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2 THE ENVIRONMENTAL EFFECTS OF HYDROELECTRIC POWER DEVELOPMENT

by Alan D. Jassby

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Dams are constructed for a variety of functions--power generation, flood control, irrigation, navigation, domestic and industrial water supply, recreation, and fish production--and a given dam usually provides a number of services simultaneously. Regardless of a dam's objectives, the creation of a reservoir and the modification of downstream hydrographic conditions result in marked changes in the physical, chemical, and biological characteristics of the impoundment and downstream areas. The diversity of these changes, and the number of alternative causal pathways that can contribute to any particular effect, make it difficult to describe the environmental consequences of hydroelectric development within a rational scheme. A single important consequence may arise directly from dam construction; others may come from secondary or tertiary effects of the dam's presence. For example, water loss typically increases both because of the larger surface area for evaporation in the reservoir and because of transpiration from aquatic macrophytes that can invade the shallow reaches of the reservoir as patterns of the current, temperature structure, turbidity, and water chemistry change.

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A second difficulty in making a general assessment of environmental effects is that each hydroelectric development represents a unique combination of climate, geology, project size, downstream water release patterns, and other factors. The effects are various. Making generalizations as to which effects are overwhelming usually is not possible; the most that can be offered is an inclusive listing of potential ecological problems.

In what follows, I have classified the environmental consequences of hydroelectric development into physical, chemical, and biological effects. The problems discussed in each category often are consequences of effects discussed in preceding categories, but, as noted above, feedback and complicated causal pathways are inevitable. Demographic, health, and climatic issues that arise in conjunction with the building of dams are, for the most part, not covered. The exclusion of these issues is not intended to undervalue their significance. On the contrary, the resettlement of huge numbers of people (as many as 120,000 with the construction of the Aswan High Dam), the improvement of habitat for vectors of human parasites (especially the carriers of schistosomiasis and malaria in tropical regions), the dangers of dam failure, and the possibility of large-scale climate modification (a valid consideration for the huge proposed James Bay project in Quebec) are problems of overwhelming importance that deserve special detailed attention.

Basically, there are three geographical areas associated with the presence of a dam: the reservoir area itself; the downstream river channel and floodplain; and the estuarine and coastal waters that are ultimately affected. Physical, chemical, and biological effects in these areas differ, and, as will be shown in what follows, a given type of effect may not be a problem in all three areas simultaneously.

PHYSICAL EFFECTS

Except where the natural grade and discharge rate of a river produce sufficient energy to rotate the turbines of a generator, a dam is required to provide adequate head for power generation. The immediate effects of constructing a dam and controlling the release of water are the formation of a reservoir, an increase in the shoreline, weight, and surface area of the water above the dam site, and the modification of downstream hydrographic conditions. The structure of the current in the impoundment is also altered radically. These immediate changes in the shape and motion of the pre-existing water supply directly produce certain ecological problems, and they also instigate a chain of events that can lead to additional, indirect effects.

Earthquakes

Filling deep reservoirs behind new dams produces an enormous local increase in the mass supported by the earth's surface.

The increased pore-fluid pressure caused by a dam may be enough to initiate or increase earthquake activity in the vicinity of large reservoirs, as has happened at approximately 30 sites all over the world (Gupta and Rastogi, 1975). Quakes like the one at Koyna, India, in 1976 have caused extensive loss of human lives and destruction of property. The general difficulty of earthquake prediction makes it impossible to determine the exact conditions under which water impoundments enhance seismic activity. The presence of faults and the added stresses produced by a reservoir obviously are causal factors, but no inclusive generalizations can be made as yet, certain large reservoirs being completely aseismic.

Temperature Structure

Most reservoirs are deep enough to develop the temperature structure typical of lakes in adjoining regions. In temperature areas during summer, the interactions among solar heating, wind-induced mixing, and nighttime convection currents generally produce a warm upper layer of water (epilimnion) at a uniform temperature and a colder underlying layer (hypolimnion) at 4°C. A transitional region (metalimnion) separates the epilimnion and hypolimnion. This temperature structure can be modified by two phenomena peculiar to reservoirs. First, silt-laden inflowing waters may produce currents of sufficient density to penetrate the hypolimnion, displacing cold water into the epilimnion. Second, water from cold layers below the surface can be discharged downstream from many reservoirs, unlike natural lakes in which predominantly warm surface outflows lead to a higher loss of heat (Kittrell, 1965).

The resulting modifications of the heat budget and temperature structure are too dependent on the particulars of morphology, climate, inflow rates, and discharge levels to allow any useful generalizations. It should be noted, however, that the upper layer of a stratified reservoir reaches higher temperatures than does the preceding river system, and that a reservoir's larger water volume delays both spring heating and autumn cooling.

Downstream water temperatures depend on the level from which water is discharged. Simultaneous discharge from two levels produces intermediate temperatures and thus permits some measure of control. Occasionally, fluctuating discharge rates and release of water above 0°C are used to maintain ice-free conditions downstream (Neel, 1966), extending navigability over longer time intervals.

