures)
Assessment of Impacts	• Land acquisition, involuntary resettlement, or economic displacement • Construction impacts (such as borrow materials extraction, spoil use/disposal, vegetation removal, erosion, construction camps) • Hydrology/Hydro-morphology changes, sediment transport and increased erosion potential • Water quality modifications

(continues)

[113] For more general guidance on ESIA, IFC Guidance Note 1 to IFC Performance Standard 1—Assessment and Management of Environmental and Social Risks and Impacts may be consulted.

[114] **Rehabilitation and/or Expansion of Existing Facilities:** An environmental and social impact assessment of the proposed rehabilitation should be carried out early in the process of preparing the project in order to allow an opportunity to evaluate alternative rehabilitation options before key design decisions are finalized. The assessment should include an environmental audit that examines the impacts of the existing facility's operations on nearby populations and ecosystems, supplemented by an ESIA that examines the changes in these impacts that would result under alternative specifications for the rehabilitation, and the estimated capital and operating costs associated with each option. Depending on the scale and nature of the rehabilitation, the audit/environmental and social impacts assessment may be relatively narrow in scope, focusing on only a small number of specific concerns that would be affected by the project, or it may be as extensive as would be appropriate for the construction of a new facility at the same site. The assessment may cover aspects applicable to the impacts of the plant under existing operating conditions—including environmental and social legacy issues—and under alternative scenarios for rehabilitation, including aspects such as potential increase in the reservoir operational levels (area of inundation), changes to downstream flows (quality, volume, and timing), changes to operational mode, and so on.

	• Aquatic and terrestrial habitat conversion, including habitat fragmentation/ impaired connectivity • Changes to ecosystem services • Upstream and downstream river use changes and effects • Water needs and uses downstream in terms of average release flow, frequency, volumes, and timing of the release (that is, appropriate time of day and year to meet downstream users' needs such as irrigation or others) • Fish stocks/fisheries livelihoods (that is, water quality, loss of spawning grounds and barriers to fish migration) • Vector-borne diseases (related to the creation of a reservoir with endemic water related disease) • Dam safety and emergency preparedness and response • Associated facilities (that is, access roads and transmission lines) • Visual impacts • Effects on cultural resources • Cumulative Impacts (that is, cumulative effects of hydropower or other infrastructure developments in the same river, watershed, or region in the present and in the foreseeable future)—see more details below • Climate change risks or vulnerability • Potential health and safety risks to affected communities
Mitigation Measures/Management Programs	• Project design modifications • Stakeholder engagement, such as community and stakeholder engagement plan, including a Grievance Mechanism • Land Acquisition, Involuntary Resettlement and Livelihood Restoration Management Plan • Construction phase management programs • Operational phase management programs • EFlows Management Plan • Traffic Management Plan • Sediment Management Plan • Occupational Health and Safety Plan • Adaptive Resource Management (ARM) programs • Emergency Preparedness and Response Plan • Industrial risk assessment, if relevant • Basinwide Management Programs
Monitoring Program	• Parameters • Sampling frequency • Evaluation criteria • Cost

General Considerations of Cumulative Effects

Project planning may also require inclusion of a cumulative impact assessment (CIA), defined as changes to the social and physical environment that are caused by an action (that is, any project or activity of human origin) in combination with other past, present, and future actions.[115] In the context of hydropower projects, cumulative impacts assessment and management (CIAM) are typically expected to do the following:

- Assess cumulative effects of cascading projects located in the same river system.
- Assess effects of other projects over a larger watershed or regional area that may cross jurisdictional boundaries.

[115] Hegmann et al. 1999.

- Include effects due to natural perturbations affecting environmental components and human actions.
- Assess effects during a longer period of time into the past and future.
- Consider effects on Valued Environmental and Social Components (VECs)[116] resulting from interactions with other actions, and not just the effects of the single action under review.
- Include other past, existing and future (for example, reasonably foreseeable) projects.
- Evaluate significance in consideration of other than just local, direct effects.

