PN-AAP-525
ISN 33892

Prepared by the Small Decentralized Hydropower (SDH) Program of the National Rural Electric Cooperative Association, 1800 Massachusetts Avenue, N.W., Washington, D.C. 20036 (202) 857-9622, under Cooperative Agreement AID/DSAN-CA-0226.

ORNL/TM-7620

Contract No. W-7405-eng-26

ENVIRONMENTAL ISSUES AND SITE SELECTION CRITERIA FOR SMALL HYDROPOWER PROJECTS IN DEVELOPING COUNTRIES[1]

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ENVIRONMENTAL SCIENCES DIVISION
Publication No. 1712

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Date Published: March 1981

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DEPARTMENT OF ENERGY

ACKNOWLEDGMENTS

Appreciation is extended to Stephen Hildebrand and Glenn Suter of the Environmental Sciences Division, Oak Ridge National Laboratory, for their critical review of the manuscript.

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FOREWORD

Since 1979 the Environmental Sciences Division (ESD) of Oak Ridge National Laboratory has been conducting analyses of environmental issues related to the development of small-scale hydroelectric technology. This research is supported by the U.S. Department of Energy, Division of Hydroelectric Resource Development, and is directed toward small-scale hydroelectric resources in the United States.

In July 1980, the Agency for International Development (AID) was beginning a small-scale hydropower project in Peru. AID requested the National Rural Electric Cooperative Association (NRECA), under their cooperative agreement for promoting small-scale hydropower, to send an assessment team to Peru to assist the AID/Lima mission. NRECA requested the services of Dr. Glenn Cada from ESD to participate in the team assessment. Dr. Cada and Mr. Frank Zadroga of the University of Costa Rica were to assess the environmental impacts. The authors traveled to northern Peru and visited two sites being developed for small-scale hydroelectric power production. In addition to assessing the potential for adverse environmental impacts of the small-scale hydro program in Peru, Glenn Cada and Frank Zadroga were asked by NRECA to outline a methodology that could be used to select, from an environmental perspective, the best sites for small hydroelectric projects in developing countries. This report details the results of this second effort.

A real challenge in developing the report was to weigh the need for precise evaluation of adverse impacts against the potentially limited

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scientific resources and environmental data available in developing countries. The standards for technical expertise and data requirements in the United States cannot realistically be expected of developing countries. We believe that the compromises made in this regard are not severe, and if the environmental recommendations in this report are followed to the greatest extent practical, meaningful environmental evaluations will result.

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ABSTRACT

CADA, GLENN F., and FRANK ZADROGA. 1981. Environmental issues and site selection criteria for small hydropower projects in developing countries. ORNL/TM-7620. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 54 pp.

Small Hydropower Projects (SHPP), defined as hydroelectric generating facilities with capacities of 1000 kW or less, have great potential for elevating the standard of living and contributing to the economic growth of isolated rural communities in developing countries. However, construction and operation of a SHPP can result in adverse environmental impacts that should be considered in the initial stages of site selection and development.

Environmental concerns can be factored into a site selection process both at the prefeasibility and feasibility stages. The prefeasibility study is the process by which a large number of potential sites is reduced to a much smaller number of candidate sites based on coarse-grained engineering, socioeconomic, and environmental criteria. Although many of the factors determining the suitability of a given site at the prefeasibility stage involve basic engineering or economic questions (e.g., availability of water and demonstrated need for power), four fundamental environmental issues that should be addressed are discussed in this report.

The feasibility study is the final stage of site selection, where a relatively small number of candidate SHPP sites are examined in greater detail and the best are selected for development. Potential environmental impacts of SHPP's are discussed, and a checklist of

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1. INTRODUCTION

The decreasing supply and increasing cost of fossil fuels for generating electricity have led to a search for more reliable, renewable sources of energy production. While supply and cost considerations are important elements in the formulation of energy policies of any nation, the need to develop cheap, renewable energy sources is particularly acute for developing countries, which can ill afford to expend limited financial resources to import costly fossil fuels. In addition to such alternative sources of power as biomass conversion, wind energy, and photovoltaic devices, hydroelectric power is seen as an important means of providing energy and promoting economic growth in developing countries (National Academy of Sciences 1976a).

