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Ecological aspects of water impoundment in the tropics

by

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Abstract: Recognition of the potentially harmful effects of water development in the tropics has led to increasing efforts to assess the environmental impact of such projects prior to construction. Decisions regarding the development or non-development of water resources must be based on sound investigation of both the long-and short-term effects of reservoir construction and operation. The environmental effects of water impoundment vary greatly with the characteristics of the region as well as the type of reservoir to be constructed (area and depth of reservoir, ratio of water inflow to storage). Of major concern are the reduction of reservoir capacity as sediments accumulate behind the dam and the loss of these sediments to downstream agriculture and fisheries. The potential impact of altered flow regimes, siltation, reduction in beach formation and nutrient enrichment at the mouths of rivers, and the possibility of saltwater encroachment should receive careful study. A thorough description of the plants and animals to be affected by inundation should be made to determine the possible loss of rare or key organisms as well as the potential development of "nuisance species". Included in this survey should be a detailed study of existing fish and the potential for commercial fishery development in the proposed reservoir. Consideration should be given to vegetation removal in the reservoir basin prior to inundation, since decaying vegetation can result in deoxygenation, formation of hydrogen sulfide, possible development of suitable habitats for undesirable species and snagging of fish nets. Sanitation and land use practices as well as erosion in the watershed surrounding the reservoir must be controlled to prevent accelerated eutrophication caused by increased nutrient loading.

Inundation in tropical areas can have serious sociological and human health implications including the increase of diseases, e.g., malaria, schistosomiasis, onchocerciasis, and dysentery, and the probable resettlement and alteration of land use practices. Census information and surveys concerning land use, housing and health standards and the social and economic structure of the community to be affected must be evaluated in order to anticipate and avoid potential problems. The archaeologic, historic, scenic and recreational value of the site to be inundated must also be considered.

Studies of the El Cajón site on the Sula River in Honduras and the Purari River Project in Papua, New Guinea, are utilized as examples in this report.

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River systems are increasingly being exploited as sources of agricultural, industrial and domestic water, hydroelectric power, and recreation. Although, historically almost any development could be justified in the name of progress, during the last decade an increasing awareness of the consequences of large-scale manipulations of land and water has developed. As populations expand, as land, water and fuel resources have diminished, and as our knowledge of the complexity of aquatic and terrestrial ecosystems has increased, we have been forced to more critically evaluate large-scale alterations of the environment and more carefully weigh the costs and benefits they provide (**Goldman** *et al.*, 17).

With the rise in the world's population and per capita energy consumption, the demand for hydroelectric power has also continued to increase. The growing demand for new power sources is reflected in the increasing number of impoundment projects throughout the world. For example, since 1958 the development of African hydroelectric energy has greatly increased. Such dams as the Kariba on the Middle Zambezi River (**Balon** and **Coche,** 1), the Akisombo Dam on the Volta River and the Aswan Dam are now in operation. Other projects on the Ivory Coast in Mozambique and on the Congo River are underway or completed. It is interesting to note that few of these projects were *preceded* by research concerning their potential environmental impact. However, investigations *following* reservoir construction are now more frequently being reported.

The world-wide energy crisis has reopened the question of water development in areas which might previously have shown a prohibitively high cost-benefit ratio. As the costs of fossil fuels rise, relatively inexpensive, clean, hydroelectric power is now in much greater demand. Increased economic incentives to develop new energy sources may have serious environmental considerations which restrict the development of these new sources.

Many years of dam building throughout the world provide a multitude of lessons regarding the effect of impoundment projects on the topography, wildlife, fisheries, water quality, disease, archaeology, and people. The science of ecology has enabled man to much more effectively predict the impact of various types of water development and use than in the past. It is obvious from these studies that all water projects have both long-and short-term environmental repercussions. A careful, objective evaluation of the costs and benefits of proposed water projects is, therefore, essential before rational decisions can be made to determine if and how development should proceed.

A good deal has now been written on the impact of impoundment in the tropics. Studies on tropical hydroelectric projects, particularly the great African dams, have been collected in surveys by **Lowe-McConnell** (27), **Moxon** (31) and **Obeng** (32). The multidisciplinary study by **Goldman** *et al.* (17) on the problems of balancing environmental considerations and water development emphasized temperate areas, although many of the same problems apply to the tropics. **Lagler** (24) and **Freeman** (9) discuss problems of impoundment projects and suggest studies to assess the environmental impacts of these projects. Despite such research, a general lack of knowledge about hydroelectric projects and aquatic biology in the tropics persists. As noted by **Freeman** (9), knowledge of the biogeochemistry of tropical watersheds, eutrophication, nitrogen and phosphorus cycles, and their relation to primary productivity and altered flows in estuaries is very limited.

The following report discusses some of the potential physical, chemical, biological and sociological implications of tropical water impoundment projects. Recommendations are included in areas of particular ecological concern which should be investigated and dealt with before, during and after construction. Ecological studies, by the author and his associates, of the El Cajón dam site on the Sula River in Honduras (**Goldman,** 14; Fig. 1) and the Purari River Project in Papua New Guinea (**Goldman** *et al.*, 16) will be used throughout this report to illustrate many of the principles that should concern ecologists, engineers and governments alike.

PHYSICAL AND CHEMICAL CONSIDERATIONS

Siltation decrease in reservoir capacity: Experiences with siltation in previous impoundments suggest that it must be considered of major importance to both the longevity and ecology of the reservoir. Projects on the Santa Ynez River near Santa Barbara, California, for example, provide clear evidence of the importance of siltation (**Marine,** 28). Loss of reservoir capacity due to deposition of settleable materials led to the construction of two additional dams which were originally not thought to be necessary. Similar problems threaten the Bhakra Nangal Dam in India, which because of siltation has a predicted lifetime of only 40 years, and the Aswan Dam, which prevents tremendous amounts of silts from travelling downstream into the sea (**Hagan** and **Roberts,** 18). A detailed study of reservoir lifetime limitations as influenced by siltation should, therefore, be a serious concern of any proposed dam construction.

It is clear that the degree of erosion control in the drainage area of a water-storage project can greatly alter the sedimentation rate and is of critical importance to the longevity and water quality of the proposed reservoir (Fig. 2). In addition to increasing runoff, the lack of a dense canopy in the watershed surrounding the proposed reservoir or inflowing rivers heightens the impact of rain on soil, allowing soil particle aggregates to be broken down and surface runoff to transport finer particles. The concentration of soil in runoff water is thus increased.

Since certain logging and agricultural practices in tropical countries have greatly increased surface runoff, it is recommended that the watershed be managed with particular attention to soil conservation and forest regeneration. Revegetation and the cessation of human activities which foster erosion can reduce the rate at which the reservoir capacity is decreased by siltation and the reservoir waters fertilized by materials washed into the system.

Heavy tropical rains, steep valley slopes, and the state of the watershed soils and vegetation all contribute to the rate of siltation in a particular region. Extreme water turbidity often appears in the tropics during the rainy season. This was found to be particularly true in the Río Humuya, a river studied in the El Cajón project. The transparency of this water, as measured with a 20 cm Secchi disk at the El Cajón Dam site, was only 16 cm.

The potential for slumping of the slopes surrounding a reservoir may also be an important factor as evidenced by the disasterous flood in northern Italy resulting from a massive landslide into a reservoir. Mass wasting following lumbering was responsible for the death of thousands during the last hurricane in Honduras. The previous hurricane, although of greater force, did not cause this level of damage because the root structure of the forest was still intact. Subsequent decay set the stage for the recent disaster (Marco Flores, personal communication).

