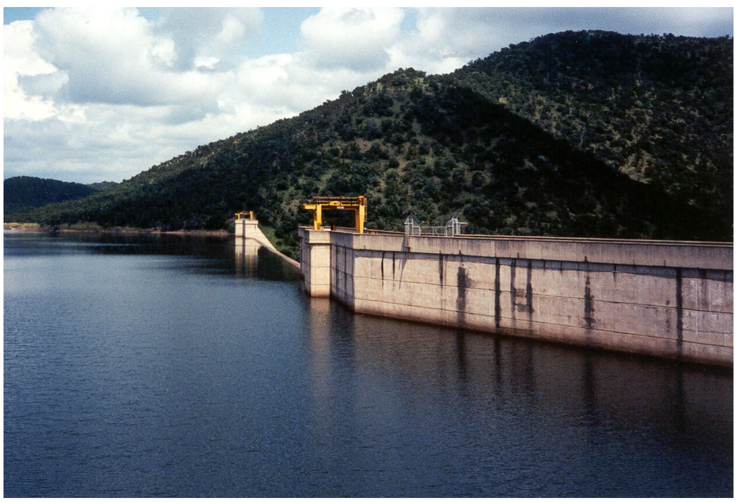
Latin America and Caribbean Region
Sustainable Development Working Paper 16

Good Dams and Bad Dams:
Environmental Criteria for Site Selection of Hydroelectric Projects

November 2003



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The World Bank
Latin America and Caribbean Region
Environmentally and Socially Sustainable Development Department (LCSES)

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Cover photos (clockwise from upper left):

Loksop Dam, South Africa
Guavio Dam, Colombia
Yacyreta Dam, Argentina/Paraguay

All photos by George Ledec

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Doug Mason (consultant) compiled data on more than twenty completed Latin American hydroelectric projects; this information was very useful in our analysis of environmental and social impacts, mitigation measures, and site selection criteria. Several current and former World Bank Group staff members provided useful comments and much encouragement, including Alessandro Palmieri, John Briscoe, Teresa Serra, Tony Whitten, Robert Goodland, Tor Ziegler, Warren Van Wicklin, William Partridge, Maria Clara Mejia, Kristine Ivarsdotter, Mateen Thobani, Salman Salman, and A. J. Glauber. This paper also reflects the helpful comments provided by Dominique Egre and Gaitan Guertin (Hydro-Quebec), Jose Goldemberg (World Commission on Dams), and Paul Dulin. Peter Brandriss helped edit and prepare the report for publication.

Foreword

Few types of development projects arouse as much controversy as hydroelectric dams. Their often serious environmental damage has been amply documented within the past decade. Nonetheless, many countries, in Latin America and worldwide, rely upon hydroelectric dams for a major portion of their electric power. Electricity remains a key ingredient for improving the lives of poor people almost everywhere. In developing countries, rapid urbanization and continued population growth will ensure increased demand for electric power for decades to come, even with the most successful of demand management and energy efficiency measures. Energy planners in many developing countries are thus likely to continue seeing hydroelectric dams as a promising source of renewable electric power.

This report provides important advice for substantially reducing the environmental damage from future hydroelectric dams (whether or not they receive World Bank Group financing) through good project site selection. Although the report's conclusions are drawn primarily from a review of Latin American dams, its innovative methodology for dam site selection--based on robust environmental and social criteria and straightforward, quantitative indicators--should prove useful worldwide. The report also helpfully summarizes the environmental mitigation options for the improved operation of existing hydroelectric dams. As such, this report should be of considerable interest to people interested in hydroelectric dams, whether at the World Bank, other multilateral and bilateral development institutions, government agencies, private energy companies, consulting firms, environmental and other NGOs, and academia.

This report is part of the LCR Sustainable Development Working Paper Series published by the Latin America and the Caribbean Region's Environmentally and Socially Sustainable Development Sector Management Unit (LCSES). This series seeks to disseminate the results of our analytical and operational work, present preliminary findings, and describe "best practices" with respect to major sustainable development issues facing the region. The findings, interpretations, and conclusions expressed in these papers are entirely those of the authors and should not be attributed to the World Bank, members of its Board of Executive Directors, or the countries they represent.

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Executive Summary

Large dams vary considerably in their adverse environmental and related social impacts. From an environmental standpoint, there are relatively good dams and bad dams. While some large dams are relatively benign, others have caused major environmental damage. The severity of environmental impacts from a hydroelectric project is largely determined by the dam site. While dams at good sites can be very defensible from an environmental standpoint, those proposed at bad sites will inherently be highly problematic, even if all feasible mitigation measures are properly implemented.

This paper provides a simple, yet robust, methodology for comparing proposed hydroelectric project sites in terms of their expected negative environmental impacts, and relating these to power generation benefits. The paper also summarizes the environmental mitigation options for large dams. If properly implemented, these mitigation measures can effectively prevent, minimize, or compensate for many (though not all) of a hydroelectric project's negative impacts. Nonetheless, **the most effective environmental mitigation measure is good site selection**, to ensure that the proposed dam will cause relatively little damage in the first place.

The paper presents quantitative indicators (using data that are relatively easy to obtain) for rating and ranking proposed new hydroelectric projects in terms of their likely adverse environmental impacts. Projects with a small reservoir surface area (relative to power generation) tend to be most desirable from both an environmental and social standpoint, in part because they minimize natural habitat losses as well as resettlement needs. **In general, the most environmentally benign hydroelectric dam sites are on upper tributaries, while the most problematic ones are on the large main stems of rivers**.

Power expansion planning should ensure that environmental criteria, of the type outlined in this paper, are given appropriate weight in hydroelectric project site selection. Many of the more problematic dam sites are best left undeveloped, because the environmental or related social impacts are likely to be unacceptably high. In those cases, other power generation technologies are likely to be more environmentally desirable. Conversely, hydroelectric dams at good sites (with relatively low adverse impacts) and with effective implementation of proper mitigation measures are likely to be more attractive from an environmental standpoint than the most likely power generation alternatives.

Introduction

1. Large hydroelectric dams are among the most controversial of all types of development projects. They have been the focus of much criticism of the World Bank and other international financing agencies. The “large dams” debate is often highly polarized. Critics of large hydroelectric projects point to a wide range of negative environmental and related social impacts, from the destruction of unique biodiversity to the displacement of vulnerable human populations. Defenders of large dams note that they are often the economically least-cost source of electric power available, especially to large urban centers; they are a renewable electricity source; and most other power generation technologies also imply significant adverse environmental impacts.