A Small Hydropower Project (SHPP) is defined in this report as a hydroelectric generating facility with a capacity of 1000 kW or less. Because SHPP's can be designed for a wide range of capacities and environmental settings, they can be an effective means for providing electric power to small, isolated rural communities. This power can have a number of social benefits, such as an increase in the standard of living by providing electricity for home lighting, in basic health services, and in educational facilities. Moreover, electricity generated by a SHPP could contribute to economic development in the region by increasing the pruductivity and profitability of agriculture, cottage industries, and commerce.

In addition to the social and economic benefits, however, poorly planned or uncoordinated SHPP development can have adverse environmental impacts in the affected region. This report provides a discussion of potential impacts that can arise from the construction and operation of SHPP's and suggests the types of environmental data that should be analyzed in order to assess their significance. As such, the report can be used as (1) a methodology for incorporating environmental factors into an overall site selection procedure which also entails engineering, sociological, and economic considerations, and (2) a guideline for judging, avoiding, or mitigating site-specific impacts to natural resources once an acceptable SHPP site has been identified.

2. PREFEASIBILITY STUDY METHODOLOGY

A prefeasibility study is necessary at the stage of site selection where a large number of potential SHPP sites (say 1000) is reduced to a smaller number (< 100) of viable sites for which data can be collected to perform a feasibility assessment. Because of the large number of sites that may be involved in the prefeasibility study, site selection is based on coarse-grained, fundamental criteria, e.g., availability of water to ensure reliable generation and demonstrated need for power.

Many of the environmental factors that are detailed in this report are relatively fine-grained, i.e., they do not greatly influence such basic considerations as reliability of SHPP operation or efficient utilization of electricity. Therefore, incorporation of most environmental factors into the overall site selection and development process is reserved for the feasibility study, where the number of sites is small and data necessary to make a meaningful assessment of environmental impacts can be collected. However, there are four basic questions that must be satisfactorily answered in the prefeasibility study in order to judge a site viable from an environmental point of view:

<u>Question (1)</u>: Should development be stimulated in the area and, if so, what type of development will be stable, productive and protective of the resource base?

<u>Explanation</u>:

Of special concern in undeveloped rural areas is the early establishment of productive land uses that will be sustainable and

non-exploitative of the renewable natural resource base (soil, water, forests, fish, wildlife, etc.). In certain areas local rural industries should be based on agriculture, while in others their resources make them most suited for forestry or fisheries. Inadequate consideration of the most appropriate development strategy could, in the long term, cause problems that would negate many of the benefits of rural electrification.

For example, there is a common tendency in developing countries to colonize forested hinterlands and to expand the agricultural frontier in order to improve economic conditions and reduce rural-to-urban migrations. When neither adequate analysis is made of the potential productivity of these new areas nor appropriate orientation given to the colonization process, the expected riches of the new frontier frequently turn into degraded and eroding wastelands that in turn take their toll on small colonist/farmers. In the wake it is also normal to find depleted forests, fish, and wildlife (upon which the colonists have had to subsist) and perhaps the initiation of watershed imbalance that will likely get worse if land use practices do not improve.

SHPP, like many other types of services, can play a decisive factor in the promotion or deterrence, success or failure, of a rural village. Land-use capabilities and general resource potential should be determined on a reconnaissance level for those areas in which development is desired and SHPP's are being requested, to determine if it is justifiable that these areas be developed and in what way. It is likely that some will be determined to be rich agricultural and/or forest resources areas and should be opened up. Others may be too

steep with poor soils or too wet, and should best be kept as protective forests. In these latter cases, SHPP's whose goals include land development should be rejected at a prefeasibility stage.

In determining SHPP prefeasibility for already developed regions, prefeasibility considerations should be based primarily on questions 2, 3, and 4 of this section. However, in special cases where sites have little or no resource productive potential or are located within inherent protection areas because of their steep physiographic and/or extreme ecological conditions, similar criteria as mentioned above should play a major role in SHPP prefeasibility determinations.

Question (2): Is the available water resource of adequate quality and quantity to meet project needs?