While a reservoir is filling and after filling is completed, it is possible to establish sampling procedures that can provide fairly accurate siltation estimates. In order to obtain these estimates, major inflows near their points of entry into the future reservoir must be sampled for settleable materials during the entire year. Since there are often several inflowing streams and rivers entering a reservoir and their point of entry may be relatively inaccessible, it is clear that the places and times of sampling must be selected with care (sampling during rainy periods obviously must not be overlooked!).

Determination of reservoir lifetime is essential in evaluating the true economic potential of the project and its multi-use aspects. A detailed sampling program, therefore, must be initiated prior to dam construction in order to realistically predict the expected life of the impoundment.

Effect of silt on the aquatic biota: Besides decreasing reservoir capacity, large-scale siltation can have pronounced effects on the reservoir biota and its distribution. Turbidity caused by suspended silt can significantly reduce photosynthesis in rivers and reservoirs. This photosynthetic reduction has widespread effects on higher trophic levels of the food chain.

Silt deposits typically form deep fine-grained muds containing only a few macroscopic organisms such as chironomids, nematodes, and oligochaetes. Fine deposits reduce the number of habitats which can support benthic organisms and tend to decrease the diversity of the benthic fauna in reservoirs.

Inorganic silt deposition most likely will dominate in the early reservoir years. Eventually, the characteristics of bottom deposits will change as autochthonous detritus, derived from planktonic and littoral organisms, accumulates to provide a more suitable environment for insect larvae.

Scanning electron microscopy (SEM) dramatically illustrates the importance of organic and inorganic particles as substrata for aquatic bacteria (**Paerl** and **Goldman,** 34). The surface area present on particulate matter provides a site for the attachment of bacteria as well as organics and inorganics which adsorb to these surfaces (Fig. 4). Thus, by providing surface area for attachment as well as nutrition, silts are able to stimulate aquatic bacterial growth (**Paerl** and **Goldman,** 35).

Many rivers obtain most of their biological energy input by the accumulation of terrestrial debris (leaves, bark, twigs, etc.) from the surrounding watershed. This detritus forms excellent substrata for bacteria that can enter the food chain in association with fine particles utilized by filter feeding organisms. In addition to providing food for filter feeders, there is good evidence that bacteria and adsorbed organic material may serve as energy for mud-feeding fish such as the *Sobalo* of the Parana River in Argentina (**Goldman,** 12).

Although drawdown with exposure of shallow breeding and food producing areas is probably the most serious threat of water impoundment to fish, sedimentation can also destroy potential spawning beds in the shallow littoral zone of the reservoir. Sediments can smother fish eggs by decreasing the rate at which oxygen is replenished and wastes are diluted in the immediate vicinity of the eggs. Certain fish originating in the riverine system may be unable to find suitable breeding conditions in the littoral zone of a reservoir.

Other aspects of silt deposition include: (a) entrapment of these sediments behind the dam with resulting loss of nutrient sources to downstream agriculture and marine fisheries; (b) changes in coastal beach erosion rates; and (c) the reduction in deltas which formerly had been replenished by sediment recharge during annual floods. Reservoirs invariably affect the pattern of downstream sediment deposition, and this aspect of any water impoundment in the tropics should receive special consideration in the planning stages.

Reservoir water quality: Water quality following the closing of a dam typically undergoes a transitional period of high organic and inorganic ion concentrations and low oxygen content. The length of the transitional period depends not only on river water quality but also on the presence of any residual submerged terrestrial vegetation, the thermal profile in the reservoir, nutrient level of submerged soils, and the rate at which reservoir water is being replaced by inflow water. Following this transitional period is a state characterized by lower concentrations of minerals and organic materials, although nutrient concentrations remain above levels found in the rivers. This lowering of reservoir fertility may prove very disappointing to a fishery that has been developing during the initial period of high fertility.

Decay of submerged terrestrial vegetation will deoxygenate the reservoir and release organic compounds into the waters, both of which lower the oxidation-reduction (redox) potential of the water. This lower potential and lack of oxygen favors certain biological reactions, in particular the reduction of sulfate to sulfide by the bacteria *Desulfovibrio* (**Hutchinson** 21). Combined with microbes that release sulfur from proteins as sulfide, these bacteria can be responsible for increasing the hydrogen sulfide concentration of the waters to a level toxic to fish and unpleasant for human use. The low solubility product of sulfide and heavy metal ions can result in large-scale precipitation of metallic sulfides that may interfere with turbine operation. Working turbine generator parts that contact reservoir water may corrode and not function properly if made of materials that can form metallic sulfides (e.g., copper). Substitutes for these materials should be investigated.

With proper watershed control of erosion and sanitation practices, noxious algal blooms are not as likely to be a problem except during the transitional period following dam closure. Eroded materials can serve as a direct source of nutrients if they originate from soils with leachable nitrogen, phosphorus, sulfur and trace elements. However, even minerals resistant to decomposition can promote the process of eutrophication by providing a substrate on which organic materials can be adsorbed and concentrated. Bacteria, as mentioned in previous sections, colonize these particles and recycle the nutrients for algae by decomposing adsorbed organic matter.

Reservoirs have a high water inflow relative to volume so that reservoir productivity is determined to a great extent by the quality of incoming rivers. Special attention should therefore be given to the water quality of inflowing rivers. A continuous water quality monitoring program should be established with any impoundment project to monitor important ions in rivers flowing to the proposed reservoir. This monitoring program would note changes in the benthic fauna, the plankton and the bacterial flora of the reservoir both as it fills and after filling is completed. Bioassays performed to determine macro-and micronutrients limiting primary productivity would also be informative (**Goldman**, 15) and helpful for designing appropriate watershed management programs. A good monitoring program including adequate provisions for data analysis will not only produce vital information concerning both downstream and reservoir water quality but will also provide essential data which should be used in the earliest stages of reservoir planning.

The existing productivity of river water can be determined by a number of ways. One method is to measure its primary productivity directly. Another method is to add river water to algal cultures and measure the resulting changes in productivity. This latter technique, also described by **Goldman** (10, 11), is a bioassay of river water and is best performed on natural plankton communities found in the area.

Bioassays to determine the most likely limiting factor should also be performed using water from the inflowing river to the proposed reservoir with varying levels and combinations of N, P, Si, Fe and trace elements (10, 11). The most likely limiting factor can then be utilized in developing strategies for lake management.

Reservoir stratification: Stratification in tropical lakes is still an inadequately understood phenomenon but one of very great importance. Deep lakes stratify during the summer with a warmer surface layer, the epilimnion at the top and a cooler hypolimnion below. Decaying organic matter in deeper waters consumes oxygen so that the hypolimnion is often depleted. Altitude. wind exposure. basin shape, and the temperature and turbidity of inflowing waters are all important variables in determining stratification. Reservoirs in the tropics with steep sides and protection from winds are most likely to be permanently stratified. Mixing of waters may occur in the tropics but often at such a slow rate that deoxygenation of the hypolimnion persists (**Beadle,** 2). Cooling of shallow littoral waters has been proposed as a slow mixing method in tropical lakes by **Beadle** (2) and was shown by **Talling** (34) to occur in Lake Albert.

Modelling of the thermal characteristics of reservoirs has been accomplished in temperate latitudes, and there are excellent prospects for achieving relatively accurate predictions in tropical areas.

The placement of dam outlets in relation to stratified layers of the reservoir nas important implications for downstream fisheries and agriculture. An outlet located in the hypolimnetic layer may release only cooler, deoxygenated water, whereas an epilimnetic outlet releases warmer, highly oxygenated water. Either situation can have major downstream effects. For example, water from the hypolimnion may be much cooler than downstream waters and may shock the fishery below. Warmer epilimnetic waters, on the other hand, may be too warm for some species. It is essential that these potential effects be evaluated so that reservoir operation can be adjusted appropriately (e.g., variable level discharges).

