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Environmental methodologies

for small hydropower projects

NRECA Small Decentralized Hydropower (SDH) Program

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Small decentralized hydropower program

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Through its Small Decentralized Hydropower (SDH) Program, the National Rural Electric Cooperative Association (NRECA), is developing a broad range of documentary materials for the use of SDH planners, managers, and consultants involved in small hydropower programs for developing nations. Several methodological guides, of which this is one, describe simple estimating and measurement techniques, rules of thumb, and common sense approaches which can be very helpful to SDH practitioners in the field, particularly in remote or rural areas where recorded data is scarce and sophisticated instrumentation not available.

These methodological guides are intended to be used by people with training and experience in water resource development and/or power generation, but perhaps with less experience in small scale projects or in developing countries. The hints and guidelines described in these documents are derived from the field experience and information abstracted from the extensive literature on small hydropower development.

This methodology was prepared with the assistance of Dr. Gene E. Willeke, Director, Institute of Environmental Sciences, Miami University, Oxford, Ohio.

Contents

Introduction, 1

Prefeasibility methodology, 2
Methodology, 2
Mitigating measures, 4

Feasibility methodology, 5
Basic elements of impact assessment, 5
Impact assessment issues, 6

Conduct of the assessment, 7
Process, 7
Environmental setting, 7
Project description, 9
Environmental impact factors, 9
Identification and evaluation of impacts, 10
Environmental impact profiles, 10
Profile development, 11
Table development, 13
Mitigating and complementary measures, 13

Appendix A: Environmental impact factors, 16

Appendix B: A review of potential impacts, 17
Flow disruption, 17
Sedimentation, 18
Alternative water uses, 20
Flood control, 20
Water quality, 21
Impacts on aquatic organisms, 21
Waterborne diseases and parasites, 23
Construction impacts, 24
Land use and development, 25
Nutrient and sediment trapping effects, 26
Aquatic weeds and eutrophication, 27
Wildlife impacts, 28
Secondary impacts, 29
Irreversible and irreparable impacts, 29

Appendix C: Literature cited, 31
Additional references, 33

Introduction

Assessing environmental impacts should be a part of the prefeasibility and feasibility studies for small hydropower projects. The environmental assessment is used along with power, economic, and social analyses in evaluating the desirability and feasibility of a proposed project.

Methodologies for prefeasibility and feasibility studies have been prepared by the National Rural Electric Cooperative Association's Small Decentralized Hydropower (SDH) program as guides for evaluating potential small hydropower sites. The methodologies incorporate environmental assessment techniques[1] intended to be sufficiently general for worldwide application.

The users of the methodologies, who are expected to have at least some experience in water resource and/or environmental studies, must make judgments as to whether each impact is significant or insignificant, detrimental or beneficial. At some stage, a judgment may be required as to whether the impact is acceptable or unacceptable. These judgments will not be the same worldwide. Both project objectives and cultural characteristics of the country will be important in making value judgments. The initial procedures for identifying and assessing impacts, however, are generally applicable.

Hydro projects as large as 15,000 kilowatts are sometimes called small, or mini, hydro. However, the range of projects for which this methodology is appropriate is not as great. Typical projects will have diversion structures under 5 meters in height. The head may be appreciably higher, if water is conveyed by canal or pipe to a place where a larger head can be obtained (see the sketch in figure 1). A few projects may use larger diversion structures which are already there for another purpose (such as municipal/industrial water supply or irrigation).

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[1] These methods were developed in part by Glenn F. Cada and Frank Zadroga, "Environmental Issues and Site Selection Criteria for Small Hydro Power Projects in Developing Countries," report to National Rural Electric Cooperative Association, October 1980.

The fundamental considerations at the prefeasibility stage are the cost and potential economic value of the project.[2] The environmental impact of a small hydro power project is often small compared with that of other energy technologies. However, a preliminary environmental assessment, conducted during this phase, helps in identifying viable sites.

The prefeasibility environmental assessment is confined mainly to identifying the most likely impacts of the proposed project, suggesting mitigating measures, and analyzing alternatives in order to determine which sites are environmentally viable. The term 'environmentally viable' does not necessarily indicate that the proposed project, or an alternative, is acceptable. It does indicate that a more detailed analysis is warranted if the site is acceptable in other respects.

Methodology

The answers to several major questions are sought in this prefeasibility assessment--

Is the provision of electrical energy in the area desirable, and will development stimulated by the provision of electrical energy be productive and protective of the resource base?

Is there enough water of adequate quality to support a hydropower project?

Are there any legal, historical, religious, archeological, scientific, wildlife or habitat features of the project area that would preclude project development?

Will relocation of people be required? If so, is relocation feasible?

In the event of dam failure, would any downstream populated area be endangered?

Are there any special physical characteristics of the site that would make it not feasible, such as volcanic activity, earthquakes, soil and rock instability, or inability to store water (as in certain limestone and basalt bedrock situations)?

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[2] See "Prefeasibility studies of candidate mini-hydro sites: A methodology," NRECA, March 1982, for a description of a prefeasibility study.

If the answer to either of the first two questions is no or the answer to any of the other four questions is yes, there are serious environmental questions about the site. It should either be eliminated from further consideration or major attention must be given to resolving the issues raised by these questions.

A second group of serious questions is listed below. Here the consequences may also be serious enough to preclude further consideration of the site, but there is a greater possibility of being able to deal with them in a satisfactory way, if there is adequate community interest in upholding the environmental aspects of the project--

Will the project be added to an existing facility or will construction of a dam and reservoir be required?

If there are undesirable environmental effects, can measures be taken to reduce their severity within the time and budgetary constraints?

Are there likely to be adverse health effects, such as parasites, diseases transmitted by insects, and waterborne diseases?

Would development for hydropower interfere with the supply of water for other uses?

To answer these questions, it is necessary to have descriptive information about the project, including--

Major characteristics of the proposed project (diversion structure size, type, and location: impoundment characteristics; land required; transmission line and powerhouse characteristics)

Special status of the project area, such as wildlife preserve, military reservation, archeological site, religious shrine, or historical landmark

Hydrologic data (mean flow, seasonality of flow, extreme high and low flows, sediment type and load, and unusual chemical characteristics)

Present and projected development and land use in the area with and without the project, including agricultural and forestry uses, industrial uses, commercial fishing, and recreation uses

Presence of existing facilities, such as dams, reservoirs, irrigation canals, hydroelectric powerplants, and transmission lines

Population and settlement patterns above, below and around the site, with implications for relocation, flooding potential, and safety hazards

Disease organisms indigenous to the region that might become prevalent in the area as a result of a hydropower project

Present domestic, industrial, recreation and agricultural water use

Physical site characteristics including soil and rock characteristics, volvanic and earthquake activity, karst conditions, etc.