Explanation:

For all sites, the availability of adequate stream flows to ensure efficient and reliable hydroelectric power generation is a fundamental criterion that must be satisfied at the prefeasibility stage of site evaluation. High sediment loads may cause excessive abrasion of the turbine and decreased life of the facility. Recent, accurate records of streamflow and sediment discharges for a minimum two- to three-year period (preferably longer) must be available in order to determine the appropriate size and type of turbines and to predict the daily and seasonal supply of water for generation of electricity.

Streamflow and sediment recording installations, suitable to the conditions of each particular site, should be installed as early as possible for all sites that are to be considered for SHPP's. If the

required two- to three-years of base data do not exist for a given potential site at the time of the prefeasibility determination, serious consideration should be given to deferring the site until such information is available.

Every effort should be made at the prefeasibility stage to identify all existing or potential public and private water users (including minimum flows necessary to support fish and other aquatic organisms) that affect flows in the stream. The location of all water intakes and discharges in the affected area, as well as the respective flow rates and nature of the effluents, must be determined. Only in this way can potential water-use conflicts which might prevent SHPP development be identified and resolved.

Question (3): Is the proposed site near or in a protected area that enjoys special legal status, or is its land use capability such that it should be declared as, or as part of, a wildlands area?

Explanation:

If a protected river or area (for example, a national park, forest reserve, wildlife preserve, sanctuary, or refuge) is threatened by construction and operation of a SHPP, it may be legally impossible or inadvisable to develop at that site, whatever the projected benefits. Similarly, if the existence or habitat of any rare or endangered plant and animal species is threatened by SHPP development, the site may not be feasible from both an environmental and legal standpoint.

Question (4): Is there adequate local interest and support to uphold the environmental protection requirements of the project?

Explanation:

The local community to be benefited by a SHPP should be involved in the planning and development of the project as early as possible. It is important that they be in agreement with the project and support it in all its ramifications. With respect to the environment, it may be necessary for the local people to provide lands for the project site and road rights-of-way; for certain projects a protection watershed will need to be established and the local or national government will have to provide these lands, watershed guards and other minor resources to assure an adequate water resource for the SHPP. Such potential requirements as these, although not yet fully developed at the prefeasibility stage, should be discussed with the community, and an affirmation of full cooperation (if possible written) should be received from the community before proceeding to feasibility stages.

3. FEASIBILITY STUDY METHODOLOGY

The feasibility study is conducted at the final stage of site selection, where a relatively small number of potential SHPP sites are examined in greater detail and the best are selected for development. This process necessarily requires precise facility designs and drawings for each site and the collection of site-specific engineering, environmental, sociological, and economic data with which to make an evaluation of benefits and impacts. Since conduct of the feasibility study will require a significantly greater investment of time and money than the prefeasibility study (Section 2), it is advisable to carry out the early site screening procedure in a way that minimizes the number of sites that must be considered and that could be rejected at the feasibility stage of site selection.

This section deals with environmental considerations that should be taken into account during the feasibility study. It is divided into two parts; Section 3.1 is comprised of discussions of potential environmental impacts of SHPP development and Section 3.2 provides a checklist of suggested information that should be gathered in order to judge the magnitude of these impacts at a given site.

3.1 DISCUSSION OF POTENTIAL IMPACTS

When considered on a global scale, Small Hydropower Projects (SHPP) will encompass a wide range of facility designs and environmental settings. For example, the basic criterion of a SHPP, i.e., a generation capacity of $\leq$ 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 single 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 if a run-of-the-river, no-impoundment design is used. The discussions of potential impacts that follow are intended to cover the entire range of SHPP designs, and therefore some of the considerations may not be appropriate for particular installations or site-specific environmental conditions.

As with most man-induced stresses, the magnitude of environmental impacts resulting from SHPP development is generally related to the size of the facility. That is, 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 for the smaller facility. 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 located on a large river. The significance of environmental impacts can vary seasonally; a 100-kW SHPP 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.

3.1.1 Flow Disruption

All SHPP 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 a complete stoppage of flow for a certain 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 SHPP's that utilize mainstem 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 SHPP 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 SHPP 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).