BIOLOGICAL CONSIDERATIONS

Infestation by higher aquatic plants: One of the many lessons emerging from experiences with dams in Africa is the seriousness of the threat of infestation with aquatic macrophytes (Fig. 3). The water fern *(Salvinia auriculata)* and water lettuce *(Pistia stratiotes)* invaded Lake Kariba on the Zambezi shortly after it began to fill in December 1958 (**Harding,** 19). Eventually the water fern severely hampered multipurpose use of the lake and a buoy barrier had to be constructed to keep higher aquatic plants away from turbine inlets (**Coche,** 7). On Lake Brokopando in Surinam similar problems occurred with the water hyacinth *(Eichornia crassipes)*, the water fern *(Ceratopteris thalictroides)*, duckweed *(Lemna)* and algal mats *(Spirogyra, Mongeotica)*. Lago Río Lempa in El Salvador and Lago Apanas in Nicaragua are two Central American reservoirs containing substantial water hyacinth populations; the turbines and spillways of the latter are frequently threatened by water lettuce (**Little,**26). Other nuisance aquatics include *Ceratophyllum* and papyrus in Africa and *Alternanthera, Elodea, Majas, Potamogeton* and *Myriophyllum* in the U ted States.

It is apparent from available literature that knowledge of the detailed ecology of many aquatic weeds is inadequate. **Mitchell** and **Thomas**(30) had limited success in their attempts to understand aquatic weed ecology in the neotropics. They did, however, report that *Salvinia* was found to be sensitive to low nitrogen levels, and grazing by cattle in small ponds was effective in controlling aquatic weeds.

Occasionally, for reasons unknown, a lake or reservoir may remain completely free from macrophyte infestation even though a source of infection is present and the water characteristics appear to resemble other areas which do suffer. For example, water hyacinth has not colonized certain areas apparently suited for it (**Little**, 26).

Important characteristics of potential aquatic weed problems include: (a) the presence of aquatic weeds in the watershed and within naturally transportable distances; (b) the presence of protected swamps or littoral areas suitable for colonization; and (c) the presence of submerged terrestrial vegetation to serve as protection for weed colonies.

Effects of aquatic macrophytes: Large stands of higher aquatics influence many aspects of reservoir use. One benefit to man is to provide additional food for desirable herbivorous fish or fish feeding on organisms which are favored by the protection and food offered by the higher aquatic plant habitat. For example, the extensive floating mats of *Salvinia* in Lake Kariba were eaten by two fish species. Fishing below the mat surfaces as well as snail populations on these mats produced high yields. Dense growth of these macrophytes may also serve to protect fish, particularly smaller fish, from excessive predation.

The negative aspects of the presence of aquatic macrophytes, however, overwhelmingly point to the need to control their growth:

(I) Decomposition of the macrophytes by aerobic bacteria can contribute to an extensive deoxygenation of the reservoir waters, the chemical effects of which have been mentioned. In addition, the lower deoxygenated waters will not be able to support fish populations and any plant productivity in this region will thus go unharvested.

(II) Huge thick floating mats (sudds), sometimes sufficiently large to support growth of other higher plants (e.g., *Scirpus cubensis* on *Salvinia*) can present real hazards to navigation and plug turbine intakes.

(III) Heavy infestations can interfere with operation of gill nets and seines and seriously hamper commercial as well as sportfishing.

(IV) Certain disease-bearing organisms, such as the snail vector of schistosomiasis and the mosquito vector of malaria, find desirable habitats among these macrophyte "forests". The snail was a possible problem among *Potamogeton perfiolatus* in the Gezira cotton area of the Nile while larvae of the mosquito bred in rafts of water hyacinth in the Sennar Reservoir on the Blue Nile (**Lewis**, 25).

(V) The volume of these plants may displace significant amounts of water and thus reduce reservoir capacity during times of overflow.

(VI) The macrophytes transpire tremendous amounts of water, perhaps five times the amount evaporating from a water surface of equivalent area. Thus, the 20% cover of water fern found on Lake Kariba in 1962 probably *doubled* the evapotranspiration rate!

The high nutrient levels produced by decaying terrestrial vegetation and leached soil as the reservoir fills will provide favorable growing conditions for aquatic macrophytes. Although it is likely that growth of *rooted* aquatic plants will be discouraged if the basin slope is sufficiently steep and if turbidity reduces the light available for photosynthesis, the potential problems outlined above apply equally to free-floating plants (*Eichornia* and *Salvinia*) and are serious enough to warrant protective measures.

Clearing of reservoir basin vegetation: A detailed study should be made of the occurrence and relative abundance of the animal and plant life in the area to be inundated. Since dam construction results in the loss of the riparian and watershed habitats to be inundated, these areas should be studied both with respect to the losses in vegetation that would occur and the effects this submerged and decaying vegetation would have on the proposed reservoir. Since tropical forests hold more nutrients relative to the soil than temperate areas (**Freeman,** 9), the submergence of vegetation is a particular problem in the tropics. Large amounts of nutrients will be released to the lake through decay of these rotting plant materials. The Siranumum Dam near Port Moresby has a H_2S-rich outflow because terrestrial vegetation was not removed and decay resulted in increased levels of H_2S in the hypolimnion. H_2S is very corrosive to metal and, as previously mentioned, can destroy turbine parts and electrical connections.

There are two basic features of submerged terrestrial vegetation which give rise to problems. First, such vegetation during decay will provide a continual source of nutrients to phytoplankton as well as higher aquatic plants. Decay also will be accompanied by deoxygenation in the hypolimnion with adverse environmental effects on certain fish. Secondly, the larger submerged vegetation forms a physical obstruction that can interfere with water circulation and prolong oxygen depletion, provide breeding places for mosquitoes and habitats for snails, interfere with the operation of fishing nets, and provide a substrate for the growth of periphyton and certain higher aquatic plants. The constant association of aquatic macrophytes with submerged trees in African lakes attests to the importance of this problem. Careful consideration should always be given to clearing the vast majority of the timber from a watershed up to the high-water mark.

Rotting vegetation is best controlled by removal and it is often recommended that the entire area to be inundated should be clear-cut and the vegetation removed or burned. Burning terrestrial vegetation is less desirable, however, since it will permit nutrients released by the destroyed terrestrial vegetation to be quickly utilized by aquatic plants (**Ewer,** 8). However, the cost of physically removing terrestrial vegetation from the watershed is often prohibitive.

Control of aquatic macrophytes: The control of higher aquatic plants has been accomplished using mechanical harvesting, but the equipment and expense is usually prohibitive and the steep sides of a reservoir make this an impractical solution. Chemical control, especially with 2, 4-D which is harmless to fish, has been successfully utilized but toxicity to downstream agriculture suggests that its use be as limited as possible. In addition, by returning the plant nutrients to the reservoir waters, chemical applications merely prolong the problem. Biological control is the most desirable method, but experiments with manatees, snails, insects and herbivorous fish have yet to show great promise. Attempts at biological control would be unwise without further research upon which to base control programs. However, in the absence of acceptable alternatives, it would be fruitful to investigate biological methods that are now under study, should aquatic macrophyte problems develop. The use of manatees is particularly attractive since they represent a possible protein source for humans although this may be an impractical solution if the steep sides of a reservoir cannot provide a suitable manatee habitat.

Grass carp or white amur *(Ctenopharyngodon idella* Val.) may be effective weed control agents in some situations, but may have disturbing side effects which should be considered.