2. Worldwide, many countries rely upon hydropower for a substantial portion of their electricity. In developing countries, rapid urbanization and continued population growth will ensure increased demand for electric power for decades to come, even with the most successful of demand management and energy efficiency measures. Electricity remains a key ingredient for improving the lives of millions of poor people throughout the developing world. Energy planners in many countries are likely to continue seeing hydroelectric dams as a promising, renewable source of electricity. Major recent international initiatives--including the World Summit on Sustainable Development (Johannesburg, 2002), World Water Forum (Kyoto, 2003), World Commission on Dams (1997-2002), and the ongoing Dams and Development Project of the United Nations Environment Program--have reaffirmed the commitment of many governments and international agencies (including the World Bank) to hydropower development, but in a manner which fully reflects modern environmental concerns.

3. In this context, it is important to remember that all large hydroelectric dams are not alike. Large hydroelectric projects vary tremendously in the extent of their adverse environmental and related social impacts. (In this paper, we define large hydroelectric dams as those with 10 megawatts or more of installed generating capacity, to distinguish them from small or micro-dams which generate power on a smaller scale.) For example, the 500–megawatt Pehuenche Hydroelectric Project in Chile flooded only about 400 hectares of land (with minimal damage to forest or wildlife resources) and has had no water quality problems. By contrast, the Brokopondo Dam in Suriname inundated about 160,000 hectares of biologically valuable tropical rainforest and is known for serious water quality and aquatic weed problems, while providing relatively little electric generating capacity (only 30 megawatts).

4. We conducted a review of more than twenty completed hydroelectric dam projects in Latin America, along with several well-known projects from other regions. Our study found that some large dams are relatively benign, while others have caused substantial environmental and related social damage. This paper provides a methodology for easily comparing proposed hydroelectric project sites in terms of their expected adverse environmental impacts, relative to their power generation benefits. The technical criteria and quantitative indicators in this paper should be viewed as complementary to

the broader and often more process-oriented advice of other recent reports on dams, including the 2000 *Dams and Development* report of the World Commission on Dams. This paper's recommendations are fully compatible with the World Bank's Water Resources Sector Strategy, although this paper provides more technical detail regarding specific environmental impacts, mitigation options, and site selection criteria.

Adverse Environmental Impacts of Hydropower Development

5. The range of adverse environmental and related social impacts that can result from hydroelectric dams is remarkably diverse. While some impacts occur only during construction, the most important impacts usually are due to the long-term existence and operation of the dam and reservoir. Other significant impacts can result from complementary civil works such as access roads, power transmission lines, and quarries and borrow pits. Table 1 summarizes the adverse environmental and social impacts associated with dams and reservoirs, along with the typical kinds of mitigation measures often proposed (and, less often, effectively implemented).

6. Our analysis indicates that with properly implemented mitigation measures, many of the negative environmental and related social impacts of hydroelectric projects can be reduced to very acceptable levels. As outlined in Table 1, mitigation measures can effectively prevent, minimize, or compensate for most adverse impacts, but only if they are properly implemented. In our review of Latin American hydroprojects, we found wide variation in the extent to which environmental mitigation measures were planned, budgeted, and actually implemented.

7. Moreover, for some types of negative impacts, at some project sites, the available mitigation measures—even when properly implemented—are inherently unsatisfactory. Examples of adverse environmental impacts which occur at some hydroelectric projects and cannot be fully mitigated include (i) irreversible biodiversity loss, if critical natural habitats not occurring elsewhere are submerged (or left dry) by the dam; (ii) fish passage facilities frequently cannot restore the pre-dam ecological balance of a river, in terms of species composition or fish migrations; and (iii) some cultural property (including sacred sites) cannot be adequately salvaged prior to reservoir inundation.

8. Thus, because mitigation measures are often not fully implemented, and are sometimes inherently inadequate, the single most important environmental mitigation measure for a new hydroelectric project is good site selection, to ensure that the proposed dam is will be largely benign in the first place. In the following summary of typical adverse environmental impacts and corresponding mitigation options, it is important to keep in mind that all these types of impacts can be either avoided or minimized through good project site selection.

Table 1. Hydroelectric Projects: Adverse Environmental Impacts and Mitigation Options

*Note: All of these impacts can be avoided or minimized by good **dam site selection**, the single most important environmental measure.*

Environmental Impacts	*Mitigation Options*
Impacts of the Dam and Reservoir	
Flooding of Natural Habitats	
Some reservoirs permanently flood extensive natural habitats, with local and even global extinctions of animal and plant species. Very large hydroelectric reservoirs in the tropics are especially likely to cause species extinctions (although such losses are only infrequently documented due to the lack of scientific data). Particularly hard-hit are riverine forests and other riparian ecosystems, which naturally occur only along rivers and streams. From a biodiversity conservation standpoint, the terrestrial natural habitats lost to flooding are usually much more valuable than the aquatic habitats created by the reservoir. One occasional exception to this rule is that shallow reservoirs in dry zones can provide a permanent oasis, sometimes important for migratory waterfowl and other terrestrial and aquatic fauna.	To offset the loss of natural habitats to reservoir flooding or other project components (such as borrow pits), one or more **compensatory protected areas** can be established and managed under the project. If an existing area is protected "on paper" only, a useful project option is to strengthen its on-the-ground protection and management. The area protected under the project should ideally be of comparable or greater size and ecological quality to the natural area lost to the project. Under the World Bank's Natural Habitats Policy, hydroelectric and other projects should not be sited where they would cause the significant conversion or degradation of critical natural habitats that do not occur elsewhere (and, hence, cannot be adequately compensated).
Loss of Terrestrial Wildlife	
The loss of terrestrial wildlife to drowning during reservoir filling is an inherent consequence of the flooding of terrestrial natural habitats, although often treated as a separate impact.	Although they may be useful for public relations purposes, **wildlife rescue** efforts rarely succeed in restoring wild populations. Instead of drowning, the captured and relocated animals typically starve, are killed by competitors or predators, or fail to reproduce successfully, due to the limited carrying capacity of their new habitats. Wildlife rescue is most likely to be justified on conservation grounds if (a) the species rescued are globally threatened with extinction and (b) the relocation habitat is ecologically suitable and effectively protected. However, the money spent on rescue would usually do much more for wildlife conservation if it were invested in compensatory protected areas. The most effective way to minimize wildlife mortality in hydroelectric projects is to choose dam sites which minimize the wildlife habitat flooded.