Mitigating measures

During the prefeasibility study it is likely that environmental impacts will be identified which will affect other aspects of the study. For example, if a mitigation measure is required, the cost of the measure, the time required to do it, and the time at which it should be done may well affect the overall economic feasibility of the project. This information should be incorporated as soon as it can be provided.

In the feasibility assessment, the objective is to determine potential impacts of the proposed project in detail. The environmental assessment at the feasibility stage requires more data and a more systematic approach to use of the data than at the earlier stage.

There are sound, pragmatic reasons for undertaking an impact assessment. First, there may be a legal requirement to do an impact assessment as a precondition to obtaining funding or permits. Second, and an underlying reason for the first, unanticipated environmental impacts can be costly. Human health may be affected. Loss of land, crops, or livestock may occur. Wildlife and ecosystems may be endangered. Less tangible, but nevertheless resources important to a country or region (such as historic or archeologic sites, religious shrines, parkland and recreation sites) may be lost or threatened.

Many projects around the world have led to disastrous environmental consequences. These effects are most often associated with large projects. The likelihood of serious effects is usually much less for smaller projects. That likelihood is nevertheless real and should be considered. In all design work, it is good practice to evaluate a project configuration or design from many various standpoints. In a small hydroelectric project, for example, the project is examined from the standpoint of availability of water, suitability for an impoundment, distance from load center, and demand for power. Environmental impact is another aspect that merits explicit attention.

Basic elements of impact assessment

The basic steps in environmental impact assessment are--

Describe the environmental setting without the project including both things as they are at the time of the study and as they are projected to be in the future without the project

Identify critical environmental factors likely to be affected with projects of this type

Describe the features of the proposed alternative projects

Make projections of changes in the environment that might be expected from each alternative

Evaluate these changes as to whether they are short-term or long-term, beneficial or adverse, avoidable or unavoidable, important or unimportant. Impacts usually cannot all be directly compared. Rather, the analyst summarizes the impacts with as high

a level of aggregation as is feasible, and displays this information to project advisors and/or decision-makers.

Technical judgments must often be substituted for measurements and calculations in environmental impact assessment, given the state of scientific data bases and understanding. Value judgments are essential as to the potential importance and acceptability of impacts.

Impact assessment issues

The issues to be addressed in the impact assessment will vary somewhat from country to country. One frequently cited set of issues is contained in the U.S. National Environmental Policy Act. The five issues are--

The environmental impact of the proposed action

Adverse environmental effects which cannot be avoided should the proposal be implemented

Alternatives to the proposed action

The relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and

Any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented.

The general message is clear, but for operational use in the field, additional interpretation is necessary. U.S. agencies have developed very detailed interpretations, which cannot be fully and directly transplanted to another country, because of their deep roots in the U.S. legal and cultural system. However, elements of these interpretations have been borrowed and adapted for the methodology that follows.

Process

The preparation of an environmental impact assessment can be simple, or it can be complicated. The potential impacts are many and varied. Modifications are frequently made in the proposed project during the assessment. To cope successfully with these factors, orderly process is needed.

First, the results of the prefeasibility assessments are reviewed. Persons knowledgable about the area are consulted for advice on the facility and on the availability of pertinent information.

Second, available information is reviewed and summarized. It includes maps, project descriptions, and other data. A more detailed work plan is prepared to guide the remainder of the investigation.

Third, agencies, organizations, and individuals that need to know about or be involved in the investigation are informed and plans laid for their involvement.

Fourth, field studies are undertaken, including at least one visit to the site. New data is collected, if necessary. During the field visit, some judgments can be made about the overall impact of the project and about mitigating measures or alternative ways either to enhance its usefulness or to reduce adverse environmental impacts. Local feelings about the project can be ascertained while in the field. However, informal observations can not take the place of more formal analysis of social and economic impacts.

Fifth, the impact assessment report is written and reviewed. Inaccuracies are corrected and the judgments made by the impact assessment team are evaluated.

The report should concentrate on the principal environmental issues and impacts. Not all of the information examined need be included. The assessment report is to be used in decision-making, it is not a piece of scientific research.

Environmental setting

The environmental setting is a description of the project area. It describes to someone who hasn't been there what the 'environment' is like. The most important purpose is to identify items that are environmentally signficant, and aspects of the environment that would be markedly changed if the project is undertaken.

The physical features of a small hydro project most likely to cause environmental impacts are new impoundments, the canal or pipeline used to carry water to the penstock, the powerhouse, and the outlet works. The methods of construction can bring about adverse impacts: for example, unnecessary carelessness in earth moving or spoil disposal; or the introduction of a disease-carrying vector by a construction crew.

Project operations can also bring about adverse impacts, especially if the project is one that has substantial storage. Sudden releases of water or sudden curtailment of releases can adversely affect fishing, navigation, water quality, and recreation below the diversion structure.

If a transmission line is regarded as part of the project, there are often associated environmental impacts. The transmission line route should be included in the description of environmental setting.

The following list of questions and items is a checklist for preparing the description of the environmental setting. Other items that look important can be added. Inappropriate items can be omitted--

How is the land in the area being used? Include the percentage of land being used for farming, urban uses, forests, etc. A map showing these land uses should be prepared.

What is the vegetation pattern of the area? Include both a general classification (grasslands, forests, cropland) as well as a more detailed description of the principal species of plants in each of the vegetal areas. But a complete species inventory is too time-consuming and contributes little to assessment of impacts.

What are the streams and other watercourses, such as canals, like? Give the approximate dimensions of the watercourses, their flow capacity, the extremes and mean flow, a characterization of water quality, presence or absence of fish (especially food fish and rare fish), and navigability and other uses of the watercourses. If the watercourses are used for waste disposal, this should be noted along with the sources and kinds of waste discharged. Sediment loads in the stream are of considerable importance. The kinds of sediment, size distributions of sediment particles, and the approximate concentrations should be noted.

