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Small-scale Hydroelectric Power for Developing Countries: Methodology of Site-selection Based on Environmental Issues

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INTRODUCTION

The decreasing supply and increasing cost of fossil fuels for generating electricity have led to an ever-widening search for more reliable, 'renewable' sources of energy. While supply and cost considerations are important elements in the formulation of energy policies of any nation, the need to develop cheap and lasting sources of energy is particularly acute for developing countries which can ill-afford to expend much of their limited financial resources to import costly fossil fuels. Fortunately, 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, 1976*a*).*

A Small Hydropower Project (SHP) is defined in this paper as including a hydroelectric generating facility with a capacity of 1,000 kW or less. As SHPs can be designed for a wide range of capacities and environmental settings, they can be an effective means of 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 through providing home lighting and electricity for basic health services and educational facilities. Moreover, electricity generated by an SHP could contribute to economic development in the region by increasing the productivity and profitability of agriculture, cottage industries, and commerce in general. Such socio-economic benefits can be useful tools in stemming the rural-to-urban migrations that have plagued large cities in developing countries and widely led to serious rural decline.

Poorly planned or uncoordinated SHP development can also have adverse environmental impacts in the affected region. Recently we discussed (Cada & Zadroga, 1981) potential environmental impacts that can arise from the construction and operation of SHPs in developing countries. In the present paper, we briefly summarize these impacts and suggest the types of data that should be analysed in order to assess their significance. As such, the paper can be used as (1) a suitable basis of 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 on natural resources when once an acceptable SHP site has been identified.*

SCREENING STUDY METHODOLOGY

A screening study is necessary at the stage of site-selection where a large number of potential SHP sites (say 1,000) is reduced to a smaller number (< 100) of viable sites for which data can be collected to perform a detailed feasibility assessment. Because of the large number of sites that may be involved in the screening study, site selection is based on coarse-grained, fundamental criteria, e.g. the availability of water to ensure reliable generation to satisfy demonstrated need for power.

Many of the environmental factors that are detailed in this paper are relatively fine-grained, i.e. they do not greatly influence such basic considerations as reliability of SHP 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

*In response to our query concerning possible illustrations, Dr Cada replied that he does 'not have any available to send to you in time. However, National Academy of Sciences (1976*a*) does provide numerous drawings and photos of SHPs in its book *Energy for Rural Development*... so that the reader may gain additional perspective of the size and appearance of these installations by obtaining this free book.' – Ed.

* For wider environmental impact assessment and site-selection, it is recommended by a referee that UNEP's *Guidelines for Assessing Industrial Environmental Impact and Environmental Criteria for the Siting of Industry* (Paris: xv + 105 pp., 1980) be consulted. – Ed.

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6

sites is small and the data necessary to make a meaningful assessment of environmental impacts can be collected. However, there are four basic questions which must be satisfactorily answered in the screening study in order to judge whether a site is viable from an environmental point of view:

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

Of special concern in the screening study is the early identification of productive land-uses that will be sustainable and non-exploitive of the renewable natural resource-base (soil, water, forests, fish, wildlife, etc.). In many areas local rural industries should be based on agriculture, while in others their natural 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.

There is a common tendency in Third World countries to colonize forested hinterlands and so expand the agricultural frontier in the hope of improving economic conditions and reducing rural-to-urban migrations. An SHP can be a decisive factor in the success or failure of this kind of effort. When neither adequate analysis is made of the potential productivity of these colonized 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 colonizing farmers. In the wake of such colonization it is all-too-common to find depleted forests, fisheries, and wildlife (upon which the colonists have had to subsist), and perhaps the initiation of watershed imbalance that will be likely to get worse and worse if land-use practices do not improve on their previous showing.

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

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 screening stage of site-evaluation. High sediment-loads may cause excessive abrasion of the turbine and decreased life of the facility. Recent, accurate records of stream-flow and sediment discharges for a minimum two- to three-years' period (preferably longer) must be available—to determine the appropriate size and type of turbines, and to predict the daily and seasonal supply of water for the generation of electricity. If the required two- to three-years of base data do not exist for a given potential site, serious consideration of the site should be deferred until such information is available.

Every effort should be made in the screening study to identify all existing or potential public and private water-users (including minimum flows necessary to support aquatic biota, navigation, and any necessary dilution of wastes) 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, such as might prevent SHP development, be identified and resolved.