The challenge in developing the CIA is determining the VECs on which to focus the analysis, and how large an area around the action should be assessed, how long in time, and how to practically assess the often complex interactions among the actions. The methodology of the CIA should follow internationally recognized good practices, such as the Canadian Environmental Assessment Agency's Cumulative Effects Assessment Practitioners' Guide[117] or the IFC proposed Standard Annotated Terms of References for a Rapid Cumulative Impact Assessment.[118]

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[116] VECs are synonymous with sensitive environmental and social receptors. A VEC is any part of the environment or socio-economic context that is considered important by the proponent, public, scientists and government involved in the assessment process. Importance may be determined on the basis of cultural values or scientific concerns and refer to sensitive environmental and social receptors that are priorities for assessment in CIA, and could be ecological, social, or cultural values.

[117] http://www.ceaa-acee.gc.ca/default.asp?lang=En&n=43952694-1&toc=show

[118] IFC 2013.

Annex C: Assessment and Provision of Instream Environmental Flows (EFlows)

EFlows are defined as water flow regime schemes, designed to support desired ecological conditions, ecosystem services, and/or downstream water uses, from a dam or diversion into downstream reaches of an affected river.[119] More recently the term "EFlows" also refers to sediment and biota flows upstream and downstream in a river. It is widely accepted that EFlow releases based on a percentage of annual hydrological average flows is typically insufficient to satisfy downstream ecological processes and human uses, and that downstream releases need to incorporate "variable flow regimes" and be expressed in terms of magnitude, duration, seasonality, frequency, and predictability.[120] Therefore, the use of the so-called "Tennant method" or "Montana method" for establishing EFlow regimes is not recommended without a robust analysis that demonstrates the adequacy of the flow regime to support desired conditions and uses.

The feasibility of integrating EFlow needs into hydropower schemes has markedly improved in recent years because of improvements in dam design, technological advancements in electricity generation and transmission, innovations in dam operations; and it is now a common good international practice.[121, 122] Furthermore, in recent years, there have been important advances in the science of hydraulic and ecological modeling, which have significantly improved understanding of the relationship between hydro-morphological characteristics (such as velocity, depth, and substrate type) and fish and invertebrate species survival success (such as species-specific habitat preference curves) and riverbed and sediment dynamics. To be most successful, these new approaches and capabilities need to be fully considered and integrated into both regional and local level planning efforts. The loss of ecosystem services can be reduced or avoided by considering EFlow dynamics and needs at the very earliest stages of project development—which includes consideration at international, national, regional, and local scales. The latter is often restricted to a single river system or hydropower scheme.

The determination of EFlow release schemes is essential to sustainable hydropower development and water management.[123] The scientific assessment of EFlow is needed to understand key baseline sediment loads, socio-ecological conditions, and ecosystem services and assess the extent to which historical sediment, biota, and water flows can be altered by hydropower development, while at the same time maintaining river integrity and associated social benefits. In the past two decades, the science of EFlow assessment has progressed considerably. Even so, tradeoffs will always need to be considered in the decision-making process.

The prevailing scientific opinion is that rather than simply maintaining minimum hydrological flows, a naturally variable pattern of water flow is needed to support functional and productive river ecosystems. Allocating the finite supply of water among the often competing users requires information on the relative benefits and costs of different allocations. While some allocations can be based on quantitative requirements for demands for power or agricultural production and municipal or industrial uses, the relationships between sediment loads, water quantity and ecosystem protection are

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[119] Krchnak et al. 2009.

[120] The Nature Conservancy at http://www.conservationgateway.org/Files/Pages/framework-monitoring-repo.aspx

[121] Brisbane declaration (2007) http://riversymposium.com/about/brisbane-declaration-2007/

[122] IHA Sustainability Protocol 2010.

[123] Ibid.

less quantitative. Increasingly, water managers and dam planners are realizing the importance of maintaining adequate EFlows and other habitat conditions to sustain river health, human uses, and other associated ecosystem services provided by river reaches located downstream of dams or diversions.