Are there water-related health problems in the area? These might be either problems caused by the use of chemical or microbiological contaminated water or problems associated with disease-carrying vectors such as mosquitoes.

What uses are being made of the water now? Is it a source of potable supply? Is it used for irrigation, for navigation, for

fishing, for recreation, or for industrial processes, including cooling?

What is the nature of the soils in the area? Describe soil types, depths of the various soil horizons, and fertility.

Project description

The project description, prepared in preliminary engineering work, will need to be supplemented for the impact assessment. At a minimum, one needs to know the location, size, and features of the proposed project alternatives. This includes the alignment, height, and type of construction of the diversion structure; the alignment, elevation, and cross-sectional properties of any canals, pipes, or penstocks; the location, size, type, and elevation of the turbine structures; the tailrace properties; and the alignment, voltage, and type of structures used on the transmission line.

Some projects will also include roads, housing, workshops, storage yards, and warehouses. Their location and characteristics should be described.

Construction of facilities requires imported and local materials, labor, and equipment. If there is to be quarrying or mining of construction materials, the location of these operations and the kinds and amounts of materials to be extracted should be included as part of the project description. The construction process nearly always includes excavation and transport of soil. Disposal areas for spoil material should be identified and described.

Construction procedures are also part of the project description. A common problem in construction is land stripping considerably in advance of further operations, leading to heavy erosion of soil. Erosion during construction cannot, of course, be eliminated, but it can be minimized with good procedures. Disposal of other waste materials: fuel spillage and overflow, chemicals of various sorts, surplus and wasted concrete, can present problems, all of which can be minimized with well-designed procedures. A key reason for including construction procedures in the project description is to be sure that their impacts can be adequately addressed in the mitigation section of the assessment report.

Environmental impact factors

A checklist, appendix A, is useful in planning the data collection program. The objective is to obtain enough relevant data to perform the impact assessment. Maps, aerial photos, site surveys, and research investigations are all desirable. In most instances, it will be necessary to collect field data at the various sites. At least one visit to the site should be made before completing the assessment.

Identification and evaluation of impacts

An early step in the feasibility study is the identification of potential impacts. Appendix B contains a description of potential environmental impacts for consideration in performing a feasibility assessment. This description was taken from the report "Environmental Issues and Site Selection Criteria for Small Hydro Power Projects in Developing Countries," by Glenn Cada and Frank Zadroga, previously cited on p. 1.

The evaluation of impacts is only one part, although a very important part, of the complete feasibility study. In looking at all aspects of project feasibility, it will be found desirable to aggregate impacts, but this should not obscure their character. In a partially aggregated display of impacts, it is possible to make judgments as to their relative importance as compared with each other and with other kinds of impacts or effects.

Impacts are labeled either positive or negative; temporary or permanent; and either highly significant, moderate, slight, or insignificant. Impacts not well enough known to evaluate should be labelled as unknown. These general, ordinal terms are made more concrete in the environmental profile of the project. The profile or table is the basic approach to analyzing, summarizing and displaying impacts. It is easy to use and to explain. Moreover, judgments of others may be easily incorporated in the analysis, whereas highly aggregated data may so obscure the relevant information that other analysts and decision-makers can not easily make judgments of their own to supplement or replace those of the original analysts.

Environmental impact profiles

In preparing an environmental impact profile, the project components and/or its impacts are first divided into logical groups. Factors of environmental importance are listed for each of the components. Each factor is then rated according to the degree of positive or negative impact. An indication of whether it is temporary or permanent in nature may be given in the remarks column.

For complex projects, it is helpful to further subdivide the profile into the various stages of the hydroelectric project: planning and design, construction, and operation. Environmental impacts occur even during the planning and design stage. For example, exploration of a site may involve drilling, blasting, and off-road travel. Land speculation in anticipation of development is common, in places where some or all of the land is in private ownership. There are often social and economic impacts deriving from uncertainty about the fate of a proposed project. Planning for the provision of other public services will likely be affected, e.g., developing housing, considering a new crop or agricultural practice, or purchasing equipment not dependent on

the electricity available from the proposed project rather than equipment that must be run by this electricity. In the planning and design stage, acquisition of land for the project will occur, with possible dislocation of people and property. This may be a very significant impact.

The impacts of a project can be summarized in a single profile, but there are advantages in developing a separate profile for each of the three stages (planning and design, construction, and operation) either as an intermediate step in the impact assessment or as part of the final assessment.

The profile is one of several techniques that may be used to display the results of an impact assessment. A matrix or table may also be used.

Profile development

The steps in developing a profile are as follows:

Step 1. Develop the list of factors to be included in the profile, organized into logical groups or into a rank-ordered list. The former is usually preferable. The logical groups might include: water quality, groundwater recharge, downstream effects, and displacement of people. Alternatively, the groups might be project components, such as planning and design, dam construction, powerplant construction, canal construction, and transmission line construction.

Step 2. For each alternative, determine for each factor the degree of positive or negative impact, and plot it on the profile, as shown in figure 1.

Step 3. Determine whether any alternative is superior to all other alternatives on all factors, or inferior to all alternatives on all factors. The former clearly indicates a superior environmental alternative and the latter clearly an inferior environmental alternative. In either of the two cases, an alternative is said to either dominate or be dominated by another alternative. Attention is then directed towards alternatives where each is better on some factors and poorer on others. Comparison of these remaining alternatives is best done in pairs--that is, considering two at a time. A judgment is made as to which is superior, considering all factors, and it is compared to another alternative. This process is continued until all alternatives have been considered. It is often useful to draw a profile line for each alternative, connecting all points on the profile for a given alternative. See lines A, B, and C on figure 1.

Several pieces of a profile are given in the accompanying sketch to illustrate the method. Three alternatives are plotted. In this profile piece, several of the points discussed are

Figure 1

Environmental impact profile

Component and parameter	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5	Remarks
	Degree of impact											
Dam construction												
Erosion		A	C		B							Temp.
Water pollution	A		B	C								Temp.
Water table increase			A	C		B						Perm.
Employment							A	B	C			Temp.
Operation												
Disease vectors			A	C		B						Perm.
Tourism/recreation	A						B	C				Perm.
Commercial fishing	A			B	C							Perm.
Employment						A	C	B				Perm.