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

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 an SHP, it may be legally impossible or inadvisable to develop the site, whatever the projected benefits. Similarly, if the existence or habitat of any rare or endangered plant or animal species is threatened by SHP 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?

The local community that is destined to benefit from an SHP, 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 and transmission line 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 resources that may be needed to assure an adequate water resource for the SHP.

Such potential requirements as these, although not yet fully developed during the screening study, should be discussed with the local community, and an affirmation of full cooperation should be received from the community before proceeding to feasibility stages of investigation.

FEASIBILITY STUDY METHODOLOGY

The feasibility study is conducted at and as the final stage of site-selection, wherein a relatively small number of potential SHP sites are examined in greater detail than hitherto, 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. As conduct of the feasibility study will require a significantly greater investment of time and money than the screening study, it is advisable to carry out the early site-screening procedure in a way that minimizes the number of sites which must be considered, and which 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 may be divided into two general parts: first, brief summarizations of potential environmental impacts of SHP development (under the next 15 side-headings), and second, compilation of a check-list of suggested information that should be gathered in order to judge the mag-

nitude of these impacts at a given site. This list, under the side-heading *'Check-list of Environmental Information'*, has 28 numbered items and starts on page 334*.

Discussion of Potential Impacts

When considered on a global scale, Small Hydropower Projects (SHPs) will encompass a wide range of facility designs and environmental settings. For example, the basic criterion of an SHP, i.e. a generation capacity of ≤ 1,000 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 substantial reservoir to store water for reliable, year-around generation may be required at some sites and not at others. The need for an impoundment is of fundamental importance to the assessment of environmental effects, because impoundment of water can result in a number of physical, chemical, and biological, changes in the stream that will not occur if a no-impoundment design is used. The discussions of potential impacts that follow are intended to cover the entire range of SHP designs, and therefore some of the considerations may not be appropriate for particular installations or site-specific environmental conditions.

Figure 1 can be used as a guide to determine which potential environmental impacts are of greatest concern for a particular SHP design. Three basic designs are listed in Fig. 1. Operation of facilities that incorporate a water-storage impoundment (above in Fig. 1) may cause substantial fluctuations in reservoir water-levels and tail-water flows on a daily or seasonal basis. Some SHPs may divert water from other drainage basins (centre of Fig. 1) to augment existing flows. Finally, run-of-the-river facilities are those whose operation is tied to normal river-flows (below in Fig. 1). These SHPs do not include an impoundment or, if one is present, experience little day-to-day change in storage capacity due to power generation.

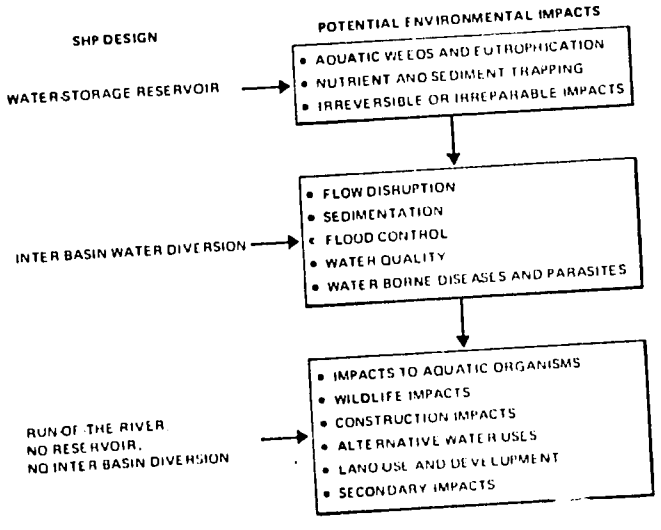

Fig. 1. *Potential environmental impacts associated with different small hydropower project designs.*

When the basic design has been selected, all impacts below the point of entry into the list should be explored. For example, if a water-storage reservoir is to be part of the development, it will be necessary to consider the entire list of possible impacts resulting from it. On the other hand, if the SHP utilizes a run-of-the-river design, without a reservoir or inter-basin diversion, many potential problems, e.g. aquatic weeds or degraded water-quality, are unlikely to occur and thus may not warrant detailed examination.