Environmental Impacts	Mitigation Options
Involuntary Displacement	
Involuntary displacement of people is often the main adverse social impact of hydroelectric projects. It can also have important environmental implications, such as with the conversion of natural habitats to accommodate resettled rural populations.	For physical displacement, the main mitigation measure is the **resettlement** of displaced populations, including new housing, replacement lands, and other material assistance, as needed. Success usually requires consultation and participatory decisionmaking by both the resettled and host populations (mandatory for World Bank–supported resettlement). Effective resettlement of vulnerable ethnic minorities is particularly challenging because some of these people are highly vulnerable to adverse social changes. Accordingly, the World Bank's Involuntary Resettlement and Indigenous Peoples policies afford special consideration to these populations, specifying that, among other requirements, all viable alternative project designs should be explored before considering physical displacement for these groups. For people who are not physically displaced but suffer an economic loss of livelihoods (based on fisheries, agricultural or grazing lands, river-edge clay for brick and tile production, or other resources), mitigation measures should involve the provision of replacement resources**,** new job training, or other **income restoration assistance**, as needed.
Deterioration of Water Quality	
The damming of rivers can cause serious water quality deterioration, due to the reduced oxygenation and dilution of pollutants by relatively stagnant reservoirs (compared to fast-flowing rivers), flooding of biomass (especially forests) and resulting underwater decay, and/or reservoir stratification (where deeper lake waters lack oxygen).	**Water pollution control** measures (such as sewage treatment plants or enforcement of industrial regulations) may be needed to improve reservoir water quality. Where poor water quality would result from the decay of flooded biomass, **selective forest clearing** within the impoundment area should be completed before reservoir filling.
Downriver Hydrological Changes	
Major downriver hydrological changes can destroy riparian ecosystems dependent on periodic natural flooding, exacerbate water pollution during low-flow periods, and increase saltwater intrusion near river mouths. Reduced sediment and nutrient loads downriver of dams can increase river-edge and coastal erosion and damage the biological and economic productivity of rivers and estuaries. Induced desiccation of rivers below dams (when the water is diverted to another portion of the river, or to a different river) kills fish and other fauna and flora dependent on the river; it can also damage agriculture and human water supplies.	These adverse impacts can be minimized through careful **management of water releases**. Objectives to consider in optimizing water releases from the turbines and spillways include adequate downriver water supply for riparian ecosystems, reservoir and downriver fish survival, reservoir and downriver water quality, aquatic weed and disease vector control, irrigation and other human uses of water, downriver flood protection, recreation (such as whitewater boating), and, of course, power generation. From an ecological standpoint, the ideal water release pattern would usually closely mimic the natural flooding regime (although this may not be feasible for densely settled floodplains where flood protection is a high priority). Dams that generate baseload electricity are typically more capable of replicating near-natural downriver flows than those that produce peaking power (where daily water releases may fluctuate sharply, often to the detriment of aquatic organisms that are adapted to less frequent flow changes). Environmental management plans for hydroelectric projects should specify environmental water releases, including for dams owned or operated by the private sector.

(table continues on following page)

Table 1. Hydroelectric Projects: Adverse Environmental Impacts and Mitigation Options *(continued)*

Environmental Impacts	*Mitigation Options*
Water-Related Diseases	
Some infectious diseases can spread around hydroelectric reservoirs, particularly in warm climates and densely populated areas. Some diseases (such as malaria and schistosomiasis) are borne by water-dependent disease vectors (mosquitoes and aquatic snails); others (such as dysentery, cholera, and hepatitis A) are spread by contaminated water, which frequently becomes worse in stagnant reservoirs than it was in fast-flowing rivers.	Corresponding **public health measures** should include preventive measures (such as awareness campaigns and window screens), monitoring of vectors and disease outbreaks, vector control, and clinical treatment of disease cases, as needed. Control of **floating aquatic weeds** (see below) near populated areas can reduce mosquito-borne disease risks.
Fish and Other Aquatic Life	
Hydroelectric projects often have major effects on fish and other aquatic life. Reservoirs positively affect certain fish species (and fisheries) by increasing the area of available aquatic habitat. However, the net impacts are often negative because (a) the dam blocks upriver fish migrations, while downriver passage through turbines or over spillways is often unsuccessful; (b) many river-adapted fish and other aquatic species cannot survive in artificial lakes; (c) changes in downriver flow patterns adversely affect many species, and (d) water quality deterioration in or below reservoirs (usually low oxygen levels; sometimes gas super-saturation) kills fish and damages aquatic habitats. Freshwater molluscs, crustaceans, and other benthic organisms are even more sensitive to these changes than most fish species, due to their limited mobility.	**Management of water releases** may be needed for the survival of certain fish species, in and below the reservoir. **Fish passage facilities** (fish ladders, elevators, or trap-and-truck operations) are intended to help migratory fish move upriver past a dam; they are usually of limited effectiveness for various reasons (including the difficulty of ensuring safe downriver passage for many adults and fry). **Fish hatcheries** can be useful for maintaining populations of native species which can survive but not successfully reproduce within the reservoir. They are also often used for stocking the reservoir with economically desired species, although introducing non-native fish is often devastating to native species and not ecologically desirable. **Fishing regulation** is often essential to maintain viable populations of commercially valuable species, especially in the waters immediately below a dam where migratory fish species concentrate in high numbers and are unnaturally easy to catch.
Floating Aquatic Vegetation	
Floating aquatic vegetation can rapidly proliferate in eutrophic reservoirs, causing problems such as (a) degraded habitat for most species of fish and other aquatic life, (b) improved breeding grounds for mosquitoes and other nuisance species and disease vectors, (c) impeded navigation and swimming, (d) clogging of electro-mechanical equipment at dams, and (e) increased water loss from some reservoirs.	**Pollution control** and pre-impoundment **selective forest clearing** will make reservoirs less conducive to aquatic weed growth. **Physical removal or containment** of floating aquatic weeds is effective but imposes a high and recurrent expense for large reservoirs. Where compatible with other objectives (power generation, fish survival, etc.), occasional **drawdown** of reservoir water levels may be used to kill aquatic weeds. **Chemical poisoning** of weeds or related insect pests requires much environmental caution and is usually best avoided.