Profile notes

Severe negative impact is represented by -5.
No impact is represented by 0.
Highly beneficial impact is represented by +5.

illustrated. First, alternatives B and C are dominant on the factors listed in this portion of the profile. On every factor, B and C either have less negative impact or greater positive impact than A. Neither B nor C has a decisive advantage over the other. Judgments must be made. B is superior to C on four factors, and C is superior to B on four factors. If, for example, a water table increase was judged to be a serious, highly important factor, the overall evaluation might have B preferred to C. On the other hand, if commercial fishing and recreation are regarded as more important, C might well be preferred to B.

Table development

A matrix or table may also be used to display the same information. The same format could be used, but with table entries rather than a semi-graphical array. The more common method has been to use a different column for each alternative. A sample is given for the same data as are displayed in the profile (figure 2). The table entries are then either positive or negative numbers (such as -5 to +5) or symbols that represent the same information. Either will work.

If numbers are used, a word of caution is in order. It is tempting to add the numbers and say the highest positive or least negative total is the preferred alternative. Such a practice does not take into account the fact that the various impacts have different degrees of importance. In the case used to illustrate the profile, erosion during construction is likely to be less important than a permanent water table increase. Commercial fishing may be more important than tourism. In either or both of these cases, the addition of the numbers would yield misleading information.

In both the profile and the table, or matrix, an important consideration is the display of information. Those who must evaluate the report and the various alternatives can determine for themselves what degree of importance should be attached to each factor. Some methodologies seek to aggregate all the information into a single index of worth. In the two methods given here, the emphasis is on revealing rather than concealing information.

Mitigating and complementary measures

Where significant detrimental impacts are expected, analysis of possible mitigating measures should be done to determine whether problem areas may be made less detrimental, and in order to increase the overall benefits of the project. If design modifications are made after mitigating measures, a profile of the modified project should be prepared. The earlier that detrimental impacts can be identified and mitigating measures proposed, the easier will be the task of preparing the final environmental impact profiles.

Figure 2
Environmental impact table

Component and parameter	Alternative A	Alternative B	Alternative C	Remarks
Dam construction				
Erosion	-4	-1	-3	Temporary
Water pollution	-5	-3	-2	Temporary
Water table increase	-3	0	-2	Permanent
Employment	+1	+2	+3	Temporary
Operation				
Disease vectors	-3	-2	0	Permanent
Tourism/recreation	-5	+1	+2	Permanent
Commercial fishing	-5	-2	-1	Permanent
Employment	-1	+2	+1	Permanent

Table notes

Severe negative impact is represented by -5.
No impact is represented by 0.
Highly beneficial impact is represented by +5.

Not infrequently, complementary actions by other agencies or organizations may be indicated to make the project or mitigating measures possible and viable. Control of mosquitoes by another agency, for example, might be necessary to prevent serious health problems resulting from impoundments. Land treatment may be needed to prevent erosion on adjacent land, with attendant sedimentation in the impoundment. The cooperation and action of other agencies may be needed in resettling people who are displaced by project construction. Examination of such complementary actions should be done as part of the impact assessment, usually at the stage where mitigating measures are considered.

Appendix A

Environmental impact factors

A basic listing of environmental impact factors is included in this appendix. These are factors that have been encountered in assessing impacts of impoundments, powerplants, and transmission lines. As with any list, it is certain to be incomplete, and to contain some items that will be irrelevant in a particular case.

1. Changes in land use and/or productivity. This may include, for example, agricultural or forest land, wetlands or marshes, commercial fisheries (including small-scale fishing operations), and mining.

2. Loss or relocation of structures and archeological/historical sites. In this category are included homes, commercial buildings, transportation facilities, cemeteries, and recreational facilities.

3. Changes in wildlife habitat. Usually, construction causes some reduction in wildlife habitat. However, impoundments may increase the habitat for waterfowl and certain kinds of fish.

4. Loss or inundation of the natural stream. The primary effects here are loss or reduction of the stream fishery and loss of some recreation potential. There may also be a reduction or elimination of some navigation. The lake environment is substituted for a stream environment.

5. Alterations of water quality. For small impoundments, this is likely to be increased algae growth and lower rates of reoxygenation. For deeper reservoirs, there may also be some thermal stratification.

6. Downstream effects. Decreased silt in the channel may lead to some downcutting in the channel below the impoundment.

7. Effects on groundwater. The two twin effects are increased recharge from the impoundment, which may or may not be a benefit (water table may rise too high), and reduced water table level below an impoundment.

8. Erosion around transmission towers.

Appendix B

A review of potential impacts

Small hydro power projects encompass a wide range of facility designs and environmental settings. For example, the basic criterion of a small hydro power project, i.e., a generation capacity of 1000 kW of electricity, can be satisfied by either high head/low flow or low head/high flow installations, and the environmental impacts resulting from the two designs are likely to be quite different. Similarly, the creation of a reservoir to store water for reliable, year-round generation may be required at some sites and not at others. This factor is of fundamental importance to the assessment of environmental effects, since impoundment of water can result in a number of physical, chemical, and biological changes in the stream that will not occur with a run-of-the-river, no-impoundment design. The discussions of potential impacts that follow cover the entire range of small hydropower project designs. Some of these considerations may not be relevant to particular installations or sites.

As with most man-induced stresses, the magnitude of environmental impacts resulting from development is generally related to the size of the facility. A 100 kW facility is likely to cause fewer problems than a 1000 kW facility, simply because the amounts of construction material, watershed disturbance, grading, and diverted water are less. Of equal importance, however, is the amount of water diverted relative to the total flow in the stream. A 100 kW plant may have a greater impact if it withdraws a proportionately larger amount of the flow from a small stream than a 1000 kW plant would have if located on a large river. The significance of environmental impacts can vary seasonally; a 100 kW project may have little adverse impact during high stream flows in the rainy season but may represent a significant stress to the aquatic system during times of low flow. These variable conditions must be considered during the conduct of the feasibility study in order to arrive at a reliable evaluation of environmental impact.

Flow disruption

All small installations will result in a disruption of the natural streamflow. Depending on facility design, the amount of runoff available, and the extent of groundwater recharge, this impact may vary from completely stopping the flow for some distance downstream to an augmentation of natural flows.