As with most man-induced stresses, the magnitude of environmental impacts resulting from SHP development is generally related to the size of the facility. Thus a 100-kW facility is likely to cause fewer problems than a 1,000-kW facility—simply because the amounts of construction material, watershed disturbance, grading, and diverted water, are less for the smaller facility than for the larger one. Of equal importance, however, is the amount of water that is 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 1,000-kW plant located on a large river.

The significance of environmental impacts can, however, vary seasonally; a 100-kW SHP 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 the expected potential and maximum foreseeable environmental impacts.

Flow-disruption

Disruptions of normal instream flows are most likely at SHPs which utilize mainstream impoundments for water-storage. Decreased flow downstream of the reservoir will occur during daily or seasonal filling. Conversely, flow can be increased above natural rates during hydropower generation or when large volumes of water are used to flush sediments from the intake structure, leading to channel- and bank-erosion and downstream sedimentation. Detailed consideration of the effects of flow regulation and disruption on the physical and biological environment is provided in Hildebrand (1980*a*) and Petts (1980).

Sedimentation

High suspended-sediment loads in the stream can affect operation and maintenance of the turbine; for examples, sediments cause turbine pitting and accelerated wear. Moreover, high suspended-sediment loads may foreclose certain downstream water-uses such as potable or irrigation water-supply.

* A specialist referee, referring to Fig. 1 and this check-list, suggests that 'A systematic list of relevant criteria would also be useful for establishing the decision-tree which allows [weighting of] the different criteria, in Step 3 of the value-analysis procedure'. – Ed.

Where impoundment or decreased water-velocities occur, sediment loads will drop out and fill up engineering structures (such as irrigation canals, reservoirs, and intake structures), thereby increasing maintenance costs and/or decreasing their useful lifetime. 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 (Loar *et al.*, 1980).

Sedimentation within a stream can be controlled to a large degree by development of a watershed management plan in which land-uses in the catchment are regulated to minimize erosion, and through strict control of project construction impacts (e.g. road-building and cutting of canals).

Alternative Water-uses

Impoundment or diversion of water for hydropower generation may affect the quantities of water that remain available for such alternative uses as irrigation, human or livestock consumption, industrial uses, or dilution of domestic sewage or industrial effluents. Under certain circumstances, it is possible that ground-water recharge may be diminished by altered stream-flows, thereby affecting the water availability in wells.

It is important to maintain minimum flows in all sections of the stream in order to ensure the survival of resident aquatic organisms, to allow migrations of fish, and to guarantee adequate supplies for human use. Every effort must be made to identify all existing or potential alternative water-users and to consider legal constraints which would determine priority uses and water-rights acquired by prior water-users.

Flood Control

An SHP which temporarily diverts a portion of the normal stream-flow for power production can be expected to have little or no effect on either diminishing or increasing the quantity of flood-flows. Those installations which include reservoirs could utilize any additional storage space to retain flood-waters and thereby reduce downstream flooding. Inter-basin transfer of generating water could have the effect of either drawing off flood-waters from the donor basin or contributing to flood-waters in the recipient watershed.

Water Quality

Direct water-quality impacts could occur at those sites whose designs include (a) diversion of water from one source or watershed to another, or (b) 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. If the diverted water is drawn from the vicinity of mines, ore-processing facilities, industrial discharges, or intensively cultivated land, it may be of lower quality than the receiving stream.

Water that is impounded in relatively deep, sheltered reservoirs may become thermally stratified. Reservoir stratification can lead to depletion of dissolved oxygen and increases in hydrogen sulphide, ammonia, and reduced iron and manganese—all of which will degrade downstream water-quality (Cada *et al.*, 1981).

Impacts on Aquatic Organisms

Operation of an SHP can affect aquatic organisms either directly (turbine-related mortality, impingement, etc.) or indirectly (habitat alteration). Injury or mortality to downstream-moving organisms may occur when they are drawn into the intake structure and passed through the turbines. Turbine mortalities can be as high as 100%, particularly when turbines are operating at low efficiencies (Turbak *et al.*, 1980). Organisms which are too large to pass through the intake debris screens may be impinged against the screen and suffer mortality due to asphyxiation and/or physical damage.