Environmental Impacts	*Mitigation Options*
Loss of Cultural Property	
Cultural property, including archaeological, historical, paleontological, and religious sites and objects, can be inundated by reservoirs or destroyed by associated quarries, borrow pits, roads, or other works.	Structures and objects of cultural interest should undergo **salvage** wherever feasible through scientific inventory, careful physical relocation, and documentation and storage in museums or other appropriate facilities. However, it is often not possible to replace the loss of, or damage to, unique or sacred sites which may have great religious or ceremonial significance to indigenous or other local people.
Reservoir Sedimentation	
Over time, live storage and power generation are reduced by reservoir sedimentation, such that much of some projects' hydroelectric energy might not be renewable over the long term.	If effectively implemented, **watershed management** can minimize sedimentation and extend a reservoir's useful physical life, through the control of road construction, mining, agriculture, and other land use in the upper catchment area. Protected areas are sometimes established in upper catchments to reduce sediment flows into reservoirs, as with the Fortuna Dam in Panama and the proposed Rio Amoya (Colombia) and Nam Theun II (Laos) projects. Aside from watershed management, **other sediment management techniques** for hydroelectric reservoirs may at times be physically and economically feasible; they include, among others, upstream check structures, protecting dam outlets, reservoir flushing, mechanical removal, and increasing the dam's height.
Greenhouse Gases	
Greenhouse gases (carbon dioxide and methane) are released into the atmosphere from reservoirs that flood forests and other biomass, either slowly (as flooded organic matter decomposes) or rapidly (if the forest is cut and burned before reservoir filling). Greenhouse gases are widely considered to be the main cause of human-induced global climate change. Many hydroelectric reservoirs flood relatively little forest or other biomass. Moreover, most hydroprojects generate sufficient electricity to more than offset the greenhouse gases which would otherwise have been produced by burning fossil fuels (natural gas, fuel oil, or coal) in power plants. However, some projects which flood extensive forest areas, such as the Balbina Dam in Amazonian Brazil, appear to emit greenhouse gases in greater amounts than would be produced by burning natural gas for many years of comparable electricity generation.	Greenhouse gas releases from reservoirs can be reduced by a thorough **salvage** of commercial timber and fuelwood, although frequently this does not happen because of (a) high extraction and transportation costs, (b) marketing constraints, or (c) political and economic pressures not to delay reservoir filling. The surest way to minimize greenhouse gas releases from reservoirs is to **choose dam sites** that minimize the flooding of land in general, and forests in particular.

(table continues on following page)

Table 1. Hydroelectric Projects: Adverse Environmental Impacts and Mitigation Options *(continued)*

Environmental Impacts	*Mitigation Options*
Impacts of Complementary Civil Works	
Access Roads	
New access roads to hydroelectric dams can induce major land use changes—particularly deforestation—with resulting loss of biodiversity, accelerated erosion, and other environmental problems. In some projects (such as Arun II in Nepal), the environmental impacts of access roads can greatly exceed those of the reservoir.	The **siting** of any new access roads should be in the environmentally and socially least damaging corridors. Forests and other environmentally sensitive areas along the chosen road corridor should receive legal and on-the-ground protection. **Road engineering** should ensure proper drainage, to protect waterways and minimize erosion. **Environmental rules for contractors** (including penalties for noncompliance) should cover construction camp siting, gravel extraction, waste disposal, avoiding water pollution, worker behavior (such as no hunting), and other construction practices. See Ledec and Posas (2003) for details.
Power Transmission Lines	
Power transmission line rights-of-way often reduce and fragment forests; indirectly, they occasionally facilitate further deforestation by improving physical access. Large birds are sometimes killed in collisions with power lines, or by electrocution. Power lines can also be aesthetically objectionable.	Power lines should be sited to minimize these concerns and built using **good environmental practices** (as with roads). In areas with concentrations of vulnerable bird species, the top (grounding) wire should be made more visible with plastic devices. Electrocution (mainly of large birds of prey) should be avoided through bird-friendly tower design and proper spacing of conducting wires.
Quarries and Borrow Pits	
Quarries and borrow pits are used to provide material for construction of the dam and complementary works. They can considerably increase the area of natural habitats or agricultural lands that are lost to a hydroelectric project.	To the greatest extent feasible, quarries and borrow pits should be sited within the **future inundation zone**. Where this is not feasible, the pits should be **rehabilitated** after use, ideally for conservation purposes such as wetland habitats.
Impacts of Induced Development	
Associated Development Projects	
Hydroelectric dams often make possible new development projects with major environmental impacts, including irrigation, urban expansion, and industrial facilities (due to new water supplies).	New development projects should be planned to minimize adverse environmental and social impacts. Environmental impact assessment studies should be carried out in the early stages of project planning; the resulting **environmental mitigation** plans should be fully implemented.
Additional Dams	
The construction of the first dam on a river can make the subsequent construction of additional dams more economical, because flow regulation by the upriver dam can enhance power generation at the downriver dam(s).	The environmental impact assessment study for the first dam on any river should include a **cumulative environmental assessment** of the likely impacts of proposed additional dams on the same river system. Implementation of mitigation measures for cumulative (rather than dam-specific) impacts should be completed or well underway prior to construction of the second dam on the river.

Key Indicators of Likely Environmental Impacts

9. Before a dam site is chosen (with a project-specific environmental impact assessment), sector-level environmental analysis can rank potential sites according to their degree of environmental desirability. A sectoral environmental assessment (SEA) should be carried out prior to making major power sector planning decisions, especially in the comparison of hydroelectric and other power generation (and demand management) alternatives. However, even without a detailed SEA, it is possible to carry out a simple environmental and ranking of different hydropower sites using basic, often readily available technical data. There exist various quantitative, easily calculated indicators that can be used to estimate the extent of adverse environmental impacts for any proposed hydroelectric project.

10. This paper presents 13 quantitative, easily calculated indicators that we consider especially useful for hydroproject site selection from an environmental standpoint. These indicators have high predictive value for likely adverse environmental (and related social) impacts. The first nine indicators (A–I) use information that is normally easy to obtain from basic dam planning data, even without a separate environmental study. The other four indicators (J–M) are also very important in the environmental comparison of alternative dam sites, but involve data that may require further environmental (or resettlement) study to obtain. Indicator A (hectares of land inundated) is perhaps the single most useful one in predicting the degree of environmental damage, because this indicator is positively correlated with many of the others. From a social standpoint, the number of people requiring resettlement (Indicator J) is an especially important.

A. Reservoir Surface Area

11. The area flooded by the reservoir is a strong proxy variable for many environmental and social impacts (Goodland, 1997). A large reservoir area implies the loss of much natural habitat and wildlife and/or the displacement of many people. Very large reservoirs are typically in the lowlands (often with tropical disease and aquatic weed problems) and usually impound larger rivers (with more fish and other aquatic species at risk). A very useful measure of environmental costs relative to economic benefits is the ratio of inundated **hectares per megawatt** (ha/MW) of electricity; it varies by four orders of magnitude for large power projects (see Table 2). The global average for all large hydroelectric dams constructed to date (not just those in Table 2) is about 60 ha/MW (J. Goldemberg, pers. comm.); it would be environmentally highly desirable for this average to be much reduced in future hydroprojects.