Operation and design factors have a major influence on the extent of flow disruption. The potential for flow regulation is greatest for projects that utilize mainstream impoundments for water storage, since downstream flow may be curtailed on a daily or

seasonal basis as the reservoir is filled. Conversely, downstream flow can be increased above natural rates during generation or when large volumes of water are used to flush silt and sediments from the intake structure. The increased flow will give rise to large tractive forces, possible channel degradation in the form of bank and bed erosion, and downstream sedimentation effects. Some small installations could import water from other watersheds in order to augment natural flows in the stream. This inter-basin water diversion invariably involves a net loss of water from the donor basin and a net gain to the recipient basin. The impact of such gains and losses, which should be evaluated for both basins, may be positive or negative, depending on water use, water abundance in both basins, and the amount of flow diverted. The design that is least disruptive of natural flows is one that operates in a run-of-the-river mode, has no water storage reservoir, and returns diverted water back to the same stream at a lower elevation. There is no net gain or loss of water with this type of installation, and the only stretch of river affected by reduced flows is the area downstream of the intake structure and upstream of the discharge.

Site-specific environmental features can also modify flow disruption impacts. For example, substantial groundwater recharge and/or tributary inflows downstream from an impoundment can reduce the potential adverse impacts of flow cessation. In general, flow disruption impacts will potentially be greater for drier regions or smaller streams and less for wetter climates or large streams.

Detailed consideration of flow regulation and disruption effects on the physical and biological environment is provided in Hildebrand (1980a).

Sedimentation

Sedimentation impacts are important for two reasons. High suspended sediment loads in the stream can affect operation and maintenance of the turbine (i.e., sediments cause turbine pitting and accelerated wear), and sediment loads resulting from project construction and operation can have adverse impacts on the aquatic system.

Different kinds of equipment have variable sensitivities to sediment damage. Water wheels, for example, can withstand heavy sediment loads with few adverse effects. Turbines, on the other hand, are much more subject to excessive wear and pitting when coarse-grained sediments are entrained in the water. In general, it is desirable to maintain the highest water quality possible. This can to a large degree be attained by a watershed management plan in which land uses in the catchment are matched to the land use capability, and through strict control of project construction impacts. Information on sediment loads is an important criterion for both feasibility determination and the design of the engineering structure. The quantification of suspended sediments

should be initiated early, preferably at the prefeasibility stage.

Sediment transport affects both the physical aspects of water quality and the biotic community in the stream. High sediment loads may foreclose certain water uses such as potable water and irrigation. Where impoundment or decreased water velocities occur, sediment loads will drop out and fill up engineering structures such as irrigation canals, or reservoirs, thereby increasing maintenance costs or decreasing the useful lifetime of the structures.

The sediment discharge of a watershed basin is related to several factors, including climate and geology. Proper land use is of utmost importance in maintaining erosion rates as close to their natural geologic rates as possible. When there is improper land use, especially deforestation of steep lands and subsequent establishment of grazing or agriculture, erosion rates are generally accelerated and sediment transport in the stream increased.

The fact that impoundments retain sediments implies a need for a more conservative upstream land use if premature siltation of the reservoir is to be avoided. Appropriate watershed management or protection measures should be a condition to the construction of an impoundment.

Downstream impacts of impoundments can have other impacts. Increased erosive potential of reservoir releases may lead to degradation of reaches of stream channel below the dam, to bank collapse, to undercutting of bridges and other structures, and to headwater erosion into adjacent hilly or mountain regions. Changes in the normal flow regime of the river through regulation can lead to the halting of flooding of downstream riparian agricultural lands with negative effects on fertility, variations in groundwater levels, and inland migrations of the salt-water/fresh water interface in coastal areas. Even beach formation of adjacent coastal areas may be impaired by the reduction of river sediments.

Sedimentation can have adverse impacts on aquatic organisms by burying rock or gravel fish-spawning areas. It can smother clams, mussels, other bottom-dwelling organisms, fish eggs, and rooted aquatic plants. By changing the texture and composition of the substrate, sedimentation will cause a shift in the composition, abundance, and distribution of aquatic biota, generally in a negative manner. The severity of these impacts are modified by (1) the amount and rate of sediment transport, (2) the velocity, turbulence, and flow rates of the stream, and (3) the frequency and magnitude of naturally occurring erosion and sediment deposition.

Alternative water uses

Since the operation of a small run-of-the-river, no-impoundment project does not consume water or significantly alter its quality, the major impact with regard to alternate water uses will result from the temporary diversion of water from the stream. Other users who withdraw water from the section of the stream affected by the diversion may not obtain adequate quantities during all or part of the year. The affected section could have been a source of water for irrigation, human or livestock consumption, industrial uses, or dilution of domestic sewage or industrial effluents. Maintainance of minimum flows in all sections of the stream is important in order to ensure the survival of resident aquatic organisms and allow migration of fish. Before judging the feasibility f a small hydro site, every effort must be made to identify all existing or potential alternative water users and resolve any water use conflicts that arise from the construction and operation of the project. Legal constraints concerning water use have to be considered to determine priority uses and water rights. It may be necessary to apply for concessions for projects.

Under some circumstances, groundwater resources can be depleted by a small hydropower project. Where diversion occurs from an effluent stream (one that is above the water table and therefore contributes to groundwater supplies) it is likely that groundwater recharge will be diminished in that stream reach between the points of diversion and discharge. This could affect water availability in wells and in the stream channel, i.e., there would be limited baseflow recharge. It could hamper uses of water for domestic consumption, irrigation, etc. In situations where influent stream conditions are found (i.e., the stream is below the water table), there will be baseflow recharge to the stream and the potential for negative impacts is lessened.

Installations which include water storage impoundments have a greater potential for adverse effects on alternative water users. Flow downstream of the reservoir can be stopped completely on a daily or seasonal basis, thereby depriving alternative water users and aquatic organisms of minimum flows. Water quality may be degraded and the spread of waterborne diseases and parasites enhanced by water impoundment. Finally, downstream flows may be reduced below normal levels, since (1) the greater surface area of an impoundment will increase evaporation rates, (2) floating or emergent vegetation will increase transpirative water losses above pre-impoundment rates, and (3) the greater substrate area of a reservoir may increase the loss of surface water to groundwater.

Flood control

A small hydropower project which temporarily diverts a portion of streamflow for power production can be expected to have little or no effect on the quantity of flood flows. Those installations

with reservoirs could use the additional storage space to retain flood waters and thereby reduce downstream flooding. Inter-basin transfer of generating water could either draw off flood waters from the donor basin or contribute to flood waters in the recipient watershed.