Indirect effects on aquatic biota of SHP operation may include deterioration in habitat due to suboptimal stream-flows (Hildebrand, 1980*a*; Loar & Sale, 1981) and turbidity, with sedimentation following maintenance dredging (Loar *et al.*, 1980). In extreme cases the river may dry up completely due to complete diversion or impoundment—resulting in a loss of bottom organisms and a potential blockage for upstream- and downstream-migrating fishes (Geen, 1974; Hildebrand, 1980*b*). Impounded water inundates terrestrial habitat as well as stream habitat and potential spawning sites of riverine fish. Aquatic organisms adapted to flowing water in the unimpounded stream will then be replaced by species which are adapted to life in a reservoir (Baxter, 1977).

Water-borne Diseases and Parasites

As with water-quality impacts, the operation of an SHP facility *per se* is not expected to affect the transmission of water-borne 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 stream-bed, this factor will probably not be significant in most cases.

Facility designs incorporating inter-basin (watershed) diversions or water impoundments can promote water-borne 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, 1977*a*), which 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, because those factors that are critical to self-purification of water in a stream (turbulence, sunlight penetration, oxygenation, etc.) 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 other animal and human parasites such as schistosomiasis) (Brown & 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).

Construction Impacts

Construction of access roads, dams, diversion canals, or other on-site activities, will result in the disturbance and movement of erodible soils. Sound engineering practices, e.g. the use of soil stabilization techniques or storm-water retention dikes, can reduce sedimentation impacts on stream organisms during construction. Care must also be taken to prevent oils, greases, and chemical wastes, from being discharged into streams.

Operation of transmission lines may require the clearing and maintenance of relatively vegetation-free 'corridors'. Such activities may restrict alternative land-uses, but impacts on wildlife are usually not significant. In cases where terrestrial habitat diversity is increased by transmission-line corridors, wildlife may actually benefit.

Land-use and Development

The immediate, direct land-use impact of an SHP is the commitment of land for on-site components (canals, penstock, turbine buildings, etc.), access roads, and transmission lines. If a water-storage reservoir is part of the design, some land (all-too-often potentially prime, river-bottom farmland or land already occupied by human settlements) will be inundated.

SHP development will be likely to have the effect of promoting other development and increased human 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 that would be feeding the project, and adequate management and protection strategies have been approved and enacted.

Nutrient- and Sediment-trapping Effects

SHP installations which incorporate reservoirs may act as sediment- and nutrient-traps. As a stream enters the reservoir, its 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 phenomena of nutrient- and sediment-trapping effects are treated in detail in Hildebrand (1980*a*).

Aquatic Weeds and Eutrophication

'Nuisance' aquatic vegetation can cause operation and maintenance problems at SHPs, 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 macrophytic floating-plants (e.g. Water-hyacinth [*Eichhornia crassipes*] and Water-lettuce [*Pistia stratiotes*]), submerged, rooted vegetation (Hydrilla [*Hydrilla lithuanica*] and water milfoil [*Myriophyllum* spp.]), and/or rooted, emergent plants (cattails [*Typha* spp.], bulrushes [*Scirpus* spp.], and many others). Not only do these plants have profound effects on the aquatic biological community, but they can also interfere with SHP operation by clogging the intake structure, increasing evapotranspiration losses of water from the reservoir, reducing the effective water-volume of the reservoir, harbouring disease vectors and parasite hosts, increasing sediment- and nutrient-trap efficiency (thereby decreasing the useful life of the reservoir), and hindering alternative water-uses (e.g. fishing, swimming, and livestock watering).

Static conditions created by reservoirs also favour the excessive growth of planktonic Algae. Some species of Algae *sensu latissimo*, 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 such Algae and large aquatic weeds can significantly degrade water-quality both within the reservoir and downstream from the SHP discharge.

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

Wildlife Impacts

Site clearance and road construction for an SHP may eliminate critical wildlife habitat, while construction noise and activities could interfere with nesting of birds or migratory movements of terrestrial mammals. Creation of a reservoir will permanently inundate floodplain vegetation (which often provides excellent wildlife habitat) and will 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 of plants and animals.

On the positive side, SHP 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 by Trefethen (1973) and by Heinzenknecht & Paterson (1978).

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 SHP development is likely to have a number of secondary effects. For example, establishment of new roads, small industries, and irrigation capabilities, and immigration into undeveloped areas, are all potential social benefits derived from rural electrification that could, in them-

10

selves, have effects of greater magnitude on the environment than the SHP *per se*.