It is clear from this discussion that infestation must be prevented in its earliest stages, control methods being expensive or ineffective once exponential growth is underway. Prevention consists of both limiting infection sources and controlling the chemical environment of these plants. In Ghana at the Volta Dam it was realized that close guard was required to prevent infestation. Posters were printed in eight languages displaying papyrus, *Eichornia,* and *Salvinia,* asking that persons seeing these plants report them immediately to the authorities. It was recommended by **Goldman** (14) that lake patrols be established, if the El Cajón Dam were to be constructed in Honduras, for the purpose of regularly surveying the reservoir shoreline and removing any observed macrophyte growth. Eventually patrols would no longer be necessary as nutrient levels in the reservoir decreased with replacement of the water that had been exposed to masses of rotting vegetation by water entering either as rain or from a stabilized watershed. It is, however, impossible to estimate the length of the initial reservoir transitional period, and early surveillance may eliminate costly control measures at a later date. In combination with this strategy, all transport of vegetative or reproductive structures of higher aquatic plants into the watershed must be forbidden by law. Aquarium plants have long been an important source of accidental aquatic weed introduction. Environmental chemical control consists of limiting as much as possible nutrient release to the reservoir water from the inundated watershed, as well as stabilizing against erosion that portion of the present watershed that will remain terrestrial.

It should also be pointed out that the annual fluctuations in reservoir level will tend to discourage those higher aquatic plants that are rooted by submerging at high water or exposing the attached macrophyte communities at drawdown. The period of low reservoir level offers a unique opportunity to completely remove stranded plants and patrol activity is especially encouraged at this time. Timing and manipulation of drawdown is also a good potential method of higher aquatic control.

Although it would be .disasterous to encourage high yields of aquatic macrophytes in the reservoir, it may be noted that the Chinese have found water hyacinth and water lettuce to be an excellent duck and pig fodder. Should higher aquatics develop in large quantities in spite of the efforts of the recommended patrols, harvested water weeds could be used to supplement animal feed. It should be noted that the particularly high water content (usually 95%) and the high costs of harvest make aquatic weeds rather poor cattle feed unless effectively "dewatered" or utilized strictly as a supplementary feed.

Wildlife: Analysis of all wildlife values including habitats, ranges, migrations, and the presence of endemic or rare species that might be affected by the proposed dam should be considered. It was found at the El Cajón site that the original biotic communities of the proposed catchment area had already been severely damaged by the activities of man, including swidden agriculture, poor forestry practices and burning. It was concluded that the biological interest of the area could be enhanced if swidden agriculture and burning were abandoned and a renewed stand of timber was encouraged. It was recommended in this study that immediate steps be taken to prevent the lumbering or clear-cutting of the few remaining stands of virgin timber in the watershed of the proposed reservoir. Not only would conservation of large tracts of broad-leaf and coniferous forests help to maintain the relatively low silt levels observed in the Río Yure, but the forests could also serve as source areas for faunal and floral repopulation of the watershed.

Natural forest habitats are disappearing rapidly in Central America as in other parts of the tropics. For this reason, watershed protection would be beneficial to proposed reservoir utilization programs, and will also provide a potential recreational and tourism commodity and a floral and faunal reserve of considerable scientific interest.

The absence of endemic birds and mammals in a particular area to be inundated should not be considered as evidence that those present are of no biological importance. As the amount of forested environment in tropical America decreases, the aesthetic and scientific value of the remaining resources increases. The great value of undisturbed forests to both the water quality and the lifetime of the proposed reservoir has already been emphasized in previous sections of this report. Establishing the watershed surrounding a reservoir as a forest and wildlife reserve should be seriously considered and can be expected to increase the lifetime of the reservoir by erosion and nutrient control.

Fisheries: One of the trade-offs in converting a large area of terrestrial habitat to an aquatic one is the potential development of viable fisheries. This can be of great importance in areas where the average protein intake is low and where agricultural practice is at a marginal level. The reservoir can, if properly managed, produce a substantial yield, particularly since the growing season in areas at tropical latitudes and suitable elevations is essentially continuous. There is, however, a tendency to overestimate the production and overfish the stock of reservoirs. Fish production rose in Lake Kariba along with the total dissolved solids (TDS) during the filling stage only to decline drastically in 1963 (**Balon** and **Coche,** 1). The decline coincided with a drop in TDS from 81 to 63 ppm, and it is concluded that:

> Hence the total potential of food production, in spite of later occupation of the open lake by some fish species, should not be higher than the potential of the undisturbed Gwembe Valley habitats prior to the dam. It may even be lower if the annual heat budget of about 15,000 cal/cm^2 (Part I, Sec. II), which is relatively low because of the evaporation rate and reflection of a substantial part of the solar energy by the water mass (Butler 1963), means anything in this connection (van der Lingen 1971). In addition, to utilize the lake's fish potential to the given limits requieres artificial subsidies of energy at present simply not available. Also, there is some doubt whether they will be found efficient later on. (**Balon** and Coche 1, p. 556).

The best means of achieving a high protein yield from an inland fishery is to promote the growth of species which feed on plant rather than animal food. There is a great loss in available food energy at each transfer of energy from herbivore through successively larger carnivorous fish. For this reason, carp, *Tilapia,* and mullet have been the favored species in agriculture. High yields of omnivorous fish such as catfish may be produced only if their natural diet is supplemented by feeding. Feeding is impractical in a large reservoir and high production can only be achieved by establishing a fish population capable of efficiently utilizing the plant and aquatic animal community which will develop in the reservoir.

It is obvious that those fish inhabiting the existing water courses prior to impoundment will be the first to colonize the reservoir. Because they are native stream fish, not all will achieve equal success in the relatively still waters of the reservoir. Further, it is certain that other fish which inhabit surrounding areas will soon find their way to the reservoir by intentional or accidental transport. It is advisable to develop a strong population of omnivorous or herbivorous fish before predatory species are introduced. Pelagic species should be found to utilize the large expanse of open water not inhabited by bottom-dwelling species. *Tilapia,* which have achieved such wide acceptance, and/or other native cichlids in Central and South America are already highly valued food sources and are logical choices in their natural range. In Honduras, for example, *Cichlasoma friedrichsthali* (a native of Lago Yojoa and the Río Ulúa) would be an excellent candidate since it is excellent to eat and grows to a length of 15 to 18 inches.

It undoubtedly would be safest to begin by first cultivating the native fish. Introduction of exotic species would follow only after a careful analysis of the entire food chain had been conducted and following the initial high productivity which often accompanies dam closure (**Harding,** 19). The development of the details of an optimum fisheries management strategy for the reservoir must be tailored to the spectrum of environmental variables that make each reservoir a unique ecosystem.

Fish predation in the reservoir will be limited to the minor activities of aquatic snakes, a few water birds, and, in some regions, to crocodiles or alligators. Predators may increase by impoundment, as has occurred in African reservoirs, requiring management of their populations.

As already noted, the development of a commercial fishery in a reservoir can be a substantial benefit of the dam. An immediate and thorough survey of the drainage area fish fauna should be conducted, including a careful analysis of the life habits of those species that will be major colonizers of the reservoir. This survey should determine the natural species composition and distribution of fishes throughout the drainage system prior to dam construction; endemic and rare species, in particular, should receive careful consideration. Such an analysis would be useful to estimate the probable composition of the future native fish community in the reservoir, including predictions on which species are most likely to dominate. This information is essential for planning a future commercial fishery and possible stocking of exotic species since stocking cannot be successfully accomplished without accounting for the life habits of those species already present. In addition, the importance of any migrant species (such as migratory eels) must be determined so that fishways or substitute habitats can be constructed if found to be necessary. Dams are well-known for their destruction of anadromous fisheries. Fish ladders, although by no means a universal or very satisfactory solution, can be built to enable fish to continue their journeys upstream. Unfortunately, most ladders and the still waters above the dam are insurmountable obstacles for anadromous fish, necessitating the establishment of fish hatcheries below the dam. The presence of large suitable tributaries below the dam can mediate blocking of the upstream areas.