3.1.2 Sedimentation

Sedimentation impacts are important from two points of view. 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 SHPP equipment installations 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 most desirable to maintain as high a physical water quality as possible. This can be attained to a large degree by the development of 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 (road building, cutting of the canals, etc.). 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, ideally prior to prefeasibility analysis.

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 (irrigation canals, reservoirs), thereby increasing maintenance costs or decreasing their useful lifetime.

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 improper land use occurs, especially the deforestation of steep lands and subsequent establishment of grazing or agriculture, erosion rates are generally accelerated and sediment transport in the stream is generally 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 conditioned to the construction of an impoundment.

Downstream impacts of impoundments can include issues other than water quality. Increased erosive potential of reservoir releases (Section 3.1.10) may lead to degradation of reaches of stream channel below the dam, bank collapse, undercutting of bridges and other structures, and the initiation of 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 saltwater/freshwater 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, and smothering 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.

3.1.3 Alternative Water Uses

Since the operation of a run-of-the-river, no-impoundment SHPP does not consume water or significantly alter its quality, the major impact with regard to alternate water uses will result from the fact that water is temporarily diverted from the stream. This raises the possibility that other users who withdraw water from the section of the stream affected by the diversion (below the SHPP intake structure and above the tailrace) will not obtain adequate quantities during all or part of the year. The affected section could serve as a source of water for irrigation, human or livestock consumption, industrial uses, or dilution of domestic sewage or industrial effluents. In addition, it is important to maintain minimum flows in all sections of the stream in order to ensure the survival of resident aquatic organisms and allow migrations of fish. Prior to judging the feasibility of a SHPP 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 SHPP. Legal constraints concerning water use have to be considered to determine priority uses and water rights acquired by prior water uses. Depending upon the points of extraction and discharge of waters, it may be necessary to apply for concessions for SHPP projects.

Under certain circumstances, groundwater resources can be depleted by a SHPP. 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 which could hamper uses of water for domestic consumption, irrigation, etc. In situations where influent stream conditions are found (stream is below the water table), baseflow recharge to the stream will occur and the potential for negative impacts is lessened.

SHPP installations which utilize water storage impoundments have a greater potential for having adverse effects on alternative water users. Flow downstream of the SHPP reservoir can be stopped completely on a daily or seasonal basis (Section 3.1.1), thereby depriving alternative water users and aquatic organisms of minimum flows. Water quality may be degraded (Section 3.1.5) and the spread of waterborne diseases and parasites enhanced (Section 3.1.7) 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.

3.1.4 Flood Control

A SHPP which temporarily diverts a portion of streamflow for power production can be expected to have little or no effect on either diminishing or increasing the quantity of flood flows. Those installations with reservoirs could utilize any additional storage space to retain floodwaters and thereby reduce downstream flooding.

Inter-basin transfer of generating water could have the effect of either drawing off floodwaters from the donor basin or contributing to floodwaters in the recipient watershed.

3.1.5 Water Quality

Operation of run-of-the-river, non-impoundment SHPP facilities will have little or no effect on water quality in the streams. Such water quality parameters as temperature and concentrations of dissolved minerals will not be altered by diversion and passage through the penstock and turbines. While turbidity and suspended solids levels in the diverted waters may be reduced in those plant designs which incorporate sand and sediment traps, in most cases this will not have a negative impact on the receiving waters. Gas supersaturation and gas-bubble disease is a potential problem, but it would be associated primarily with hydroelectric plant designs which utilize deep plunge basins or which allow air to enter the turbines as a means of controlling negative pressures resulting from reduced operating levels (Wolke et al. 1975).

Direct water quality impacts could occur 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, and the possibility should be considered that this water will 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 levels of temperature, turbidity, dissolved minerals and plant nutrients, pesticides, and herbicides.

Another way in which water quality may be degraded in the stream containing the SHPP facility is by physical and chemical processes which occur within a water impoundment. The most common event, especially in relatively deep, sheltered reservoirs, is that the water will undergo thermal stratification. Not only does this have the effect of creating water that is warmer at the surface and colder at the bottom than the normal stream temperature, but it can also result in a depletion of dissolved oxygen levels and greater concentrations of hydrogen sulfide and reduced ionic forms of iron and manganese. All 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. On the other hand, contaminants that are adsorbed to suspended detritus may settle out of the water column and subsequently be buried in the sediments of the impoundment.