Several methods have been developed to determine adequate flows to be released downstream from hydropower projects. These methods attempt to identify the components and characteristics of natural flow regimes, as to assess what flow regimes would need to be maintained to protect downstream human uses and ecological processes. The examples below should not be considered exhaustive or suitable for all situations.

At a regional planning stage, the Ecological Limits of Hydrologic Alteration (ELOHA)[124] framework aims to produce coarse-scale estimates of EFlow needs applicable to regional water and energy planning. This is a scientifically robust and flexible framework for assessing and managing EFlows across large regions, when lack of time and resources preclude evaluating individual rivers or projects. ELOHA systematically translates understanding of the ecological ramifications of human-induced streamflow alterations from rivers that have been studied to rivers that have not, without requiring detailed site-specific information for each river. Water managers, policy makers, stakeholders, and scientists with diverse expertise have used ELOHA to accelerate the integration of EFlows into regional water resource planning and management.[125]

ELOHA includes five essential steps:

- Build a hydrologic foundation of daily streamflow hydrographs representing at least two conditions—baseline (pre-development) and present-day—for a single time period for every analysis point within the region.
- Classify river types according to hydrologic and other characteristics.
- Assess flow alteration from baseline conditions at every analysis point.
- Determine flow-ecology relationships that quantify biological responses to different degrees of hydrologic alteration for each river type, based on existing biological and related data and models.
- Propose and implementpolicies to maintain and restore EFlows through a social process involving stakeholders and water managers informed by the flow-ecology relationships.[126]

Project specific EFlow assessment methods can generally be classified into either Prescriptive or Interactive methods as summarized in Table C1.[127] The specific types of methodologies, their relative requirements for data collection and assessment, and the relative confidence in their predictive abilities are summarized in Table C2. Prescriptive methods are based on general principles and most suited to small, simple, singular use projects, but even in those applications, there is often a need to validate the relationship between the flow parameter being assessed and river health and productivity. Interactive approaches are more complex than Prescriptive methods and are illustrated in Table C3 by two representative approaches—Instream Flow Incremental Methodology (IFIM and associated Physical Habitat Simulation (PHABSIM) model) and Downstream Response to Imposed Flow Transformations (DRIFT).

Although IFIM requires consideration of all aspects of fish and macro-invertebrate habitats and stream ecology, other aspects of the environment are often assumed to be unchanged, and flow is often the only variable of interest in some regulatory contexts. Even when other aspects of aquatic habitat and stream ecology are considered, the flow–habitat relationship developed with PHABSIM is fundamental to the model output. Once PHABSIM habitat preference and flow-habitat relationship are determined, IFIM methodology can then be used to propose downstream flow regimes that would appropriately incorporate all remaining in-stream flow uses, such as water quality, assimilation, navigation, and recreation, among others.

[124] http://conserveonline.org/workspaces/eloha.

[125] Ibid.

[126] The scientific basis for ELOHA was published in 2006 by an international group of river scientists (Arthington et al. 2006). Practical guidelines for its application have been developed by consensus of leading international environmental flow experts (Poff et al. 2010).

[127] See Davis and Hirji (2003) for a detailed discussion of the various flow assessment methodologies.

Table C1 Features of Prescriptive and Interactive Methodologies

Prescriptive	Interactive
Often provide a single flow regime to maintain a single objective (river condition)	Provide a range of flow regimes, each linked to a different river condition
Motivate for the inclusion of specific parts of the flow regime	Explain the consequences of flow manipulations
Not conducive to exploring options	Conducive to exploring options
Suited for application where objectives are clear, and the chance of conflict is small	Suited for application where the eventual environmental flow is an outcome of negotiations with other users

Source: Davis and Hirji (2003)