Construction of harbors and channels is most easily and economically accomplished prior to inundation. It is thus advisable to determine the constructive requirements of a future fishery as soon as possible (**Jackson,** 22). The importance and complexity of fisheries development merits the creation of some permanent body to research the various problems and develop stringent laws to protect the new fishery. It is always easier to relax old laws rather than institute new ones which conflict with people's newly acquired habits. For example, overfishing during an initial transitional period of high productivity following dam closure can seriously damage the fish populations for many years, particularly if it coincides with the natural fall of reservoir fertility.

DOWNSTREAM ECOLOGICAL CONSEQUENCES

Nutrient loss: Consideration of the potential ecological effects of dam construction should not be limited to the catchment area but should be extended to downstream effects as well. The decreased silt load in waters downstream from the impoundment area has significant effects on the nutrient load and hence productivity of these waters. Nutrients contained in or bound to river-borne particulate matter have a fertilizing effect on the land and on ocean waters near rivers. This may contribute significantly to the productivity of existing coastal fisheries. The removal of this silt can decrease phytoplankton photosynthesis which in turn decreases fish productivity. An example of this is probably occurring in the eastern Mediterranean where much smaller sardine catches were made following the closure of the Aswan High Dam.

The potential effects of dam construction on the productivity of coastal waters can readily be analyzed by means of bioassays in which river water containing present and future silt loads (the latter prepared by allowing a controlled amount of settling) is added to ocean water, and the change in the growth rates by phytoplankton is measured. With proper selection of river water volumes added, this growth change can be used as a rough indication of what changes may occur in fisheries production.

A similar problem exists in the effects of reduced silt load on the fertilization of river valley agricultural lands. Flood plains which are periodically inundated can be greatly affected by decreased river flow. Nutrient-rich sediments, which are deposited during flooding, are no longer periodically replenished. Flood plains are normally very rich areas of vegetative growth and agriculture, but this richness can slowly be lost by the lack of nutrient renewal during flooding. The cost of supplementing this agriculture with chemical fertilizers may be prohibitive. Techniques of bypassing sediment through the reservoir during floods merit engineering attention. Studies of the ecological consequences of flooding in river valleys should include the question of how much agricultural productivity is supported by the silt-bearing flood waters. The loss of such fertilization after the closing of a dam could prove to be greater than the value of the new power. This possibility should receive careful study, for example, an experimental comparison of harvests from land watered with present water supplies as compared with land watered with water supplies of predicted quality (e.g., after water has been allowed to settle in lagoons). A decrease in traditional agriculture has been reported in the flood plains below the Volta Dam (**Hilton** and **Kown-tsei**, 20), and Lake Kariba apparently does not produce the protein that the area was capable of producing prior to the dam.

Besides changes in silt content, certain other parameters of downstream water quality will be altered by chemical and biological processes occurring in the reservoir. Water removed from the reservoir hypolimnion may be deoxygenated and laden with hydrogen sulfide or the reduced forms of iron and manganese. This can seriously alter its usefulness as a domestic and industrial water source as well as a fish habitat. The extent to which this will take place is impossible to predict, but an analysis of the dilution of this discharged water by inflowing streams, combined with a survey of the location and type of water use, will indicate whether there is a potential problem. It may be found, when this information becomes available, that alternative plans are in order, such as the possibility of using a different water supply or discharging the reservoir's water from different depths. After completion of the dam the altered hydrological regime and altered demographic situation will create water quality problems with regard to dilution of human and industrial wastes that may be greater than those current in the existing river system.

Only actual surveys of downstream and coastal fisheries and wildlife resources enable protective measures to be planned and implemented before completion of the dam, and such surveys are strongly recommended. Many of the watershed problems discussed in this report apply equally well to the downstream area (e.g., disease), and it is suggested, therefore, that detailed investigations be expanded where possible to include downstream effects of the impoundment. The Gulf of New Guinea, for example, could be greatly altered from its current rich fishery potential by a complete hydroelectric development of the Purari River system.

Beach erosion: The deposition of silt in the reservoir and the subsequent absence of this silt in the downstream water has many ramifications. The possibility that changes in sediments carried to the sea can alter patterns of beach and bay formation is of serious concern. Silt transported via rivers is of importance in renewing the sand of these beaches. Sand beaches, by nature of their small extent, are a valued commodity in the world for their aesthetic, scientific and recreational interest. Water storage projects throughout the world have reduced the sand formation process and in many areas, including much of the eastern seaboard of the United States, beaches are being continuously reduced. In some cases tourist industries have been adversely affected. An in-depth study of the effect of dam construction on beach formation and renewal processes is essential.

Coastal wildlife resources deserve special attention since they play a major role in the maintenance and reproduction of many valuable and endangered wildlife species. For example, over 90% of the world's green turtles (the major source of turtle soup) breed along 30 km of beach sands 300 km south of the Río Ulúa delta. Beaches in Central America are important nesting and resting spots for numerous species of rare and sometimes endangered water birds.

Deltas: Deltas and their associated estuaries are especially rich and dynamic areas, where sediment loads are deposited, resuspended and redeposited (**Tison,** 40; **Mikhailov,** 29). Altered flow rates and sediment loads can have particularly dramatic effects in these areas, particularly in relation to the distance of salt water intrusion (**Goldman,** 13). Deltas are ecosystems adjusted to a constantly changing environment usually with a continuum of plant communities, each adapted to a given environmental regime. Altering upstream flows can alter the ecological balance in the delta to favor some plant and animal association and harm others.

Altered flow rates should be evaluated for their potential effects on estuarine communities. It must also be remembered that the alteration of flow rate will change according to dam location and time of filling. If large tributaries enter below the proposed dam site, and carry strong flows and large sediment loads, these tributaries will have a mitigating effect on the diversion of water to fill the proposed reservoir. Once the reservoir is filled, flow rates will return to near natural amounts (depending upon the plans for flood control) although the bed load of sediment and water quality are almost certain to be greatly altered.

The delta environment remains one of the richest of all ecosystems. Any alteration of its fertility should be viewed with great concern and the long-term cost benefits reviewed with care.

RESERVOIR ASSOCIATED DISEASE PROBLEMS

An increase in health problems often accompanies the creation of large reservoirs in the tropics. The high concentration of people and the low level of sanitation common to work camps of the dam labor force create an ideal environment for the spread of malaria, dysentery, tuberculosis, venereal disease, etc. The foreign labor force is both a source of new diseases and its people are highly susceptible to endemic diseases. The large population entering a previously sparsely inhabited region provides high host densities, thereby increasing the likelihood of spread of many diseases. At different stages of dam construction in the tropics, increases and decreases in malaria, dysentery, schistosomiasis and onchocerciasis have been reported (**Kershaw**, 23; **Waddy**, 41; **Warmann**, 42; **Obeng**, 32; and **Paperna**, 36).

Factors relevant to vector ecology should receive special attention. Disease-causing agents, vectors, and the nutritional status of the people are all important variables in physical health and should be considered in evaluating the impact of hydroelectric dam projects. Methods of preventing health hazards associated with the project must be developed at an early stage in the planning process.