3.1.6 Impacts to Aquatic Organisms

There are numerous impacts to aquatic organisms that must be considered when evaluating the feasibility of a SHPP site. Some impacts, such as turbine-related fish mortality, are potential problems for any type of facility design, whereas others, such as interference with upstream migration of fishes, are generally of greatest concern when water is impounded for a store-and-release type of operation. This section will briefly discuss important effects that hydroelectric generation can have on aquatic biota.

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, and 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 occurred when turbines were running at peak efficiency, and 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 in a process called impingement. These animals, commonly downstream-migrating fish such as trout and salmon, eventually suffer

mortality due to asphyxiation and physical damage if not adequately removed and bypassed.

Temporary diversion or impoundment of water for hydroelectric power generation results in decreased flow in that portion of the river downstream from the intake structure and upstream of 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 (insects, crayfish, snails, clams) in that stretch of river (Hildebrand 1980a). In extreme cases the river may dry up completely due to complete diversion or impoundment for power generation, resulting in a loss of these bottom organisms and a potential blockage for upstream and downstream migrating fish.

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

Maintenance dredging, to remove sediment deposits from 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

visually feeding fish. 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). Depending on the particular situation, this change in aquatic community composition may be either beneficial or detrimental from a human-use standpoint, and its desirability must be evaluated on a site-specific basis.

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 from the types of impacts described in this section, so as not to threaten this component of the food supply. It should also be borne in mind that many SHPP 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.

3.1.7 Waterborne Diseases and Parasites

As with water quality impacts, the operation of a SHPP facility per se is not expected to 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 parcel of water over the natural streambed, this factor will probably not be significant in most cases.

Facility designs incorporating inter-basin (watershed) 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), and they 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 of SHPP development 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 necessitate the installation of adequate drinking water and waste treatment facilities (Stein 1977b).

3.1.8 Construction Impacts

The effects of SHPP 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 SHPP facility, will result in the disturbance and movement of erodible soils. Unless mitigative measures are taken, such as the construction of dikes to retain storm water 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 are described in Sections 3.1.2 and 3.1.6.

In addition, 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 normally responsible for much more earth movement and disturbance than SHPP site preparation activities. The magnitude of the siltation impact, which

will principally affect stream hydrology and aquatic communities, can be reduced by sound engineering practices of 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 SHPP 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 land uses that would be incompatible with transmission line uses. Such devegetation and land-use restrictions may imply limited but nonetheless significant impacts under certain circumstances. In exceptional cases in developing countries, visual or esthetic impacts and restrictions on air or some kinds of terrestrial traffic may need to be taken into account and planned for.

Construction and maintenance of transmission lines and corridors may impede the movement of certain species of wildlife and cause mortality to birds. In general, operation of the low and less sophisticated transmission lines of small hydro installations can be expected to cause much less impact in this respect than large-scale, high tension lines.

3.1.9 Land Use and Development

The immediate, direct land-use impact of a SHPP installation is the commitment of land for on-site components (canals, penstock,

turbine buildings), access roads, and transmission lines. If a water-storage reservoir is part of the design, some land (potentially prime, river bottom farmland or human settlements) will be inundated. 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.

SHPP development will likely have an effect of promoting development and increased populations in its area of influence. 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 that will assure the required protection. Rights-of-way for the access road including requirements to reforest or stabilize slopes in some other way is also necessary.

Proper land use in the watershed is critical to the avoidance of a complex series of impacts that could far outweigh the total direct impacts of SHPP construction and operation. These long-term impacts, which basically have to do with improper land use and deforestation of steep uplands and watershed degradation, will 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 SHPP useful life.

A common experience in Latin American water resource development projects has been that colonization and its resultant erosion and torrential hydrologic effects have completely stopped the projects. The Anchicaya hydroelectric project in Columbia is an excellent example in which the investment was lost by reservoir sedimentation a very few years after construction due to 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 on-site 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 SHPP. 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 land use. 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 promoting environmental education and awareness.