Table C2 Selected Flow Assessment Methods

Output/Method	Data and Time Requirements	Approximate Duration of Assessment/Relative Confidence in Output	Level of Experience
Prescriptive			
Tennant	Moderate to low	Two weeks/Low	USA/extensive
Wetted perimeter	Moderate	2–4 months/Low	USA/extensive
Expert panels	Moderate to low	1–2 months/Medium	South Africa, Australia/extensive
Holistic	Moderate to high	6–18 months/Medium	
Interactive			
IFIM	Very high	2–5 years/High	USA, UK/extensive
DRIFT	High to very high	1–3 years/High	Lesotho, South Africa/very limited

Source: Davis and Hirji (2003)

Table C3 Phases of IFIM and DRIFT

<table>
<tr><th>PHASES</th><th>IFIM</th><th>DRIFT</th></tr>
<tr><td>Problem identification or issues assessment</td><td>• Identification of interested and affected parties, their concerns, information needs and relative influence of power
• Identification of the broad study area, and the extent of probable impacts</td><td>• Identification of the main components of the project and the interested and affected parties
• Identification of the population at risk
• Identification of the broad study area, and the extent of probable impacts
• Identification of social concerns (local, national, and international) to be addressed in the biophysical studies

Two weeks/Low</td></tr>
<tr><td>Study planning</td><td colspan="2">Both approaches require:

• Assessment of existing biophysical, social, and economic data, and evaluation of the need for further data;
• Selection of representative river reaches;
• Design of data collection procedures; and
• Identification of key data collection sites.

Interdisciplinary integration of site selection and data collection avoids overlaps and gaps, and maximizes the usefulness of the data.

Addition of social considerations in selection of study area and sites, in particular, compatibility ensured between biophysical data (collected at river sites) and social data (collected in rural villages)</td></tr>
<tr><td>Study implementation</td><td>• Collection of hydraulic and biotic data
• Calibration of habitat model</td><td>• Collection of hydraulic, chemical, geomorphological, thermal and biotic data, and analyses to develop predictive capacity on how flow changes will affect each
• Multidisciplinary workshop to compile a database of biophysical consequences of a range of flow manipulations</td></tr>
<tr><td rowspan="2">Options analysis</td><td colspan="2">Both approaches require:

• Development of environmental flow alternatives or scenarios, each describing a possible future flow regime and the resulting river condition; and
• Yield analysis of water available for development with each scenario.</td></tr>
<tr><td>• Determination of the direct costs and benefits of the alternatives</td><td>• Determination of the direct costs and benefits of each scenario
• Additionally, for each scenario, determination of the social impacts and costs to the population at risk of changing river condition</td></tr>
<tr><td>Problem resolution</td><td colspan="2">Both approaches require:

• Assessment of the bigger picture (for example, data on the other costs/benefits of the water resource development);
• Negotiation with off-stream water users;
• Public participation; and
• Transparent decision-making processes.</td></tr>
</table>

Source: Davis and Hirji (2003)

The IFIM–PHABSIM method has been criticized for its assumptions and lack of validation. A key assumption is that the variables measured are important to fish and macro-invertebrate habitat selection and that habitat selection contributes to survival, such that more high-quality habitat will favor higher survival through a particular life stage, if habitat is a limiting factor. However, there have been instances where PHABSIM model results have countered empirical data, which indicates there can be other variables that are as important for habitat selection cues. In these cases, the model can incorrectly identify habitat associations and fail to predict the flow regime necessary to produce the desired ecological objectives.

DRIFT is a newer method than IFIM and was developed for use in semi-arid, developing regions, where water-supply is tenuous, and uncertainties about river-linked ecological and social processes are high.[128, 129] Using a basic philosophy that all major abiotic and biotic components constitute the ecosystem to be managed; and within that, the full spectrum of flows, and their temporal and spatial variability, constitutes the flows to be managed, DRIFT uses the expertise of scientists from the biophysical and socio-economic disciplines to combine data and knowledge from all the disciplines to produce flow-related scenarios for water managers to consider. DRIFT consists of four modules:

- Biophysical module, where the river ecosystem is described and predictive capacity developed on how it would change with flow changes.
- Socioeconomic module that describes the links between riparian users, the resources they use, and their health.
- Scenario building module, where potential future flows and the impacts of these on the river and the riparian people are developed.
- Economic module, where compensation and mitigation costs are considered.