B. Water Retention Time in Reservoir

12. Mean water retention time during normal operation (the shorter, the better) is very useful in estimating the extent to which reservoirs will have long-term water quality problems. This figure (number of days) is calculated as a function of reservoir volume (cubic meters) and mean river flow (cubic liters per second).

C. Biomass Flooded

13. Biomass flooded is calculated in tons per hectare based on the percent cover of different vegetation types in the reservoir area. For good reservoir water quality, dams should minimize flooding of forests (which have high biomass content). Flooding native forests also threatens biodiversity and releases greenhouse gases.

D. Length of River Impounded

14. To conserve aquatic and riparian biodiversity (including riverine forests), dam sites should minimize the length (kilometers) of river (main stem plus tributaries) impounded by the reservoir (measured during high flow periods).

E. Length of River Left Dry

15. This measures the kilometers of river left dry (with less than 50 percent of dry season mean flow) below the dam, due to water diversion. The length of dried-up river bed (before the next important downstream tributary) should be minimized, due to the loss of fish and other aquatic life, damage to riparian ecosystems, and disruption of human water supplies, agriculture, and/or fishing.

F. Number of Downriver Tributaries

16. The more (major, undammed) tributaries downriver of the dam site, the better, in terms of maintaining accessible habitat for migratory fish, the natural flooding regime for riverine ecosystems, and nutrient or sediment inputs needed for the high biological productivity of estuaries.

G. Likelihood of Reservoir Stratification

17. Stratification in a reservoir occurs when the lake's upper zone (epilimnion) is thermally divided from the deeper zone (hypolimnion); the latter becomes stagnant and lacking in dissolved oxygen (anaerobic), thereby unsuitable for most aquatic life. A rapid estimate of stratification tendencies in a reservoir can be obtained with the Densimetric Froude Number (F). F can be calculated as: $F = 320(L/D)(Q/V)$, where L = length of the reservoir (meters), D = mean reservoir depth (meters) (for which dam height can be a proxy), Q = mean water inflow (cubic meters per second), and V = reservoir volume (cubic meters). If F is less than 1, some stratification is expected, the severity of which increases with a smaller F. When F is greater than 1, stratification is not likely.

H. Useful Reservoir Life

18. Useful reservoir life is the expected number of years before a reservoir's dead storage is completely filled, so that further sedimentation reduces the live storage and curtails power generation. Dead storage comprises all reservoir water beneath the level of the intakes for the dam's turbines; all of the water at or above this intake level is part of the live storage. Useful reservoir life is a function of dead storage and river-borne sediment loads. Useful reservoir life is a good indicator of the relative sustainability of electric power generation; it varies from less than ten years before dead storage is filled (such as the Paute Dam in Ecuador) to potentially thousands of years. In general, reservoirs with the longest useful life are relatively deep and situated on rivers with low sediment loads. Maintaining low sediment loads over time typically requires good watershed management.

I. Access Roads through Forests

19. Where the risks of induced deforestation are high, project siting should minimize the kilometers of required new or upgraded access roads passing through or near natural forests.

J. Persons Requiring Resettlement

20. The number of people physically displaced by hydroelectric projects ranges from zero (e.g. Pehuenche, Chile) to over 50,000 in Latin America (e.g. Yacyretá, Argentina-Paraguay) and well over 1 million in Asia (Three Gorges, China). Dam siting should generally seek to minimize the number of individuals or households requiring resettlement from lands affected by the reservoir and complementary civil works. A useful measure for relating resettlement costs to hydropower benefits is the ratio of **people displaced per megawatt** (Table 2). Because of their usually greater vulnerability to social disruption, it is especially important to minimize the number of indigenous people with traditional land-based models of production who would require resettlement.

K. Critical Natural Habitats Affected

21. It is important to know the number of sites and hectares of critical natural habitats that would be lost to inundation, borrow pits, or other project components. Critical natural habitats include existing and officially proposed protected areas, as well as unprotected areas of known high importance for biodiversity conservation. To comply with the World Bank's Natural Habitats Policy, hydroelectric projects should not cause any significant loss or degradation of critical natural habitats. On the other hand, some hydroelectric projects imply very important **conservation opportunities** by providing a strong justification (sediment reduction) and financial resources needed for protecting natural habitats in upper catchment areas.

L. Fish Species Diversity and Endemism

22. Fish species diversity is the number of species known from the project area, including the dam and reservoir site, as well as the downstream zone of project influence. Fish species endemism is the number of native species known only from the project area, or the river system where the project is located, and nowhere else on Earth. Dams are environmentally less objectionable if they affect rivers with a naturally low diversity and endemism of native fish species. In general, large, lowland rivers in warm (tropical or subtropical) climates have a high diversity of native fish and other aquatic organisms, while small rivers in cold (tropical highland or temperate) climates have relatively low diversity. Large, lowland rivers are also more likely to have significant seasonal fish migrations, which are effectively blocked by most dams. However, highland rivers and streams often have relatively high endemism in their fish fauna, especially if they are isolated from other rivers by waterfalls or other natural barriers. River segments with threatened fish species found nowhere else should be classified as critical natural habitats and, ideally, would receive permanent protection from dams or other potentially damaging civil works. However, dams and reservoirs in upper tributary rivers and streams need not threaten the survival of any endemic fish (or mollusks, or other aquatic life) if they affect only an insignificant portion of the river area used by these species (see Indicators D and E); they should also be sited so as not to block important fish migrations.

M. Cultural Property Affected

23. An indication of the cultural significance of the area to be inundated (or otherwise affected by the project) is the number (by type) of cultural (archaeological, historical, paleontological, or religious) objects or sites. It is important to note whether each type of cultural property at the project site is salvageable (totally, partially, or not at all).