The promotion of proper land use in the project area is an activity that offers multiple opportunities for benefits. Potable water supplies, recreation areas, forest reserves with certain 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 possibilities.

It is extremely 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."

3.1.10 Nutrient and Sediment Trapping Effects

SHPP installations which incorporate reservoirs may act as sediment and nutrient traps. As a stream enters the reservoir, the cross section normally 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 in this section 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. Thus, the size of the impoundment, 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. Impoundments trap or retain nutrients by sedimentation of nutrient-bearing particulate matter, and

transformation of dissolved nutrient forms to particulate forms (adsorption or biological uptake) which subsequently settle out. In general, 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.

Rivers and streams normally constitute 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 have the effect of regulating or altering 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 SHPP facility may have the effect of reducing long-term productivity of important alluvial agricultural and forest soils or estuarine systems. In general, the larger the impoundment and the closer its proximity to potentially affected areas, the greater is the impact that can be expected with regard to sediment and nutrient trapping.

Additional deleterious effects of the sediment-trapping capabilities of SHPP 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, stream-banks, docks, and bridge abutments). Greater detail with regard to the specific impacts that can be expected and the variables that determine such impacts is presented by Hildebrand (1980a).

3.1.11 Aquatic Weeds and Eutrophication

Nuisance aquatic vegetation can cause operation and maintenance problems at SHPPs, 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 nyacinth and water lettuce), submerged, rooted vegetation (hydrilla and water milfoil) and/or rooted, emergent plants (cattails, bullrushes, reeds). Not only do these plants have profound effects on the aquatic biological community, but they can also interfere with SHPP operation by clogging the intake structure, increasing evapotranspiration 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), and hindering alternate water uses (e.g., fishing, swimming, livestock watering).

Static conditions created by reservoirs also favor the excessive growth of planktonic microscopic plants known as algae. Some species of algae, especially some 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 SHPP 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 SHPP sites, especially those located in warm climates or low altitudes.

3.1.12 Wildlife Impacts

SHPP installations will also have some impacts on terrestrial habitats and wildlife, although these effects have been less well studied than aquatic impacts. Construction and maintenance of any SHPP will involve some land disturbance and clearing for access roads, transmission lines, and on-site structures. The resultant alteration in vegetation and habitat may have negative or positive impacts on wildlife, depending on the particular 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 SHPP water storage impoundment will permanently inundate floodplain vegetation (often very productive of wildlife) and displace associated terrestrial animals. Flow regulation during operation may prevent or alter the extent and 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, SHPP 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 SHPP construction and operation and the secondary effects of rural electrification (Section 3.1.13) on wildlife should be given serious consideration at the feasibility stage of site selection.

3.1.13 Secondary Impacts

In addition to the primary, direct impacts on environmental resources that have been discussed in previous sections, the provision of electricity to rural areas by SHPP 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 SHPP facility per se.

The development of SHPP's will impose restrictions upon land use at the construction site and ideally also in the catchment area above the intake structure, i.e., watershed protection. On the other hand, it will create resource opportunities (hunting, recreation, alternative water supply uses), the extent of which depends upon the manner in which the area of influence of the project is managed. If the SHPP

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 SHPP 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), agricultural (irrigation) activities, livestock production, and industries, any of which could have important consequences to the water and land-use patterns in the region. Population increases in the regions served by SHPP 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 encounter 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 fishes may occur as an indirect result of rural electrification, and may add unacceptable stresses to limited resources. It is of great importance that different 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 the planning process.

3.1.14 Irreversible and Irreparable Impacts

Irreversible and irreparable impacts will occur most commonly when SHPP 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 normally result in siltation in the reservoir and an irreversible alteration in the topography of the valley bottom.

Construction of SHPP's without impoundments will normally 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.