Water Quality

Operation of the run-of-the-river, non-impoundment facilities will have little or no effect on water quality in the streams. Such water quality parameters as temperature and concentrations of dissolved gases and minerals will not be altered by diversion and passage through the penstock and turbines. Turbidity and suspended solids levels in the diverted waters may be reduced in those plant designs which incorporate sand and sediment traps, but in most cases this will not have a negative impact on the receiving waters.

Direct water quality impacts could occur, however, at those sites whose designs include (1) diversion of water from one source or watershed to another, or (2) creation of a substantial impoundment of water above the intake structure. Diversion of water from another source to augment existing flows will introduce to the receiving stream water with different physical and chemical characteristics. This water could be of lower quality than the water in the receiving stream. For example, if flow-augmentation water is taken from the vicinity of mines, ore processing facilities, or industrial discharges, it may contain elevated concentrations of heavy metals, turbidity, or salts. Water draining land devoted to irrigation and intensive agriculture frequently has elevated temperature, and higher levels of turbidity, dissolved minerals and plant nutrients, pesticides, and herbicides.

Another way in which water quality may be degraded in the stream is by physical and chemical processes which occur within a water impoundment. The most common, especially in relatively deep, sheltered reservoirs, is that the water will undergo thermal stratification. Not only does this have the effect of making the water warmer at the surface and colder at the bottom than the normal stream temperature, but it results in a depletion of dissolved oxygen levels and greater concentrations of hydrogen sulfide and reduced ionic forms of iron and manganese. These impoundment effects can lead to a serious degradation of downstream water quality.

Retention of water within a reservoir increases the exposure time of aquatic organisms to contaminants and may therefore aggravate both acute and chronic toxic effects. Bioaccumulation of toxic chemicals through the aquatic food chain can also be increased by the impoundment of contaminated water.

Impacts on aquatic organisms

Many impacts on aquatic organisms must be considered when evaluating the feasibility of a small hydropower site. Some impacts, such as turbine-related fish mortality, are potential problems for any type of facility design. Others, such as interference with upstream migration of fishes, are generally of greatest concern when water is impounded for a store-and-release operation.

Turbine mortality occurs when organisms are carried into the intake structure along with diverted water and pass through the turbines before being discharged back into the receiving stream. These organisms, including drifting aquatic insects, zooplankton, and fish eggs, larvae, and juveniles, are subjected to sudden and extreme pressure changes, turbulence, shear forces, abrasion against the walls of the penstock, and contact with the turbine blades. Most studies of turbine mortality have dealt with fish. It has been found that increased hydraulic head and/or increased turbine runner speed resulted in increased turbine mortality (Turbak et al. 1980). Lowest mortality occurs when turbines are running at peak efficiency. At low efficiencies turbine mortality was as high as 100 percent.

Organisms which are too large to pass through the intake debris screen, yet cannot avoid the flow, may be trapped against the screen, which is called impingement. The victims, usually downstream-migrating fish such as trout and salmon, eventually die from asphyxiation and physical damage if they are not removed.

Temporary diversion or impoundment of water for hydroelectric power generation results in decreased flow in that portion of the river between the intake structure and the turbine discharge. Under low streamflow conditions, this can result in a significant decline in the natural flow available to support fish and bottom-dwelling animals, such as insects, crayfish, snails, or clams (Hildebrand, 1980a). In extreme cases the river may dry up completely from diversion or impoundment for power generation, resulting in a loss of bottom organisms and blockage for upstream and downstream migrating fish.

Many fish migrate upstream or downstream seasonally for spawning. The use of a dam for impounding or diverting water could seriously hinder or prevent these migrations (Geen, 1974, Hildebrand, 1980b). The possibility of limiting the reproductive potential of commercially important or endangered fish species should be considered in the feasibility study.

Maintenance dredging, to remove sediment deposits from the sand trap and the area around the intake structure, may result in temporary increases in suspended material and turbidity, low dissolved oxygen tensions, and high concentrations of dissolved minerals and toxic contaminants. If dredged material is allowed to enter the receiving stream, silt and sand deposition and the alteration of substrate and bottom habitat will result. Increased

turbidity can decrease the productivity of aquatic plants by decreasing sunlight penetration, and can disorient fish that depend on vision in feeding. High suspended solids concentrations causes stress or death to aquatic animals by clogging their gills or feeding structures. Low dissolved oxygen levels or high concentrations of toxic substances will result in stress or death to aquatic biota. Finally, improper disposal of dredged sediments can smother bottom-dwelling animals and fish eggs, or alter the benthic community structure by changing the texture and composition of the substrate. Dredging impacts are considered in detail in Loar et al, 1980.

Impounded water inundates terrestrial habitat as well as stream habitat and potential spawning sites for riverine fish. Aquatic organisms adapted to flowing water in the unimpounded stream will be replaced by species which are adapted to life in a reservoir habitat (Baxter, 1977). This change in aquatic community composition may be either beneficial or detrimental from a human standpoint. Its desirability must be evaluated site-by-site.

Evaluation of these impacts is especially important for streams that contain commercially or recreationally valuable aquatic species, or species that enjoy legal protection due to their unique or endangered status. For example, a stream that supports an important food fish for the local community must be carefully protected so as not to threaten this component of the food supply. Many small hydropower sites will be located on streams that have a very low natural flow, especially during the dry season. Diversion of a portion of this water for hydropower production will further reduce the ability of that stream to support aquatic life, and therefore may represent a serious additional stress to fish and fish food organisms.

Waterborne diseases and parasites

The operation of a small hydropower facility per se usually will not affect the transmission of waterborne diseases. Although the self-purifying capacity of water moving quickly in a non-turbulent flow through a headrace and penstock may be reduced relative to movement of that same water over the natural streambed, this factor will not be significant in most cases.

Facility designs incorporating inter-basin diversions or water impoundments can promote waterborne disease problems. Water contaminated by human sewage or runoff from livestock enclosures can spread a wide range of diseases such as typhoid and cholera (Stein, 1977a). These diseases could be introduced into a previously uncontaminated stream by inter-basin diversions. The impoundment of water in a hydroelectric reservoir could enhance survival of disease organisms, since those factors which are critical to self-purification of water in a stream (turbulence, sunlight penetration, oxygenation) are reduced or eliminated in a reservoir. Finally, water impoundments provide increased habitat

for mosquitoes, which are vectors of such diseases as malaria, encephalitis, yellow fever, and dengue, and snails which are alternate hosts of animal and human parasites such as schistosomiasis (Brown and Deom, 1973). On the other hand, the elimination of fast-flowing sections of streams by impoundment could cause a localized decrease in the incidence of onchocerciasis (river blindness).