Regional developments following electrification could include increases in the human population (by either promoting immigration or stemming emigration), agricultural (irrigation) activities, livestock production, and local industries—any of which could have important consequences for the water and land-use patterns in the region. Population increases in the regions served by SHP electricity will create an augmented demand for potable and/or irrigation water and also for waste-water treatment. Small communities that currently have no drinking- or waste-water treatment facilities may encounter increasing problems with water-borne diseases as the population increases and the ability of the environment to assimilate their wastes decreases (Stein, 1977*b*).

In similar manner increased needs of water for such purposes as irrigation or aquaculture may occur as an indirect result of rural electrification and concomitant population increases, and may add unacceptable stresses to limited resources. It is accordingly of great importance that different planning and development programmes 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.

Irreversible and Irreparable Impacts

Irreversible and irreparable impacts will occur most commonly when SHP 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/or 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 below the reservoir (Buma & Day, 1977).

Construction of SHPs 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.

Check-list of Environmental Information

The check-list 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 means of the check-list 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 SHP 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 stream-flow data through a number of recent years with a view to being assured of the maintenance of sufficient flow in the stream (for aquatic biota) and for reliability of the SHP operation.
(4) Obtain rainfall data (e.g. rainfall intensity values) for the study area.
(5) Determine water withdrawal rates for SHP operation and the location of the intake and discharge structures.
(6) If a water-storage impoundment is part of the SHP design, determine the timing of reservoir releases on a daily and seasonal basis.
(7) Determine the alternative water-uses (including in-stream needs for the protection of aquatic biota) in the area, the location of all water intakes or discharges in the affected areas, and the 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 SHP.
(9) Locate important alluvial floodplains that will (or may) no longer be seasonally flooded owing 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 and ecological maps of the country or other area involved, determine which of these 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 there are in each annual water-cycle.
(12) Obtain an up-to-date map of actual land-uses of the area, determining which are the predominant ones.
(13) Obtain or prepare land-use capability or land-use potential maps developed for the general study area, and determine what resource-use potentials exist for the watershed with which you are concerned.
(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 would or could be lost as a result of site construction, access-road construction, transmission-line construction, impoundment or other SHP activity.
(16) Determine whether the SHP site is near a protected area (preserve, sanctuary, refuge, or dedicated area, etc.) 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 of plants or animals inhabit the region.
(19) Identify the principal aquatic species present in the area affected by SHP 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 water-borne diseases or parasites that are endemic to the area, and determine the possibility of spreading or accentuating disease problems by SHP development.
(22) Identify species of aquatic plants in the area, or capable of introduction to it, that could interfere with hydroelectricity production and alternative water-uses.
(23) Identify any pre-existing (natural or man-induced) environmental stresses in the area, and any future developments that may be planned for the area and 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 (relatively large sediment particles moving along the channel bottom) of the stream.
(25) Obtain water-quality data, especially regarding temperature, dissolved solids, salt, nutrient, and dissolved oxygen levels, and investigate the possible presence of toxic materials or disease organisms.
(26) Identify any active or projected mining activities in the study area and, if there are any, determine whether they are (to be) open-pit or tunnel mines and how their wastes are (to be) handled.
(27) Consider any particular design features of the SHP plant (e.g. impoundment or 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 SHP site-development, by adequate prior planning to keep any undesirable effect to an absolute minimum.

Responses to all of these requests for information should be provided on the basis of the questions as stated and the foreseeable outcomes. If no information is available for a particular item, this should be expressly stated, and a list kept of the full names and addresses of all people contacted in the search. If certain information is critical to the final assessment, and could be generated with relatively little time and resource expenditure (e.g. field checking), this should be done.

When all available information has been assembled, the significance of definite or possible environmental impacts arising from development and operation of the SHP should be judged by competent people with experience in environmental impact assessment — by weighing the cost of irreversible impacts or preventive and mitigative measures against the benefits of electricity to the community. In general, due to the small scale of SHP 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 or rejection of a given site, it may be desirable to estimate monetary costs and/or benefits.

RECOMMENDATIONS

Small Hydropower Projects (SHPs) have a number of advantages over other sources of power as a means of providing electricity to rural areas especially in the Third World. They represent a relatively simple, proven technology and are generally easier to operate and maintain than thermal power-plants. As SHPs 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 SHPs. Since decisions about the significance of these impacts at a candidate site will be largely judgmental, both the screening 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, or forestry), and with experience regarding impact assessments.