Health records in the El Cajón area reveal that aside from basic malnutrition, the most prevalent diseases in the area are tuberculosis, typhoid, dysentery and malaria. In the Purari delta area and coast, gastro-intestinal problems are common, as well as a high incidence of malaria and tuberculosis. It has been found in Africa that the stress associated with resettlement of the people inhabiting the water project site significantly increases disease and mortality, particularly among the very young and the very old. Therefore, it can be expected that the incidence of any diseases occurring at the site is likely to increase, and steps should be taken to offset this probability. Aside from the necessity of an intensive health survey of the area and innoculation programs, it should be pointed out that in the period of transition, normal cultivation will be interrupted, and the people's diet will be more tenuous than ever. Therefore, it is essential that the people receive sufficient nourishment during this transitional period until new communities are established. This could include milk programs for children and food supplements for the families involved.

Malaria: Malaria is endemic in most tropical areas of the world. Submerged trees and swampy higher aquatic plant habitats encourage the development of *Anopheles* mosquitoes, certain species of which carry the various malaria-causing protozoa. Mosquito habitats obviously must be avoided in the reservoir, and it is probable that the stêep reservoir sides and fish population will provide adequate control over much of the area. In view of the relatively high human population densities that the building of the dam will introduce into localized sections of the catchment area, anti-malarial prophylactic measures must be stringently followed.

Schistosomiasis: Schistosomiasis bears certain ecological similarities to malaria since snail vectors (such as *Bulinus* ·d *Biomphalaria*) of the parasitic blood fluke (*Schistosoma* spp.) is favored by submerged trees and higher aquatic plants. Transmission takes place, however, not through biting, but by penetration of humans by the free-swimming cercaria stage of the fluke. Although no cases were reported in Honduras, *Biomphalaria*-bearing *Schistosoma mansoni* does occur in South America and the Caribbean. Schistosomiasis has increased in association with water development in Rhodesia (**Schiff,** 37) and Ghana (**Paperna,** 36). Preventive measures include the destruction of terrestrial vegetation and control of higher aquatic vegetation as in the case of malaria. If schistosomiasis is not endemic to the area under consideration, detailed medical examinations should be performed on all personnnel associated with the dam project that will be entering the watershed in order to prevent the introduction of the disease. In addition, a careful survey should be made of aquatic habitats in the vicinity for possible snail hosts.

Onchocerciasis: Onchocerciasis, or "river blindness", is a disease caused by the nematode *Onchocerca* which is transmitted to humans by the bite of the black fly *Simulium* spp. The common name of the disease originates from the fact that blindness is produced in some of the victims. These black flies can breed effectively only in swiftly-flowing and well-oxygenated waters, an environment which characterizes the catchment area rivers and which will decrease in extent as the reservoir basin fills (**Waddy,** 41). In other words, the likelihood of onchocerciasis will diminish as a new dam slows the movement of water into the area and decaying vegetation produces deoxygenation in the reservoir. DDT was used to control *Simulium* spp. larvae during construction of the Volta River. Attention below the dam is of course warranted as this area with lowered sediment transport may improve as a *Simulium* habitat. Further, there is the possibility that migrant labor could bring the disease into the area.

Water related diseases: Gastro-intestinal problems (such as dysentery) attributable to water contact continue to be a common health problem in the tropics. Although the inevitable increase in human contact with the surface waters of the catchment area following completion of the dam will introduce protozoa and bacteria, removal from the watershed of people not connected with construction of the dam would reduce human sources of infestation. This tactic should be combined with adequate treatment of drinking water supplies and wastewater produced by people remaining in the area.

The history of watershed management provides global evidence of the need to anticipate sewage-treatment requirements. Lack of such foresight has resulted repeatedly in undesirable eutrophication and loss of sanitary water supplies. Therefore, a wastewater treatment study should be initiated that would provide future watershed populations with satisfactory treatment facilities. A series of strategically located small secondary treatment plants and septic tanks near population centers on the watershed is indicated by past experience to be an absolutely necessary investment.

HUMAN ECOLOGICAL CONSIDERATIONS

Resettlement: Impoundment projects in the tropics often necessitate the relocation or resettlement of people inhabiting the area. Previous work in the field of resettlement points to certain general factors that should be taken into account as well as problems that are likely to develop unless anticipated. The reader is referred to **Chambers** (4, 5), **Brokensha** and **Scudder** (3), and **Scudder** (38) for further details. Although the patterns of resettlement that emerged in Africa cannot necessarily be expected to have direct parallels in the social profile of other tropical areas, **Brokensha** and **Scudder**'s analysis (3) can serve as a useful guide.

Whenever possible, large-scale resettlement schemes should be avoided. However, if resettlement is found to be mandatory, several factors must be considered. First, it is essential that population relocation be recognized as an integral and important part of the hydroelectric project, and that *local people be actively involved* in the planning of resettlement. An in-depth study of the potentially displaced people and the maintenance of close communication with these people throughout the project is vital to its success. Analysis and communication with local groups can best be established by using people familiar with their culture such as local missionary, community development and administrative contacts to keep the people informed of the government's intentions and plans.

Experiences in the African dam projects underscore the importance of an accurate census which should be taken as soon as the dam construction is a certainty. If there is a single factor underlying the social and economic complications that emerged in African resettlement projects, it is the issue of timing. Problems must be foreseen while there is still sufficient time to develop the most positive and resourceful strategies for dealing with them.

One of the current issues confronting resettlement policy is whether a commission should concern itself simply with restoring to the people what they had before, so that no one will be hurt by the project (as was stated in the initial Volta Dam guidelines in 1952), or whether it should use this opportunity to provide an improved standard of living. The trend in recent years, certainly as far as the African projects are concerned, is toward greater government involvement and more ambitious social planning. **Brokensha** and **Scudder** (3) advocate this latter policy, pointing out that the community to be resettled need not be regarded merely as a "problem", but with careful planning can become a potential human resource. In the Kainji Lake basin in Nigeria, for example, 100,000 people were relocated without taking into account the fact that they possessed very special irrigation skills which could have been used to advantage.

The proposed Wabo Project in Papua New Guinea, provides a good example of a small resettlement project; approximately 300-500 people and three villages would be displaced by inundation. A thorough understanding of their social structure and careful consideration of their opinions about resettlement were found to be essential in formulating appropriate relocation plans. Assessment of their spiritual and physical attachments to the land would help prevent resentment over evacuation. The government's handling of these people will be a major factor in establishing their relationship to the government and in the social success or failure of the entire project.

In many respects El Cajón could be considered an ideal situation for resettlement planning. There were, at the time of the study, 1,500 to 3,000 people to be accounted for, as compared with 100,000 in the Aswan Dam project, 70,000 in the Volta Dam project, and 50,000 at Kariba. The basic social structure at El Cajón is adaptable without the tribal complexities confronting resettlement projects in Africa. In Africa, for example, tribes loyal to a particular chief have been relocated to areas loyal to other chiefs! In contrast, problems occurring in El Cajón would more likely result from the basic individualism of the people, their possible resistance to being part of a common solution, or the prospect of their being moved into more densely populated or less fertile areas. All people interviewed at Agua Blanca seemed ready to accept the possible changes that El Cajón might introduce into their lives, whether it be moving into a new area, the opportunity of learning new farming techniques, or the presence of a new commercial fishery in the area. Nevertheless, resettlement, even in what appears to be ideal circumstances, should proceed with care in order to avoid administering progress from above at the cost of provoking natural human resistance to interference and change. It would be far more practicable to evoke the cooperation of the evacuees by drawing representatives of the people into the consultation and planning process wherever possible, and working together towards providing a better way of life of their own design.