3.2 CHECKLIST OF ENVIRONMENTAL INFORMATION

Section 3.1 has discussed the types of potential environmental impacts that should be considered when evaluating the feasibility of a SHPP site for development. The checklist in this section provides suggestions for the types of information that should be collected and analyzed in order to assess the relative significance of these impacts at a given site. Most of the necessary information is at the reconnaissance level; that is, it can usually be quickly obtained by examining existing maps, reports, and publications, or by contacting appropriate people in government agencies, universities, or local communities. The items requested by the checklist are intended to

represent the minimum information needed to cover a wide range of potential sites and environmental settings. In certain instances, particular factors may be inappropriate or additional questions may need to be asked in order to understand and predict the environmental impacts of the site development.

(1) Obtain topographical maps (1:25,000 if possible) which show the location of the SHPP facility components and, if a water impoundment is planned, the bathymetry of the future reservoir.

(2) Obtain low-level aerial photographs of the site and watershed.

(3) Obtain recent stream flow data for a number of years in order to ensure both the maintenance of minimum flows in the stream and reliability of SHPP operation.

(4) Obtain rainfall data for the study area. Do rainfall intensity values also exist?

(5) Determine water withdrawal rates for SHPP operation and the location of the intake and discharge structures.

(6) If a water storage impoundment is part of the SHPP design, determine the timing of reservoir releases on a daily and seasonal basis.

(7) Determine the alternative water uses in the area, the location of all water intakes or discharges in the affected areas, and flow rates and nature of all effluents.

(8) Locate important wetlands that could be affected (for example, drained or filled with sediment) by construction and operation of the SHPP.

(9) Locate important alluvial floodplains that will no longer be seasonally flooded due to reservoir flow regulation.

(10) Locate other water bodies (lakes, reservoirs, etc.) that are associated with the surface waters of the study area.

(11) According to the life zones (ecological) map of the country, determine what life zones occur in the watershed under study, what runoff distribution could naturally be expected from each Life Zone (or other appropriate ecological classification unit) according to water balance estimations, and how many effectively dry months are there in each water year.

(12) Obtain a map of actual land use for the area. Determine the predominant land uses.

(13) Obtain land-use capability or land-use potential maps developed for the general study area. Determine what resource-use potentials exist for the watershed of concern.

(14) Determine what land-use and watershed protection plans can be developed in order to minimize adverse secondary impacts.

(15) Determine what important soil, geological, historical, cultural, or archaeological resources will be lost by site construction, access road construction, transmission line construction, or impoundment.

(16) Determine whether the SHPP site is near a protected area (preserve, sanctuary, refuge, dedicated area) that may require special consideration.

(17) Determine whether stream waters near the site are used for fish spawning, nursery, or feeding areas, or as fish migration routes.

(18) Determine whether any rare, endangered, or commercially or recreationally important species are present in the region.

(19) Identify the principal aquatic species present in the area affected by SHPP construction and operation.

(20) Determine what species are harvested for sport or commercial purposes in the area, the harvest level and seasonality of harvest, and what fishes or shellfishes are harvested from the stream for food by the local community.

(21) List the waterborne diseases or parasites that are endemic to the area and determine the possibility of spreading or accentuating disease problems by SHPP development.

(22) Identify species of aquatic plants in the area that could interfere with hydroelectricity production and alternate water uses.

(23) Identify any preexisting (natural or man-induced) environmental stresses in the area and any future developments planned for the area that might add additional stresses. Characterize and, if possible, quantify these stresses.

(24) Estimate the nature and size of suspended sediments in the stream as well as the bedload of the stream.

(25) Obtain water quality data, especially regarding temperature, dissolved solids, salt, nutrient, and dissolved oxygen levels, or the presence of toxic materials or disease organisms.

(26) Identify projected or active mining activities in the study area. Are these open-pit or tunnel mines and how are wastes handled?

(27) Consider any unique plant design features (impoundment, trans-basin diversion) which would necessitate special consideration with regard to environmental impacts.

(28) Determine the possibilities for avoiding, reducing, or mitigating environmental impacts of SHPP site development by adequate prior planning.