To streamline the site-selection process, competent individuals within the utility (or other organization involved in SHP development) could carry out the screening 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 SHP 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. suitable and usually senior university staff) 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 (who are legion but not always good) 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. This could be done most efficiently by contact-

* A referee suggests that 'contacts with foreign consultants could be established with the help of international institutions such as UNEP, or IUCN's new "Conservation for Development Centre"'. Ed.

12

ing 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 SHP development. For example, information on the potential for disease problems and necessary preventive measures could be provided by a governmental health department or World Health Organization office, whereas present and planned land-use patterns in the affected area could be determined by consultation with agricultural agencies. It is essential that all potential sources of information be contacted at this stage, to identify any possible environmental problems and to ensure coordinated, well-planned development.

When the requisite environmental data and detailed engineering drawings of each seriously considered site have been obtained, the short-listed candidate sites 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, and others) to weigh the various projected benefits and consequences of SHP development at each short-listed candidate site before making its final selection.

In summary, the principal objective 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 that has every chance of permanent and universal acceptability. To the degree that SHPs promote rural industries and improve the lot of 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 SHPs will receive some environmental education and technical training, and will have the opportunity to manage and control their own resource-base. Finally, as the screening 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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SUMMARY

Small Hydropower Projects (SHPs), defined as including hydroelectric generating facilities with capacities of 1,000 kW or less, have great potential for elevating the standard of living and contributing to the economic growth of isolated rural communities especially in Third World countries. However, construction and operation of an SHP can result in adverse environmental impacts that should be assessed in the initial stages of site-selection and avoided in the development.

Environmental concerns can be factored into a site-selection process both at the screening and feasibility stages. The screening study is the process by which a large number of potential sites are reduced to a much smaller number of candidate sites based on coarse-grained engineering, socio-economic, and environmental, criteria. Although many of the factors determining the suitability of a given site at the screening stage involve basic engineering or economic questions, fundamental environmental issues that should be addressed include an appropriate resource-development strategy to accompany the SHPs, the quality and quantity of water available for all project needs, the presence of near-by protected areas, habitats, or important species, and the adequacy of local support for environmental protection requirements of the project.

The feasibility study is the final stage of site selection, where a relatively small number of candidate SHP sites are examined in proper detail and the best are selected for development. Potential environmental impacts of SHPs range from flow-disruption downstream to the spread of water-borne diseases and parasites, and are related to the design and size of the facility. We provide a check-list of environmental data that should be collected at this stage in order to judge the significance of projected impacts of candidate SHPs.

It is important that site selection and impact evaluation be conducted by competent individuals with formal training and experience in an appropriate environmental field. After compiling relevant information (e.g., through literature searches and contacts with government agencies or universities), the feasibility study team should visit the site of each at all likely-to-be chosen SHP. This will allow the interdisciplinary team's members to identify any previously unanticipated problems, to receive inputs from the local community, and to weigh the various benefits and consequences of SHP development before making their final selection.

REFERENCES

BACHMAN, R. (1978). Algae – an overview. Pp. 65–79 in *Environmental Effects of Large Dams*. (Report by the Committee on Environmental Effects of the U.S. Committee on

Large Dams.) American Society of Civil Engineers, New York, NY, USA: 225 pp.

BAXTER, R.M. (1977). Environmental effects of dams and impoundments. *Annu. Rev. Ecol. Syst.*, **8**, pp. 255–83.

BROWN, A.W.A. & DEOM, J.O. (1973). Summary: Health aspects of man-made lakes. Pp. 755–64 in *Man-made Lakes: Their Problems and Environmental Effects* (Ed. W.C. Ackermann, G.F. White & E.B. Worthington). Geophysical Monograph 17, American Geophysical Union, Washington, DC, USA: xvi + 847 pp., illustr.

BUMA, P.G. & DAY, S.C. (1977). Channel morphology below reservoir storage projects. *Environmental Conservation*, **4** (4), pp. 279–84, 10 figs.

CADA, G.F. & ZADROGA, F. (1981). *Environmental Issues and Site Selection Criteria for Small Hydropower Projects in Developing Countries.* (ORNL TM-7620.) Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA: 47 pp.