Table 2. Land Area Flooded and People Displaced in Large Hydropower Projects

Project (country)	*Installed capacity (MW)*	*Reservoir area (hectares)*	*People displaced*	*Hectares flooded / MW*	*People displaced / MW*
Arun II (Nepal)	402	43	775	<1	2
Pehuenche (Chile)	500	400	0	<1	0
Pangue (Chile)	450	500	50	1	<1
Guavio (Colombia)	1,000	1,530	4,959	2	5
Tehri (India)	2,400	4,200	100,000	2	42
Ghazi Barotha (Pakistan)	1,450	2,640	899	2	1
Nam Theun-Hinboun (Laos)	210	630	0	3	0
Ertan (China)	3,300	10,100	30,000	3	9
Fortuna (Panama)	300	1,050	446	4	1
Chixoy (Guatemala)	300	1,400	3,445	5	11
Grand Coulee (United States)	6,494	33,306	10,000	5	2
Three Gorges (China)	18,200	110,000	>1,300,000	6	>71
Tarbela (Pakistan)	3,478	24,280	96,000	7	28
Salvajina (Colombia)	270	2,030	3,272	8	12
Zimapan (Mexico)	280	2,300	2,800	8	10
Itaipu (Brazil/Paraguay)	12,600	135,000	59,000	11	5
Victoria (Sri Lanka)	210	2,270	45,000	11	214
Kararao/Belo Monte (Brazil)	8,381	116,000	n.a.	14	n.a.
Aguamilpa (Mexico)	960	13,000	1,000	14	1
Betania (Colombia)	510	7,370	544	14	1
Urra I (Colombia)	340	7,400	6,200	22	18
Mangla (Pakistan)	1,000	25,300	90,000	25	90
Bakun (Malaysia)	2,400	70,000	9,000	29	4
Ataturk (Turkey)	2,400	81,700	55,000	34	23
El Cajon (Honduras)	300	11,200	4,000	37	13
Ilha Solteira (Brazil)	3,200	125,700	6,150	39	2
Guri Complex (Venezuela)	10,300	426,000	1,500	41	<1
Salto Grande (Argentina/Uruguay)	1,890	78,300	n.a.	41	n.a.
Nam Theun II (Laos)	1,086	45,000	5,700	41	5
Arenal (Costa Rica)	157	7,000	2,500	45	16
Yacyreta (Argentina/Paraguay)	3,100	165,000	50,000	53	19
Tucurui (Brazil)	3,980	243,000	30,000	61	8
Narmada Sagar (India)	1,000	90,820	80,500	91	81
Porto Primavera (Brazil)	1,815	225,000	15,000	124	8
Churchill Falls (Canada)	5,225	665,000	0	127	0
Khao Laem (Thailand)	300	38,800	10,800	129	36
Kedung Ombo (Indonesia)	29	4,600	29,000	159	1,000
Kainji (Nigeria)	760	126,000	50,000	166	66
Pak Mun (Thailand)	34	6,000	4,945	176	145
Cabora Bassa (Mozambique)	2,075	380,000	250,000	183	120
Aswan High (Egypt)	2,100	400,000	100,000	191	48
Nam Ngum (Laos)	150	37,000	3,000	247	20
Sobradinho (Brazil)	1,050	415,000	65,000	395	62
Kariba (Zambia/Zimbabwe)	1,260	510,000	57,000	405	45
Balbina (Brazil)	250	236,000	1,000	944	4
Akosombo (Ghana)	833	848,200	80,000	1,018	96
Bayano (Panama)	30	35,000	4,400	1,167	147
Kompienga (Burkina Faso)	14	20,000	1,842	1,426	132
Brokopondo (Suriname)	30	160,000	n.a.	5,333	n.a.

n.a. = Data not available.

Sources: Compiled from Goodland 1997, Goodland 1995, Mason 1995, several World Bank project reports, and data provided during the World Commission on Dams Regional Consultation (Sao Paulo, Brazil, August 1999).

1. The data are approximate.
2. Installed capacity is the power generation potential of a project (not the power actually generated) but is easier to calculate *ex ante*.
3. This table should **not** be interpreted as an endorsement *per se* of those projects with favorable ratios of hectares flooded or people displaced per megawatt. Some of the projects with favorable ratios in this table nonetheless have other, unfavorable siting characteristics (in terms of the other criteria noted in this paper); some others were relatively well sited, but implementation of environmental or social mitigation measures was inadequate.
4. This table includes a few multipurpose projects for which hydroelectric power was less important than other objectives (e.g. irrigation water for the Aswan High Dam in Egypt).

Overview of Environmentally Good and Bad Hydroelectric Dam Sites

24. The exact ranking of potential new hydroelectric dam sites will vary somewhat according to the indicators used and the relative weight accorded to each. Indicators similar to those listed above have recently been used in countries such as Colombia and Brazil to incorporate environmental concerns within power expansion plans. However, this methodology is remarkably robust, in that most dam sites tend to get broadly similar ratings, even when different combinations of the environmental indicators A–M are used. An environmentally "good" large dam site (such as Fortuna in Panama) will receive favorable ratings from most of these indicators (including small reservoir surface area with low hectares per megawatt ratio, short water retention time, short stretch of river impounded, and low fish diversity) while a particularly "bad" site (such as Bayano, also in Panama) will receive unfavorable ratings from the same indicators (large flooded area with high hectares per megawatt ratio, long water retention time, much biomass flooded, long stretch of river impounded, and high fish diversity, among others).

Typical Features of Environmentally Good and Bad Hydroproject Sites

25. Although there are many points on a continuum, the typical "bad" large dam site from an environmental standpoint involves: (a) A large reservoir surface area; (b) much flooding of natural habitats and consequent loss of wildlife; (c) a large river with much aquatic biodiversity damaged; (d) a relatively shallow reservoir (sometimes with a fairly short useful life); (e) few or no downriver tributaries; (f) water quality problems due to the decay of submerged forests; (g) location in the lowland tropics or subtropics, conducive to the spread of vector-borne diseases; and (h) serious problems with floating aquatic weeds. Conversely, an environmentally "good" large dam typically involves: (a) A relatively small reservoir surface area (often in a narrow gorge with a high head and even a tunnel); (b) little loss of natural habitats and wildlife; (c) a relatively small (often highland) river with little aquatic biodiversity at risk; (d) a deep reservoir which silts up very slowly; (e) many downriver tributaries; (f) little or no flooding of forests; (g) no tropical diseases (often due to high elevations or temperate latitudes); and (h) no aquatic weed problems. Generalizing from these findings, a useful rule of thumb is that usually the most environmentally benign hydroelectric dam sites are on upper tributaries, while the most problematic ones are on the large main stems of rivers.

Environmental vs. Resettlement Criteria in Site Selection

26. An important tradeoff between environmental and social objectives in hydroproject site selection can emerge with choosing to inundate either (a) relatively wild areas with significant natural habitats but few people (thereby minimizing resettlement needs) or (b) more densely settled areas with few or no natural habitats but many people (thereby minimizing natural habitat loss). This dilemma can be reduced by favoring projects with a small reservoir surface area, which tends to minimize both resettlement needs and natural habitat losses. Also, dam sites with extensive natural habitats often

may harbor very traditional indigenous peoples, for whom successfully resettlement is more difficult than for more socially integrated populations; hydroelectric development at these sites is often best avoided on both environmental and social grounds. Some projects (such as Tucurui in Brazil) have the unfortunate combination of both a major loss of natural habitats and the resettlement of a large number of people (indigenous or otherwise); applying the site selection criteria in this paper will help to keep such "doubly cursed" projects from being highly recommended in future power expansion planning exercises.