In some cases, the DRIFT process is conducted in parallel with other external exercises, such as a macro-economic assessment of the wider implications of each scenario or a stakeholder consultation process where people other than subsistence users can indicate the level of acceptability of each scenario.

Although instream flow models provide a logical framework for discussion and may serve as decision-making tools when preliminary or rapid decisions are needed, in cases where models have not been validated by empirical data, commitments to long-term downstream flow releases may be difficult to implement. Use of model results for decision making should not preclude adaptive management that incorporates monitoring and alternative proven measures for mitigation or restoration. All information—not just model results—needs to be considered in the context of what is known when decisions are made about modifying flow or other aspects of a river system.

Regardless of the flow assessment method selected for use in a specific project, the provision of adequate EFlows are not the only means of river ecosystem protection or provision of a secure source of water to affected communities. The effectiveness of EFlows depends on sound management of water quality, watershed management, and stream channel structure and function. Quantifying an instream flow and defending it requires repeatable methods and documented relationships between river productivity, ecosystem health, and flows. Most EFlow methods address habitat, an intermediate factor between flow and river health (such as fish production). Documenting the relationship between ecosystem health and EFlows requires multiple assessments of selective productivity indicators under multiple EFlow scenarios, while other variables remain similar. Other assumptions of any EFlow method require identification and validation.

In recent years, considerable experience has been gained in the integration of EFlows and other environmental and social considerations into dam design. Structural and operational options that can facilitate integration of EFlows and environmental and social objectives in hydropower dam developments include:

- Effective EFlow Management Plans that outline procedures to define and implement EFlow regimes, social and environmental values of concern, key indicators, monitoring programs, and adaptive management criteria
- "Variable flows regime," that combines the use of low flow, periodic high flow pulse, and controlled flooding in an integral manner

[128] Beilfuss, R. and C. Brown. 2010.

[129] King et al. 2003.

- Variable outlet and turbine-generator capacities
- Multilevel, selective withdrawal outlet structures
- Re-regulation reservoirs
- Power grid interconnection
- Coordinated operations of cascades of dam
- Flood management in floodplains
- Sediment bypass structures and sediment sluice gates
- Functional fish passage structures designed for both upstream and downstream migration
- Habitat enhancement and river bed modifications

Both single-purpose and multiple-objective hydropower projects should consider the following points when assessing EFlow considerations:[130]

- Integrate ecosystem-based objectives that address biodiversity and ecosystem service protection in planning efforts at all levels of governance and decision-making.
- When considering tradeoffs among alternative planning scenarios, take into account the consequences for ecosystem-based benefits.
- Integrate EFlow considerations into the planning and design of hydropower schemes, which will be easier and more cost effective than modifying or retrofitting the design and operation of existing schemes.
- Consider EFlow needs in every stage of a hydropower development project, including location (or siting) of dams, dam design, dam and reservoir operations, and reoperation (or changing existing operations).
- Design hydropower schemes with built-in flexibility to accommodate changes in socioeconomic and environmental values, market conditions, technologies, and climate.

[130] Krchnak et al, 2009.

Annex D: Glossary

Anadromous Fish: A fish that migrates from salt water up rivers to spawn in fresh water.

Base-load facilities: Electricity production facilities used to meet a continuous energy demand and produce energy at a constant rate (generally, operating 24 hours per day).

Biodiversity offset: Measurable conservation outcomes, delivered away from the project site, resulting from actions designed to compensate for significant residual adverse biodiversity impacts arising from project development and persisting after appropriate avoidance, minimization, and restoration measures have been taken at the project site.

Biomethylation: Any bioalkylation reaction in which a methyl group is attached. The biomethylation of toxic elements in the environment can modify their toxicity.

Cascade: An arrangement of several hydropower schemes on the same river, configured so that the same water generates electricity in each individual hydropower scheme within the cascade.

Catadromous fish: A fish that migrates from fresh water, down rivers to salt water to spawn.