CADA, G.F., KUMAR, K.D., SOLOMON, J.A. & HILDEBRAND, S.G. (1981). *Analysis of Environmental Issues Related to Small-scale Hydroelectric Development. VI: Dissolved Oxygen Concentrations Below Operating Dams.* (ORNL/TM-7887.) Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA: 68 pp.

GEEN, G.H. (1974). Effects of hydroelectric development in western Canada on aquatic ecosystems. *J. Fish. Res. Board Can.*, **31**(5), pp. 913–27.

HEINZENKNECHT, G.B. & PATERSON, J.R. (1978). Effects of large dams and reservoirs on wildlife habitat. Pp. 101–47 in *Environmental Effects of Large Dams.* (Report by the Committee on Environmental Effects of the U.S. Committee on Large Dams.) American Society of Civil Engineers, New York, NY, USA: 225 pp.

HILDEBRAND, S.G. (Ed.). (1980*a*). *Analysis of Environmental Issues Related to Small-scale Hydroelectric Development. III: Water Level Fluctuations.* (ORNL/TM-7453.) Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA: 78 pp. + 1 appendix.

HILDEBRAND, S.G. (Ed.). (1980*b*). *Analysis of Environmental Issues Related to Small-scale Hydroelectric Development. II: Design Considerations for Passing Fish Upstream Around Dams.* (ORNL/TM-7396.) Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA: 78 pp.

LOAR, J.M., DYE, L.L., TURNER, R.R. & HILDEBRAND, S.G. (1980). *Analysis of Environmental Issues Related to Small-scale Hydroelectric Development. I: Dredging.* (ORNL/TM-7228.) Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA: 134 pp.

LOAR, J.M. & SALE, M.J. (1981). *Analysis of Environmental Issues Related to Small-scale Hydroelectric Development. V: Instream Flow Needs for Fishery Resources.* (ORNL/TM-7861.) Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA: 123 pp.

MITCHELL, D.S. (1973). Aquatic weeds in man-made lakes. Pp. 606–11 in *Man-made Lakes: Their Problems and Environmental Effects* (Ed. W.C. Ackermann, G.F. White & E.B. Worthington). Geophysical Monograph 17, American Geophysical Union, Washington, DC, USA: xvi + 847 pp., illustr.

NATIONAL ACADEMY OF SCIENCES (1976*a*). *Energy for Rural Development.* National Academy of Sciences, Washington, DC, USA: 306 pp., illustr.

NATIONAL ACADEMY OF SCIENCES (1976*b*). *Making Aquatic Weeds Useful: Some Perspectives for Developing Countries.* National Academy of Sciences, Washington, DC, USA: 175 pp., illustr.

PETTS, G.E. (1980). Long-term consequences of upstream impoundment. *Environmental Conservation*, **7**(4), pp. 325–32, 4 figs.

RHODES, M.L. (1978*a*). Aquatic weeds in man-made lakes: Their nature, some problems, and potential solutions. Pp. 81–92 in *Environmental Effects of Large Dams.* (Report by the Committee on Environmental Effects of the U.S. Committee on Large Dams.) American Society of Civil Engineers, New York, NY, USA: 225 pp..

RHODES, M.L. (1978*b*). Aquatic weeds in man-made lakes: Disease vectors. Pp. 93–99 in *Environmental Effects of Large Dams.* (Report by the Committee on Environmental Effects of the U.S. Committee on Large Dams.) American Society of Civil Engineers, New York, NY, USA: 225 pp.

STEIN, J. (1977*a*). Water for the wealthy. *Environment*, **19**(4), pp. 6–14.

STEIN, J. (1977*b*). Fumbled help at the well. *Environment*, **19**(5), pp. 14–45.

TREFETHEN, J.B. (1973). Man-made lakes and wildlife values. Pp. 750–4 in *Man-made Lakes: Their Problems and Environmental Effects* (Ed. W.C. Ackermann, G.F. White & E.B. Worthington). Geophysical Monograph 17, American Geophysical Union, Washington, DC, USA: xvi + 847 pp., illustr.

TURBAK, S.C., REICHLE, D.R. & SHRINER, C.R. (1980). *Analysis of Environmental Issues Related to Small-scale Hydroelectric Development. IV: Fish Mortality Resulting from Turbine Passage.* (ORNL/TM-7521.) Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA: 112 pp.