Indirect effects on the incidence of waterborne diseases and parasites must also be taken into account when evaluating a site. Provision of electricity to a community may lead to an increase in the human and/or livestock population, and the resulting increased risk of disease epidemics would make necessary the installation of adequate drinking water and waste treatment facilities (Stein, 1977b).

Construction impacts

The effects of small hydro construction on the aquatic environment fall into two categories: (1) turbidity and sedimentation, and (2) water quality degradation. Construction of a road to provide access to the site, dams for water impoundments, and on-site construction of the various components of the facility, will result in the disturbance and movement of erodible soils. Unless mitigative measures are taken, such as the construction of dikes to retain stormwater runoff, this soil will eventually be washed into the streams. The effects of the resultant increases in turbidity, suspended solids, and sedimentation on aquatic organisms were described above.

Oils, greases, and chemical wastes from the construction of the concrete canals and turbine building may be carried into the streams and seriously degrade water quality, especially under low flow conditions. The toxic effects of these chemical wastes would cause stress or death to aquatic animals.

Road construction providing access to the site is responsible for much more earth movement and disturbance than the hydropower site preparation. The magnitude of the siltation, which will principally affect stream hydrology and aquatic communities, can be reduced by sound engineering practices in road construction, especially as they affect water control and site stabilization. When properly constructed and stabilized, a road may cease to produce significant amounts of sediment in a short time period (2-5 years).

The passage of transmission lines between a small generation facility and points of energy consumption will give rise to a series of impacts relating to both land use and wildlife resources. The establishment and operation of transmission lines requires the clearing and maintenance of relatively vegetation-free corridors, resulting in exclusion of alternative incompatible land uses. Such devegetation and land use restrictions may imply

limited but nonetheless significant impacts under certain circumstances. There could be visual or esthetic impacts and restrictions on air or ground traffic.

Transmission lines and corridors may impede the movement of certain species of wildlife and kill birds. In general, the low and less sophisticated transmission lines of small hydro installations cause much less damage than large scale, high tension lines.

The potentially most detrimental long-term impact of road and small hydro construction is the opening up of forests and critical watershed areas to spontaneous human colonization. For example, a common experience in Latin American water resource development projects has been that colonization and the resulting erosion and torrential hydrologic effects have completely stopped the projects. The Anchicaya hydroelectric project in Columbia is an excellent example. The investment was lost by reservoir sedimentation a very few years after construction. This was caused by colonization in the headwaters region of the watershed, which was made accessible by the project road. Spontaneous colonization of marginal protection areas produces innumerable impacts on soil, water, forest and wildlife resources, both onsite and downstream.

Wherever possible, contractual agreements should be developed with the benefitting communities so that they help develop and implement a watershed protection plan that will avoid such impacts and insure the useful life of the downstream project. For virgin forested watersheds, the best approach would be protection involving local forest guards. Where the watersheds are already populated, the plan should be oriented toward promoting proper soil and water conservation practices and compatible landuse. In either case, community involvement in such watershed management activities will be important to the success of the project and will have beneficial social effects in promotig environmental education and awareness.

Land use and development

The immediate, direct land use impact of small hyro installation is the commitment of land for onsite components, access roads, and transmission lines. If a water-storage reservoir is part of the design, some land will be inundated, potentially prime, river bottom farmland or human settlements. The effects of this long-term or irreversible loss of land on the region's economy or settlement patterns should be assessed during the feasibility study.

Small hydropower development will be likely to promote development and increased populations in its area. Construction of a hydro installation should not be approved until land use capability determinations have been made for the entire drainage basin

feeding the project and adequate management and protection strategies have been approved and enacted. Whenever possible, multiple use of watershed resources should be encouraged. In many cases, it will be necessary to declare a forest reserve, or some other category of wildland to assure the required protection. Rights-of-way for the access road including rights to reforest or stabilize slopes in some other way is also necessary.

Proper land use in the watershed is critical to avoid a complex series of impacts that could far outweigh the total direct impacts of small hydropower construction and operation. These long-term impacts, which basically come from improper land use and deforestation of steep uplands and watershed degradation, lead to erosion and sediment discharges, torrential flow regimes, and decreased dry season base flows. These impacts will have negative effects on plant operation and maintenance costs and will thereby affect the useful life of the project.

The promotion of proper land use in the project area is an activity that offers many opportunities for benefits. Potable water supplies, recreation areas, forest reserves with restricted possibilities of wood product extraction, and other compatible uses could be promoted so that the community appreciates and takes advantage of environmentally-sound multiple use. It is important that the community develop both (1) an understanding of the relationships between proper land use and the maintenance of good water quality, quantity and timing, and (2) a feeling of responsibility toward the management and protection of their own watershed.

Nutrient and sediment trapping effects

Installations which incorporate reservoirs may act as sediment and nutrient traps. As a stream enters the reservoir, the cross section increases, reducing flow velocities and decreasing sediment transport capacities. This causes a selective sedimentation phenomenon (delta formation) which depends primarily on the fall velocities of the sediment particles and the mean flow velocity through the reservoir. The discussion of nutrient and sediment trapping effects here is drawn largely from Hildebrand, 1980a.

Trap efficiency for sediment varies as a function of (1) inflowing sediment particle size, (2) reservoir capacity/annual inflow ratio, (3) location and operation of the reservoir outlet, (4) reservoir shape, and (5) chemical properties of the water (American Society of Civil Engineers 1973, Chow, 1964). Thus, the size of the impoundment, the design specifications of the dam, and the nature of inflowing waters will largely determine the amounts of sediments that are retained in or pass through the reservoir.

The term "trap efficiency" can also be used to describe nutrient retention by reservoirs (Glymph 1973, Rausch and Schreiber,

1977). Impoundments trap or retain nutrients by sedimentation of nutrient-bearing particulate matter, and transformation by adsorption or biological uptake of dissolved nutrient forms to particulate forms which subsequently settle out. Nutrient trap efficiency is reported to vary in response to the same factors that affect sediment trap efficiency, and thus nutrient retention impacts would be expected to occur in tandem with sediment retention (Prochazkova, 1975, Gill et al., 1976, Rausch and Schreiber, 1977).