Responses to all of these requests for information should be provided. If no information is available for a particular item, it should be expressly stated, along with a list of people contacted in the search. If certain information is critical to final assessment and could be generated with relatively little time and resource expenditure (i.e., field checking), this should be done. When all available information has been assembled, the significance of environmental impacts arising from development and operation of the SHPP should be judged by competent people with experience in environmental impact assessments by weighing the cost of irreversible impacts or preventative and mitigative measures against the benefits of electricity to the community. In general, due to the small scale of SHPP developments, sophisticated monetary quantifications of environmental costs and benefits are not justified. However, for certain impacts that involve excessive costs or benefits and that therefore have a decisive role in the acceptance of rejection of a given site, it may be desirable to estimate monetary costs and/or benefits.

4. SUMMARY AND RECOMMENDATIONS

Small Hydropower Projects (SHPP's) have a number of advantages over other sources of power as a means of providing electricity to rural areas in developing countries. They represent a relatively simple, proven technology and are generally easier to operate and maintain than thermal power plants. Since SHPP's utilize a renewable resource to generate electricity, they are not subject to the problems of fuel cost and supply which may affect the reliability of thermal power plants.

As with other energy technologies, however, there are potential environmental impacts associated with the construction and operation of a SHPP. Discussions of impacts ranging from land-use changes to water quality degradation have been provided in the previous section, along with a checklist of the types of information that should be gathered at an early stage in site selection and project planning in order to judge the significance of these impacts. It should be noted that the discussions are intended to cover a broad range of possible sites and SHPP designs; for particular SHPP designs, sizes, or sites, some of these concerns may not be relevant.

Since decisions about the significance of environmental impacts at a candidate site will be largely judgmental, both the prefeasibility and the feasibility stages of site selection should be conducted by individuals with formal training in an environmental field (e.g., natural resources management, ecology, forestry) and experience in impact assessments. In order to streamline the site selection process,

competent individuals within the utility (or other SHPP development agency) could be used to carry out the prefeasibility study. This would have the advantages of (1) speeding the process of early site-selection (much of which is based on engineering and need-for-power criteria) and (2) developing a sensitivity to environmental issues within the utility. The feasibility study, however, should be conducted by an independent individual or agency that has no organizational connections to the SHPP development agency and therefore has no potential conflicts of interest. Ideally, the expertise needed to carry out a meaningful feasibility study could be found within the country, either in the form of a government agency which has such capabilities and authority or professionals (e.g., university professors) who could be put on contract as consultants. If the required expertise cannot be found within the country itself, it may be necessary to obtain the services of foreign consultants to ensure that a critical and objective analysis will be made of the candidate sites.

The first step in the feasibility study is to compile relevant environmental information for the region in question (Section 3.2). This could be done most efficiently by contacting local individuals or government agencies that have responsibilities and expertise in the particular environmental discipline or that may have some regulatory responsibility with regard to SHPP development. For example, information on the potential for disease problems and necessary preventative measures could be provided by a governmental health department or World Health Organization office, whereas present and

planned land-use patterns in the affected water could be determined by consultation with agricultural agencies. It is essential that all potential sources of information be contacted at this stage in order to identify any possible environmental problems and to ensure coordinated, well-planned development.

When the requisite environmental data and detailed engineering drawings of the site have been obtained, the site of each proposed SHPP should be visited by the entire feasibility study team. This will allow the team members to assess the environmental and social setting in which the project will be developed, identify any previously unanticipated problems, and discuss the project with the local community. The site visit will provide a valuable perspective which will enable the interdisciplinary team (engineers, ecologists, sociologists, economists) to weigh the various projected benefits and consequences of SHPP development at each proposed site before making its final selection.

In summary, the principal object of incorporating environmental concerns into an overall site selection methodology should not be to hinder the provision of electricity to developing countries, but rather to orient development in an environmentally sound manner. To the degree that SHPP's promote the intensification of rural industries and improve the lot of the small farmers without entering into conflict with basic environmental resources, they will be doing a service to rural development. In addition to the obvious benefits of electrification, rural populations served by SHPP's will receive some environmental education and technical training and will have the

opportunity to manage and control their own resource base. Finally, since the prefeasibility and feasibility study methodologies may require personnel training and collection of basic environmental data, they will have secondary benefits of enhancing the environmental capabilities of the country's institutions and promoting better resource management and conservation.

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