14

(Concluded from page 348)

sult in these habitats drying up by midsummer and hence before the completion of metamorphosis. The Wyoming Toad and Leopard Frog may have failed to reproduce in recent years as a result of generally dry years.

4. Predation is an ever-present factor in amphibian biology. Gulls, Raccoons *(Procyon lotor)*, foxes, and Skunks *(Mephitis mephitis)*, are plentiful in the Laramie Basin; most such predators have increased in numbers during the last 50 years, probably in response to changes in habitat and to certain human activities which have benefited some animals at the expense of others. Anuran tadpoles, and, especially, newly-transformed juveniles, are particularly susceptible to predation by gulls and foxes.

5. Certain diseases may have caused excess mortality in anuran populations in recent years. Anurans are known to be very susceptible to bacterial infections such as redleg.

6. The combined effect of all the factors listed above may have had a cumulative and or additive effect on the population dynamics of anurans. The relatively small population of a supposedly relict form such as the Wyoming Toad, in a restricted area such as the Laramie Basin, might be expected to decline and quite possibly become extinct under the influence of the factors listed above.

Conclusion

The Wyoming Toad is currently scheduled in the 1982 Program Advices of the US Fish and Wildlife Service for listing as an Endangered species under provisions of the Endangered Species Act of 1973. While listing is an important measure towards the subspecies' conservation, it is not sufficient to prevent extinction. There is an urgent need for research on the causes of decline of amphibian populations throughout the Laramie Basin and elsewhere. Meanwhile searches should continue for additional populations of the Wyoming Toad; if such are found, they should be protected immediately through cooperative agreements with landowners. In addition, it might be adviseable to start a captive breeding programme such as has been undertaken by the Houston Zoo on behalf of the endangered Houston Toad, *Bufo houstonensis*. Unless such measures are forthcoming, the Wyoming Toad may become extinct in the very near future.

REFERENCES

BAXTER, GEORGE T. & MEYER, J.S (1982). The status and decline of the Wyoming toad, *Bufo hemiophrys baxteri*. *J. Colo.-Wyo. Acad. Sci.*, **14**(1), p. 33.

BAXTER, GEORGE T. & STONE, M.D. (1980). *Amphibians and Reptiles of Wyoming*. Wyoming Game and Fish Department, Laramie, Wyoming, USA: 137 pp. (mimeogr.)

BAXTER, GEORGE T. & STROMBERG, M. (1980). *Status Report*. Rep. to US Fish and Wildlife Service, Denver, Colorado, USA: 5 pp. (mimeogr.).

BEHLER, JOHN L. & KING, F.W. (1979). *The Audubon Society Field Guide to North American Reptiles and Amphibians*. Alfred A. Knopf, New York, NY, USA: 719 pp., illustr.

HAZELWOOD, ELLEN (1970). Frog pond contaminated. *Brit. J. Herpetol.*, **4**, pp. 177-85.

JOHNSON, C.R. & PRINE, J.E. (1976). The effects of sublethal concentrations of organophosphorus insecticides and an insect growth-regulator on temperature tolerance in hydrated and dehydrated juvenile Western Toads, *Bufo boreas*. *Comp. Biochem. Physiol.*, **53A**, pp. 147-9.

PACKARD, GARY C. (1971). Inconsistency in application of the biological species concept to disjunct populations of anurans in southeastern Wyoming and north-central Colorado. *J. Herpetol.*, **5**(3-4), pp. 191-3.

PORTER, KENNETH R. (1968). Evolutionary status of a relict population of *Bufo hemiophrys* Cope. *Evolution*, **22**(3), pp. 583-94.

SANDERS, H.O. (1970). Pesticide toxicities to tadpoles of the western Chorus Frog, *Pseudacris triseriata*, and Fowler's Toad, *Bufo woodhousei fowleri*. *Copeia*, *1970*, pp.246-51.

STROMBERG, MARK R. (1981). Wyoming Toad (*Bufo hemiophrys baxteri*) endangered. *J. Colo.-Wyo. Acad. Sci.*, **13**(1), p. 47.

VANKIRK, EDWARD A. (1980). *Report on Population of* Bufo hemiophrys *on Laramie Plain, Albany County, Wyoming*. Rep. to Wyoming Natural Heritage Program, The Nature Conservancy, Cheyenne, Wyoming, US: 6 pp. (mimeogr.).

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15