It was obvious during our El Cajón survey that the health and welfare of the people would be improved if their homes had better sanitary facilities and, if possible, better quality of drinking water was available. It is also true that their houses contribute to the pride that comes with self-sufficiency. The people have a sense of being able to control their own lives, even at the cost of hard work and an uncertain future. It must be remembered that resettlement due to hydroelectric projects is an involuntary migration and as such has several characteristics unique to the situation. Involuntary migration thus becomes a delicate issue not to be ignored until rising water forces it. If the resettlement policies adopted follow the precedent of the Aswan, Volta and Kariba projects by relocating these communities in improved housing, the people should be supplied with the materials to build houses (as at Kariba) and trained or assisted in the techniques necessary for building better ones. Furthermore, the approach suggested in this report would be more likely to preserve the people's sense of autonomy and pride, and might involve them in the mechanics of resettlement in a more positive, active manner. In the final analysis, whether or not a dam should be built should involve the decision-making abilities of those most affected. To ignore their wishes is likely to promote the disordering effects of misery and dissent and not be in the best long-term interest of the nation or nations involved.

Recreation and tourism: Tourism in Honduras, for example, and all of Central America south of Mexico is largely confined to cities, coasts, and archaeological sites. In Mexico, trailer-type tourism from the United States and Canada is now giving an economic value to a much broader spectrum of sites. This traffic depends not only upon a high quality and extensive highway system, but also upon close proximity to the source of North American tourists. Careful consideration should be given to the touristic value of the impoundment area. This can then be compared with the touristic value of the proposed reservoir, which can be attractive to tourists because of its large size and potential sports fishery. Recreational use of an area is in most cases enhanced by water but certainly not in all cases, and the same care must be exercised in promoting a hydroelectric project on the basis of its recreational benefits.

In view of the changing shoreline of the reservoirs, the primary function of the watershed as erosion control, and the need to protect developing fisheries, it is recommended that no tourist or recreational development be considered until the reservoir has been filled for several years, the water quality has stabilized somewhat, the characteristics of the fish populations are known, and the biologically important areas of the terrestrial part of the watershed have been studied. It is only then and with proper planning that the recreational facilities should be developed.

Archaeology: The possibility of valuable archaeological sites existing in the area should be investigated carefully to ensure that such sites can be excavated by a trained team of archaeologists well before inundation is due to begin. Archaeological field work is greatly facilitated by information from the local people and knowledge of local geology. Archaeological surveys should be made in conjunction with linguistic, biological and geological surveys. These should obviously be undertaken well in advance of inundation.

SECONDARY IMPACTS OF IMPOUNDMENT

Of considerable importance are the secondary impacts of impoundment projects caused by increased development made possible by the availability of electrical power and the potential for industrial development. Industry associated with a new source of energy generally results in population influx with a higher birth rate, lower death rate, and increased urbanization. The presence of electrical power provides the capacity for greater resource utilization through industrialization, the economic potential for more rapid development, and new potential for attracting foreign investments. All of these events result in very major environmental impacts on the area.

An evaluation of the anticipated long-range effects of any project are at best speculative. Nonetheless, attention must be focused on the spectrum of the most likely environmental impacts in order to facilitate their future management and help the project become a rational component of future development for the region and nation involved.

Natural resources such as timber and mineral or petroleum reserves are usually much more effectively exploited by the development of electrical power. If an industrial complex is planned as part of a new dam project, it should be described and brief scenarios of the potential impacts of alternative plans for utilization of these resources made. Primary impacts of the industrial complex associated with the water project will include the construction of facilities on natural areas, pollution, and increased utilization of renewable and non-renewable resources.

In addition, during construction of any water development project, impacts particular to construction will arise. For example, road development in previously unopened areas causes a series of ecological impacts including increased levels of erosion both during and after road construction. Further, the road serves as an avenue of travel for diseases and pests. The transportation of construction crews and equipment by barges will also have ecological and sociological impacts. Construction camps are notorious for their lack of sanitation, diseases and poor living conditions. Major problems of health and morale could be avoided by more careful planning and enforced regulations in construction phases.

The process of construction is all too frequently carried on with little regard for the environment. This may be particularly true for foreign construction crews who were reported to be insensitive to both the environment and people in Papua, New Guinea (**Goldman**, *et al.*, 16). For this reason, as well as the public health and sociological reasons discussed previously, the use of foreign labor should be avoided except when essential for technical and managerial expertise.

Further, secondary impacts on environment and social life result from any irrigation or water diversion and subsequent agricultural changes. Altered agricultural patterns invariably change population growth rates in the region as well as contribute to environmental changes. Intensive agriculture is in its pioneering stages in the tropics and the problems of tropical monocultures are not well understood. The decision to embark on comprehensive development of the area should be based on a careful study of the problems and advantages of replacing naturally balanced ecosystems with man-made ones. Effects on the nation's health, nutrition, style and standard of living, land-use patterns and population growth rate should receive particular attention. In every case it is essential to involve local leadership at an early stage and provide them with a broad view of both primary and secondary impacts of the proposed project.

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RESUMEN

El reconocimiento de los efectos potencialmente dañinos del desarrollo hidrológico en los trópicos ha conducido a esfuerzos continuos por evaluar el impacto que tales proyectos tendrían sobre el ambiente, antes de iniciar la construcción. Las decisiones de si desarrollar o no los recursos acuáticos deben basarse en investigaciones serias, tanto de los efectos a corto plazo como los de largo plazo, sobre la construcción y manejo del embalse. Los efectos ambientales del almacenamiento de agua varían grandemente de acuerdo con las características de la región y con el tipo de embalse a construirse (area y profundidad, relación de la entrada de agua con la capacidad de almacenaje). De vital importancia son la reducción de la capacidad del embalse por la acumulación de sedimentos detrás de la represa y la pérdida de estos sedimentos a la agricultura y las pesquerías que se encuentren aguas abajo. El impacto potencial de regímenes de flujo alterado, sedimentación aluvial, disminución en la formación de playas y el enriquecimiento nutricional en las bocas de los ríos, y la posible invasión por aguas saladas, deben recibir especial atención. Debe hacerse una descripción exhaustiva de las plantas y animales que se afectarían por la inundación para determinar la posible pérdida de organismos escasos o claves, asi como el desarrollo de "especies nocivas". Como complemento a esta encuesta debe haber un estudio detallado de los peces existentes y de la posibilidad de establecer la pesca comercial en el futuro embalse. Debe considerarse seriamente la eliminación de la vegetación en la cuenca del embalse, pues la descomposición de esta vegetación produciría la desoxigenación de las aguas, la formación de sulfuro de hidrógeno, el posible desarrollo de habitats adecuados para especies indeseables, y enredar las redes de pesca. Debe controlarse

la sanidad asi como las prácticas de uso de la tierra y la erosión en las cuencas que rodean el embalse para evitar una eutroficación acelerada por el aumento de nutrimentos.

Las inundaciones en áreas tropicales pueden tener consecuencias sociológicas y sanitarias humanas serias, como son el incremento de las enfermedades, e.g., la malaria, la schistosomiasis, la oncocercosis, y la disentería, además de los problemas de reubicar a las gentes desplazadas y de la alteración de sistemas de uso de la tierra. Debe evaluarse la información de los censos y encuestas relativas al uso de la tierra, la habitación, y las estructuras de salud y socio-económicas que se verían afectados para evitar problemas futuros. También debe estudiarse los valores arqueológico, histórico, estético y recreativo del lugar a inundarse.

En este estudio se usaron las experiencias adquiridas en los proyectos de El Cajón en el Río Sula, Honduras y en el del Río Purari, Papua, Nueva Guinea.