Rivers and streams generally are an important source of sediment and nutrients to downstream riverine, wetland, and estuarine ecosystems through the transport and deposition of dissolved and suspended loads. Large impoundments will regulate or alter the natural flow regime of the river and will tend to eliminate periodic flooding and siltation of downstream floodplain soils. The reduction of sediment and nutrient loads below a facility may have the effect of reducing the long-term productivity of important alluvial agricultural soils or estuarine systems. In general, the larger the impoundment and the closer its proximity to potentially affected areas, the greater the impact of sediment and nutrient trapping.

Additional deleterious effects of the sediment-trapping capabilities of impoundments are (1) decreasing the useable volume of the reservoir (which may require periodic maintenance dredging), and (2) increasing the erosive potential of less-turbid water leaving the reservoir, which may result in downstream erosion of sandbars, streambanks, docks, and bridge abutments.

Aquatic weeds and eutrophication

Nuisance aquatic vegetation can cause operation and maintenance problems at small hydropower facilities, especially when an impoundment has been created. By slowing the river currents and trapping sediments and nutrients, many new reservoirs provide excellent conditions for the growth of floating plants (e.g., water hyacinth and water lettuce), submerged, rooted vegetation (hydrilla and water milfoil) and/or rooted, emergent plants (cattails, bullrushes, reeds). These plants have profound effects on the aquatic biological community. They can also interfere with hydropower operations by clogging the intake structure, increasing evapo-transpiration losses of water from the reservoir, reducing the effective water volume of the reservoir, harboring disease vectors and parasite hosts, increasing sediment and nutrient trap efficiency, thereby decreasing the useful life of the reservoir. They also hinder alternate water uses.

Static conditions created by reservoirs also favor the excessive growth of planktonic microscopic plants known as algae. Some species of algae, especially the blue-green algae that thrive in warm, nutrient-rich waters, release chemicals that are toxic to animals. The decomposition of excessive growths of algae and

large aquatic weeds can significantly degrade water quality both within the reservoir and downstream from the discharge.

The problems of nuisance growths of algae and aquatic weeds, as well as techniques for dealing with them, are considered in greater detail in Mitchell, 1973, Bachman, 1978, Rhodes, 1978a,b, and National Academy of Sciences, 1976b. The development of aquatic weeds and the cost of their subsequent control must be given serious consideration when examining the feasibility of sites, located in warm climates or low altitudes.

Wildlife impacts

Small hydropower installations will also have some impacts on terrestrial habitats and wildlife, although these effects have been less well studies than aquatic impacts. Construction and maintenance will involve some land disturbance and clearing for access roads, transmission lines, and onsite structures. The resultant alteration in vegetation and habitat may have negative or positive impacts on wildlife, depending on the site. For example, site clearing may be detrimental to wildlife by eliminating critical habitat, whereas in other cases it may be beneficial by creating greater habitat diversity in homogeneous environments. Construction noise and activities may interfere with nesting activities of birds or migratory movements of terrestrial animals.

The creation of a water storage impoundment will permanently inundate floodplain vegetation, which is often very productive of wildlife, and displace associated terrestrial animals. Flow regulation during operation may prevent or alter the seasonal timing of natural flooding of downstream marshes and wetlands, systems that are extremely important to numerous aquatic and terrestrial species.

On the positive side, reservoirs may create or improve habitats for terrestrial wildlife. In arid regions, impoundments may constitute a permanent source of water where none existed before, and therefore could allow for the expansion of wildlife populations. Impoundments with emergent, shallow-water vegetation will provide nesting sites, food, and shelter for waterfowl and shorebirds.

Impacts of water storage reservoirs on terrestrial wildlife and habitat are discussed in greater detail in Trefethen, 1973, and Heinzenknecht and Paterson, 1978. Both the direct impacts of facility construction and operation and the secondary effects of rural electrification on wildlife should be given serious consideration at the feasibility stage of site selection.

Secondary impacts

In addition to the primary, direct impacts on environmental resources that have been discussed, the provision of electricity to rural areas by small hydropower development is likely to have a number of secondary effects. For example, establishment of new roads, small industries, irrigation capabilities, and immigration into undeveloped areas are all potential social benefits derived from rural electrification which could, in themselves, have effects on the environment of greater magnitude than the facility per se.

The small hydropower development will impose restrictions on land use at the construction site and ideally also watershed protection in the catchment area above the intake structure. On the other hand, it will create opportunities for hunting, recreation, and alternative water uses. The extent of this depends upon the manner in which the area is managed. If the facility involves a water storage impoundment, additional benefits may be realized (fishing, recreation) but additional constraints on watershed management and reservoir operation will also be necessary to ensure efficient, long-term operation.

Secondary impacts of rural electrification may have great significance to aquatic resources in the project area. Regional developments following electrification could include increases in the human population either by promoting immigration or stemming emigration. It could increase agricultural activities, irrigation, livestock production, and industries, with important consequences to the water and land use patterns in the region. Population increases in the regions served by electricity will create a greater demand for potable and/or irrigation water and water treatment. Small communities that presently have no drinking or waste water treatment facilities may have increasing problems with waterborne diseases as the population increases and the ability of the environment to assimilate their wastes decreases. Similarly, increased need for irrigation water or food fish may occur as an indirect result of rural electrification, and may add unacceptable stresses to limited resources. It is of great importance that planning and development programs which affect land and water resources within a region be coordinated so that present or projected additive impacts can be identified and mitigated at an early stage in planning.

Irreversible and irreparable impacts

Irreversible and irreparable impacts will occur most commonly when small hydropower development involves impoundment of water. Irreversible commitment of soil resources will result from impoundment and consequent flooding of river valley bottoms. Depending on the site, geological, archaeological, historical, and cultural resources may also be lost to flooding. In addition, the

creation of an impoundment will result in an irreversible alteration in the topography of the valley bottom.

Construction of facilities without impoundments will usually not result in irreversible or irreparable commitments of resources except in cases of alteration of unique waterfalls or wild rivers. With adequate planning and project designs, these impacts can usually be avoided or minimized.

Appendix C

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