Multipurpose Dams

27. Although this paper is focused specifically on dams built exclusively or primarily for hydroelectric power generation, much of our analysis is also applicable to dams constructed for other purposes. For example, with minor adjustments, the same site selection criteria can be applied to dams planned primarily for water supply, whether for drinking water or irrigation. In this case, the relevant indicators could then include the hectares flooded, or people displaced, per million cubic meters (or other unit) of water stored in the reservoir. It is worth noting that many so-called "multipurpose" dam projects claim a variety of benefits (flood protection, navigation, fisheries, and recreation, among others) but their economic viability is determined overwhelmingly by one main objective (normally power generation or water storage). Even for truly multipurpose dams (in which no single benefit predominates in the economic analysis), project planners should take into account the environmental site selection criteria, as well as the available mitigation options summarized in this paper.

Conclusions

28. All large dams are not alike. From an environmental standpoint, there are relatively good dams and bad dams. The amount of possible environmental damage from a proposed hydroelectric project is largely determined by the dam site. While dams at good sites can be very defensible from an environmental standpoint, those proposed at bad sites will inherently be highly problematic, even if all available mitigation measures are properly implemented. Moreover, in the real world of limited budgets, tight construction timetables, conflicting priorities, and weak implementing agencies, the ideal mitigation measures are often not carried out, even if properly planned. For hydroelectric projects, the single most important environmental mitigation measure is good dam site selection. In general, the most environmentally benign hydroelectric dam sites are on upper tributaries, while the most problematic ones are on the large main stems of rivers.

29. Many developing countries still have numerous, and varied, choices for hydroelectric project sites. For example, Colombia has developed less than 10 percent of its potential hydroelectric sites; Ethiopia, about 3 percent. Worldwide, the proportion of developed hydropower sites is roughly 15 percent. Large dams are usually connected to a national or regional electricity grid. Thus, power sector planners should identify those dam sites which would be the least damaging from an environmental standpoint, especially in relation to the amount of electric power or other economic benefits generated. The relatively simple, quantitative indicators proposed in this paper should be used for preliminary rating and ranking of proposed new hydroprojects in terms of their expected adverse environmental impacts, until more complete information is provided by sectoral environmental assessments or other detailed studies. Power sector expansion planning should ensure that environmental criteria, of the types outlined in this paper, are given appropriate weight, in relation to the social, economic, financial, and other criteria that are typically used in hydroproject site selection.

30. At the same time, many hydroelectric project sites are best left undammed, because developing them would cause unacceptably high environmental damage. If all of the feasible hydroelectric dam sites in a country (or other power sector planning unit) are environmentally highly undesirable, it is preferable to promote other power generation technologies, including renewable sources (such as wind, photovoltaic, and biomass) as well as fossil fuels (especially natural gas, which is environmentally more benign than petroleum or coal). On the other hand, those hydroprojects at good sites (with fairly low adverse impacts)--and with a high probability that proper mitigation measures will be effectively implemented--are likely to be more attractive from an environmental standpoint than the most likely power generation alternatives (which will also have some adverse environmental impacts).

Bibliography

Andrews, J., and D. Kinsman. 1990. *Gravel Pit Restoration for Wildlife*. Royal Society for the Protection of Birds, U.K.

Claffey, Patrick. 1999. "Dams as New Habitat in West African Savannah." *Bull ABC* 6(2): 177–120.

Colombia, Ministry of Energy and Mines. 1992. *Sector Eléctrico Colombiano: Plan de Expansión de Referencia Generación–Transmisión*. Interconexión Eléctrica S.A., Medellín.

da Gloria Lima Cruz Teixeira, M., M. da Conceição Nascimento Costa, V. Lucia Pires de Carvalho, M. dos Santos Pereira, and E. Hage. 1993. "Gastroenteritis Epidemic in the Area of the Itaparica Dam, Bahia, Brazil*." Bulletin of the Pan American Health Organization* 27(3): 244–253.

Dampier, B. 1981. "Hydropower: Untapped Resource and Environmental Hazard." *Ambio* 10(5): 252–253.

Dixon, John A., Lee M. Talbot, and Guy J.-M. LeMoigne. 1989. *Dams and the Environment: Considerations in World Bank Project*s. World Bank Technical Paper No. 110. Washington, D.C.

Fearnside, Philip M. 2001. "Environmental Impacts of Brazil's Tucuruí Dam: Unlearned Lessons for Hydroelectric Development in Amazonia." *Environmental Management* 27(3): 377–396.

Freeman, P. H. 1974. "The Environmental Impact of a Large Tropical Reservoir: Guidelines for Policy and Planning." Paper based on a case study of Lake Volta, Ghana, in 1973 and 1974. Available from the National Technical Information Service, Springfield, Va. Washington, D.C.: Smithsonian Institution.

Gagnon, L. 1998. "Greenhouse Gas Emissions from Hydro Reservoirs: The Level of Scientific Uncertainty in 1998." Montreal: Hydro-Quebec.

———. 2002. "The International Rivers Network Statement on Greenhouse Gas Emissions from Reservoirs: A Case of Misleading Science." International Hydropower Association, U.K.

Giampaoli, D. A. 1986. "Hydro Development in Latin America: A View from IDB." *International Water Power and Dam Construction* 38(6): 13–14.

Goodland, Robert. 1995. "The Big Dam Controversy. Killing Hydro Promotes Coal & Nukes: Is That Better for Environmental Sustainability?" Prepared for the Public Lecture in GTE Technology and Ethics Series. Washington, D.C.: World Bank.

———. 1996. "The Environmental Sustainability Challenge for the Hydro Industry." *Hydropower & Dams* 1: 37–42.

———. 1997. "Environmental Sustainability in the Hydro Industry: Disaggregating the Debate." In IUCN–World Conservation Union and the World Bank, *Large Dams: Learning from the Past, Looking at the Future*. Cambridge, U.K., and Washington, D.C.

Goodland, Robert, A. Juras, and R. Pachauri. 1993. "Can Hydro-Reservoirs in Tropical Moist Forests Be Environmentally Sustainable?" *Environmental Conservation* 20: 122–130.