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Fig. 1. A narrow valley forms an ideal site for a high arched, hydroelectric dam at El Cajón, Honduras. Slash and burn agriculture has removed much of the topsoil from this area, and the major agricultural concern is for the fertility of banana plantations and flood control in the Sula Valley below.

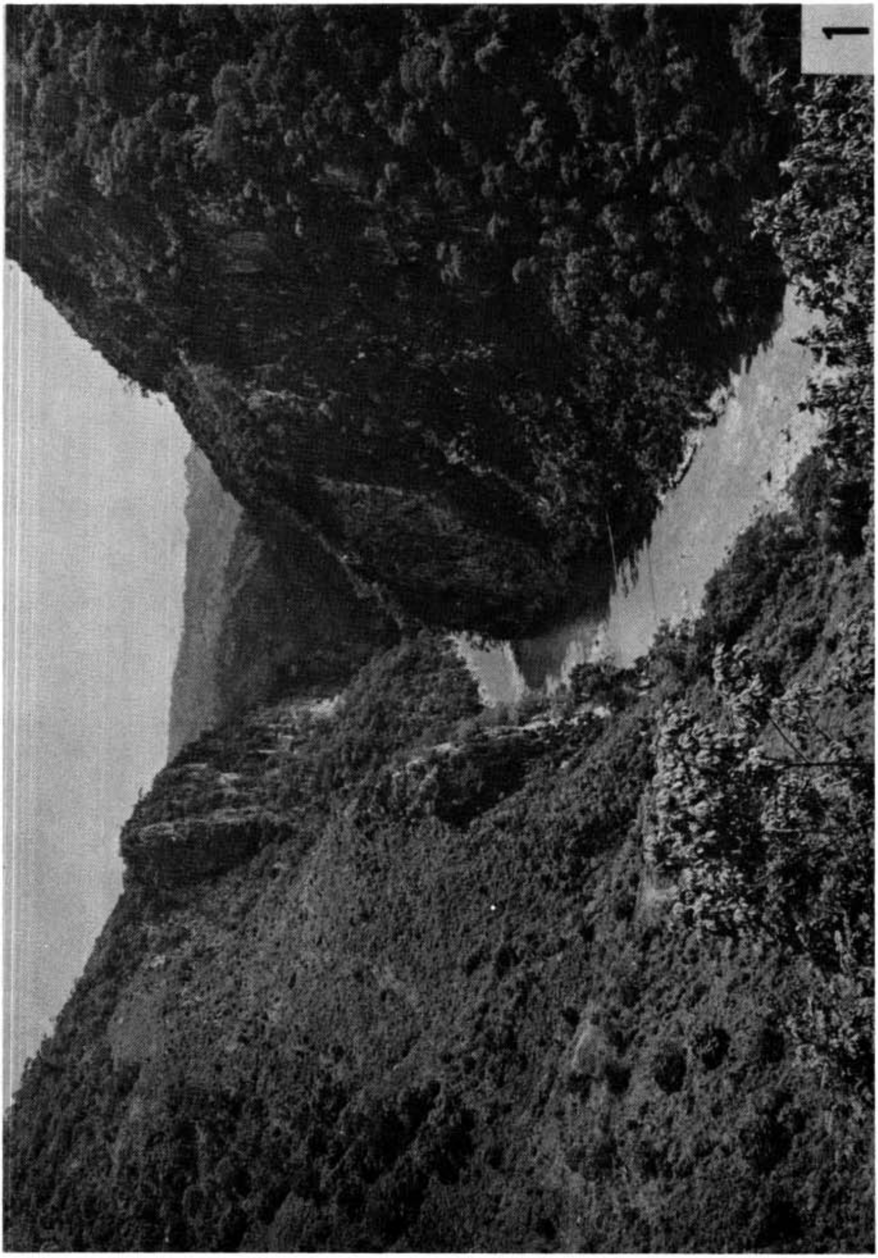

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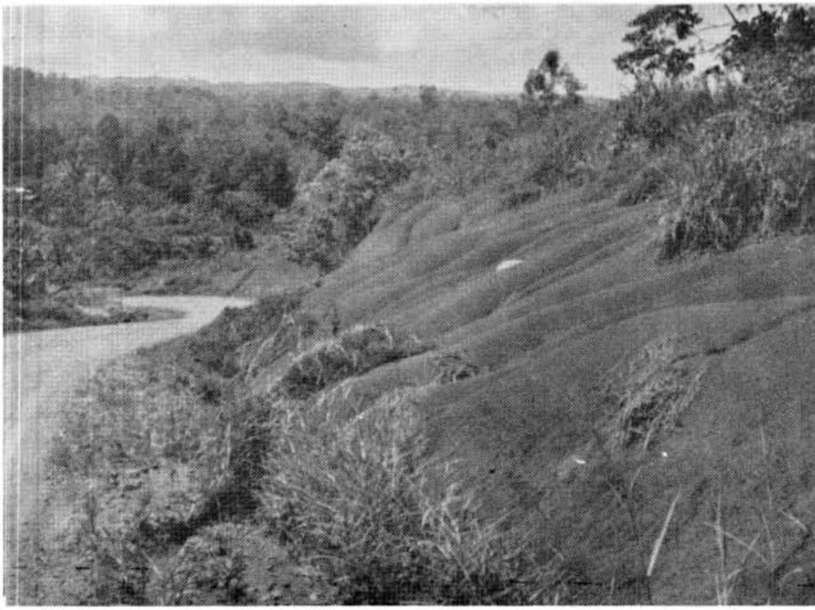
Fig. 2. Erosion along roadways associated with the Surinumu Reservoir is among the most serious sources of sediment. Particular caution should be exercised in the drainage area during and after construction.

Fig. 3. Aquatic plants at the Wabo or other reservoir sites could become a problem in the proposed reservoir.



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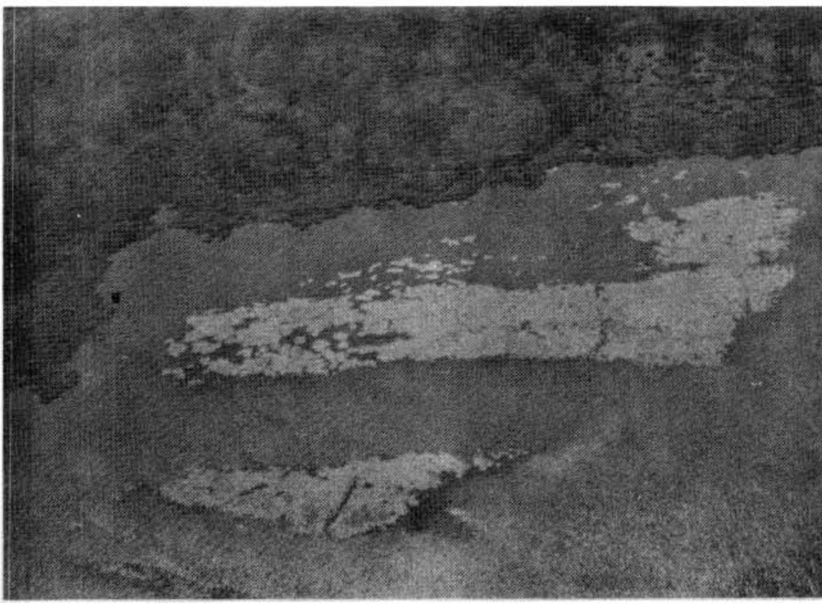

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Fig. 4. Filamentous bacteria on detrital particle, Lake Tahoe, California. Photograph taken by Dr. Hans W. Paerl using a scanning electron microscope at 10,900 magnification.


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