Channel morphology: Physical characteristics of a water channel (such as, the rate of sedimentation transport).

Critical Habitat: Areas with high biodiversity value, including (i) habitat of significant importance to Critically Endangered and/or Endangered species, (ii) habitat of significant importance to endemic and/or restricted-range species, (iii) habitat supporting globally significant concentrations of migratory species and/or congregatory species, (iv) highly threatened and/or unique ecosystems, and/or (v) areas associated with key evolutionary processes.

Defensive driving: Driving skills that save lives, time, and money, in spite of the conditions around the driver and the actions of others.

Dewatered reach: Area or section of a water body where water flow/volume is reduced or removed via diversion to another section.

Diversion: Involves redirection of a body of water that can be used to supply irrigation systems, reservoirs, or hydroelectric power generation facilities.

Freshet: The flood of a river from heavy rain or melted snow.

Geomorphological delineation: The delineation of homogenous reaches/zones along a river based on a systematic assessment of similarities in geographic location, size, climate, geology, topography, land use and river zonation (slope, channel types, biotic distributions, and condition).

Groyne: Hydraulic structure built from a bank that interrupts water flow and limits the movement of sediment.

Hydrograph: A graph showing the rate of flow versus time past a specific point in a river, or other channel or conduit carrying flow.

Hydro-peaking: An operating mode in hydropower generation in which water from the dam is released and power generated for only part of the day, corresponding to peak demand for power in the system.

Hydrosuction removal: A variation of traditional dredging that uses the hydraulic head of the dam for dredging. Environmental issues and the potential costs of mitigation actions related to the downstream discharge of these sediments can be high and need to be considered in the development of this option.

Hypolimnion: The lower layer of water in a stratified lake, typically cooler than the water above and relatively stagnant.

Hyporheic: Denoting an area or ecosystem beneath the bed of a river or stream that is saturated with water and that supports invertebrate fauna that play a role in the larger ecosystem.

Intake: Main entry of water into hydropower system.

Lateral connectivity: Connectivity between a channel with floodplains or other secondary channels around it, which results in the exchange of water, sediment, organic matter, nutrients, and organisms.

Lentic: Inhabiting or situated in still, fresh water.

Longitudinal connectivity: Connectivity of the entire length of a river or stream.

Lotic: Inhabiting or situated in rapidly moving fresh water.

Modified Habitat: Areas that may contain a large proportion of plant and/or animal species of non-native origin, and/or where human activity has substantially modified an area's primary ecological functions and species composition. Modified habitats may include areas managed for agriculture, forest plantations, reclaimed coastal zones, and reclaimed wetlands.

Natural Habitat: Areas composed of viable assemblages of plant and/or animal species of largely native origin, and/or where human activity has not essentially modified an area's primary ecological functions and species composition.

No Net Loss: The point at which project-related impacts on biodiversity are balanced by measures taken to avoid and minimize the project's impacts, to undertake on-site restoration and finally to offset significant residual impacts, if any, on an appropriate geographic scale (such as local, landscape-level, national, and regional).

Potadromous: That requires movement through fresh water systems to complete lifecycle.

Powerhouse: The hydropower structure that houses generators and turbines.

Quantitative Risk Assessment: A determination of the major hazards associated with a project, based on quantitative estimate of risk (magnitude of the potential loss and probability that the loss will occur) related to a hazard.

Ramping rates: The increase or reduction of electricity production per unit or time. Usually expressed as megawatts per minute (MW/min).

River training: The structural measures to improve a river and its banks (for example to prevent and mitigate floods).

Scouring: Erosion of a riverbed (vertical scour) or riverbanks (lateral scour) by flowing water.

Shotcrete: Concrete pneumatically projected at high velocity onto a surface.

Tailrace: The channel that carries water away from a dam.

Trapping bedload: Trapping in a reservoir of the sediments that move along the bed of a river by rolling, sliding, and/or hopping.

Weir: A low wall built across a river to raise the level of water upstream and/or to regulate its flow.

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