Gutman, Pablo. 1993. "Involuntary Resettlement in Hydropower Projects." IEN Staff Report. World Bank, Industry and Energy Department, Washington, D.C.

Hafez, M., and W. K. Shenouda. 1977. "The Environmental Impacts of the Aswan High Dam." *Water Management and Development, Proceedings of the United Nations Water Conference, Mar del Plata, Argentina, March 1977* 1(4): 1777–1786. New York: Pergamon Press.

Hunt, C. E., and V. Huser. 1988. *Down by the River: The Impact of Federal Water Projects and Policies on Biological Diversity*. Washington, D.C.: Island Press.

International Commission on Large Dams. 1988. *World Register of Dams*. Paris: ICOLD.

International Rivers Network. 1993. "World Bank Dams: A Complete List of Dams Funded Directly by the World Bank." *World Rivers Review* Second Quarter: 9–12.

ICOLD. 1988. *World Register of Dams.* International Commission on Large Dams, Paris.

IUCN–World Conservation Union, and the World Bank. 1997. *Large Dams: Learning from the Past, Looking at the Future*. Workshop proceedings from Gland, Switzerland, April 11-12, 1997. Cambridge, U.K., and Washington, D.C.

Ledec, George. 2000. "The World Bank's Natural Habitats Policy: A Tool for Mainstreaming Conservation within Development Projects." Hong Kong: International Association for Impact Assessment, Annual Meeting.

Ledec, George, and Paula Posas. 2003. "Biodiversity Conservation in Roads Projects: Lessons from World Bank Experience in Latin America." *Transportation Research Record,* No. 1819.

Liao, W., D. S. Bhargava, and J. Das. 1988. "Some Effects of Dams on Wildlife." *Environmental Conservation* 15(1): 68–70.

Mason, Douglas. 1995. "The Environmental and Social Impacts of Hydroeletric Dams: Case Studies from Latin America." Dissemination Note draft. World Bank, Washington, D.C.

McCully, Patrick. 1996. *Silenced Rivers: The Ecology and Politics of Large Dams*. London: Zed Books.

Monosowski, E. 1991. "Dams and Sustainable Development in Brazilian Amazonia." *International Water Power and Dam Construction* 43(5): 53–54.

Palmieri, A. 2003. *Reservoir Conservation: Economic and Engineering Evaluation of Alternative Strategies for Managing Sedimentation in Storage Reservoirs* (2 volumes). World Bank, Washington, D.C.

Pangue S.A. Electrical Company. 1992. *Environmental Aspects of Pangue Project*. Santiago, Chile.

Poole, Alan Douglas. 1999. "Energy Trends in Brazil and Large Dams." Paper prepared for the Second World Commission on Dams Regional Consultation held in São Paulo, Brazil, August 12-13, 1999.

Razvan, E. 1992. "The Environmental Impact of Large Dams." *International Water Power and Dam Construction* 44 (October): 48–50.

Rudd, J. W. M., R. Harris, C. A. Kelly, and R. E. Hecky. 1993. "Are Hydroelectric Reservoirs Significant Sources of Greenhouse Gases?" *Ambio* 22: 246–248.

Russo, T. N. 1994. "Making Hydropower Sustainble." *Hydropower & Dams* November: 126–131.

Salas, H. J., and P. Martino. 1991. "Simplified Phosphorus Trophic State Model for Warm-Water Tropical Lakes." *Water Research* 25(3): 341–350.

Szekely, F. 1982. "Environmental Impact of Large Hydroelectric Projects on Tropical Countries." *Water Supply and Management* 6(3): 233–242.

United Nations Environment Programme. 1978. "Environmental Issues in River Basin Development." *Water Management and Development, Proceedings of the United Nations Water Conference, Mar del Plata, Argentina, March 1977* 1(3): 1163–1172. New York: Pergamon Press.

U.S. Congress, Office of Technology Assessment. 1995. *Fish Passage Technologies: Protection at Hydropower Facilities.* Washington, D.C.: U.S. Government Printing Office.

Veltrop, J. A. 1991. "Water, Dams and Hydropower in the Coming Decades." *International Water Power and Dam Construction* 43(6): 37–44.

Wali, Alaka. 1989. *Kilowatts and Crisis: Hydroelectric Power and Social Dislocation in Eastern Panama*. Boulder, Colo.: Westview Press.

World Bank. 1985. "Inventory of Dams Related to World Bank Projects." Volume 2, No. 6: Latin America and the Caribbean Region. Agriculture and Rural Development Dept. Washington, D.C.

———. 1991a. *Environmental Assessment Sourcebook. Volume III: Guidelines for Environmental Assessment of Energy and Industry Projects*. World Bank Technical Paper No. 154. Environment Department, Washington, D.C.

———. 1991b. *Operational Directive 4.20: Indigenous Peoples*. Washington, D.C.

———. 1994. *The World Bank Policy on Disclosure of Information, BP 17.50*. Washington, D.C.

———. 1996a. "Analysis of Alternatives in Environmental Assessment." Environmental Assessment Sourcebook Update No. 17. Washington, D.C.

———. 1996b. "World Bank Lending for Large Dams: A Preliminary Review of Impacts." OED Précis No. 125. Operations Evaluation Department, Washington, D.C.

———. 1997. "Hydropower Dams and Social Impacts: A Sociological Perspective." Environment Department Paper No. 44. Environment Department, Social Policy and Resettlement Division, Washington, D.C.

———. 1998. *Environmental Assessment Operational Policy 4.01.* Includes *BP 4.01, Annex B: Application of Environmental Assessment to Dam and Reservoir Projects.* Washington, D.C.

———. 1999 *Operational Policy Note No. 11.03: Management of Cultural Property in Bank-Financed Projects.* Washington, D.C.

———. 2001a. *Operational Policy 4.04: Natural Habitats*. Includes Bank Procedures 4.04 and Good Practices 4.04. Washington, D.C.

———. 2001b. *Operational Policy 4.12: Involuntary Resettlement*. Washington, D.C.

———. 2003. *Water Resources Sector Strategy: Strategic Directions for World Bank Engagement.* Washington D.C.

World Commission on Dams. 2000. *Dams and Development: A New Framework for Decision-Making.* London and Stering, Va.: Earthscan Publications, Ltd.

Woynarovich, E. 1991. "Hydroelectric Power Plants and the Fish Fauna." *Internationale Vereinigung fuer Theoretische und Angewandte Limnologie* 24(4): 2531–2536.

Ziegler, T. 1995. "The Norwegian Master Plan for Hydropower and Water Resources." Washington: World Bank, unpublished.

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