Water Loss

The increased surface area, surface temperature, and wind speeds in reservoirs lead to higher evaporative losses than in the river systems dams replace, despite the decrease in surface water motion. This loss of water may be critical in arid or semiarid areas, where supplies are lowest and evaporation rates highest. Seepage into underlying rock strata is another, though usually less important, sink for impounded water. The evaporative loss from reservoirs in the western United States is approximately 20 billion cubic meters per year (Symons, Weibel, and Robeck, 1964), enough to supply the domestic water needs of 100 million people. Water loss from the Colorado River projects alone could supply 4 million people (van Hylckama, 1971). Attempts have been made to decrease evaporation by applying a monomolecular layer of fatty alcohols such as hexadecanol to reservoir surfaces (Neel, 1966), but disruptive turbulent motion usually renders these techniques ineffective.

Bodies of water downstream also may face significantly lower water levels because of upstream evaporation. For example, power projects on the Volga River have lowered the level of the Caspian Sea (Davis, 1971).

Losses due to evapotranspiration by "water weeds" can be enormous. Water hyacinth (Eichhornia crassipes), for example, can increase water loss three to eight times above the evaporation rate from weed-free surfaces (Holm, Weldon, and Blackburn, 1971). A vegetation cover of 15 percent thus can double losses from a reservoir.

Landslides, Erosion, and Sedimentation

Altered current structure and the saturation of soils that previously had limited infiltration of water can affect markedly the physiography of the watershed. The most dramatic effect is landsliding. The Temple, a limestone-covered butte in Lake Mead, has been severely scarred by a number of landslides (Gould, 1954). Occasionally, landslides into reservoirs have had disastrous consequences. A massive slide in 1963 into the Variant Dam reservoir in Italy displaced most of the reservoir's water, killing large numbers of people in the floodplain below (Goldman and Hoffman, 1975). In general, severe undercutting of steep slopes is most common in arid areas.

Many slower changes in physiography accompany dam construction, but the long-term results of these changes can be of great significance. The decrease in current velocity as inflowing water enters the reservoir frequently results in suspended sediment being deposited and forming a delta. The subsequent rise in the upstream river channel may require the construction of levees to prevent flooding, as in the case of the Elephant Butte Dam on the Rio Grande (Ortolano, Ringel, and Jones, 1973).

Smaller silt particles that do not settle in the headwaters are carried into the reservoir itself in "density currents" (i.e., currents with increased density because of the presence of silt) (Neel, 1966). These currents, which flow at a level determined by the temperature structure of the reservoir, often carry sediment the entire distance to the dam, slowly losing the suspended silt to large areas of the reservoir's bottom. Siltation decreases the capacity of reservoirs and may be rapid enough to limit seriously the lifetime of reservoirs. The Bhakra-Nangal Dam in India, for example, may lose its entire storage capacity within 40 years (Hagan and Roberts, 1975).

If the water levels of a reservoir fluctuate markedly during normal operation, a strip of land around the rim of the reservoir often becomes destitute of vegetation. If these bare slopes are steep, waves can erode the banks, and this eroded material also ends up on the reservoir bottom. The problem is accentuated when people use the large shoreline created by the reservoir for recreation (Hagan and Roberts, 1975).

Erosion and sedimentation in the downstream river channel depend largely on how much sediment is in the discharged water. When the level of discharge coincides with the level of a density current, layers of fine silt can be deposited on the river bed below the dam. The high-velocity downstream flow that seasonal flooding brought prior to construction of the dam is no longer present to flush out the accumulations of sediment. Discharge of silt-laden waters is common especially when the clay soils of a watershed suffer from constant erosion because of inadequate vegetation cover.

In most reservoirs, however, the average amount of suspended materials in the discharge is less than in the original river, and downstream waters generally become more clear on an annual basis. Still, bank erosion and bed scouring, with subsequent downstream displacement of sediment, sometimes accompany irregular discharges of water. For example, downstream displacements of sediment to Needles, California, following construction of Hoover Dam on the Colorado River caused local flooding at Needles (Thomas, 1956).

Marked changes in sediment load and hydrography also can modify the delta and shorelines of the bodies of water into which downstream rivers flow. Decreases in the rate of formation of the delta at the mouth of the Tigris and Euphrates rivers during the last millennium are correlated with increased diversion of water upstream (Davis, 1971). More recently, water impoundment projects on the Nile River have caused the delta shoreline to recede severely (Kassa, 1972). Interference with the process of renewing sediment along beaches beyond the delta is an additional problem that accompanies the formation of the reservoirs.

WATER CHEMISTRY

Water quality in reservoirs is affected by such a myriad of feedback processes, processes involving both physical and biological phenomena, that numerous exceptions can be found to any generalization. The details of a particular project are crucial in making a sound prediction of even the qualitative chemical consequences of forming a reservoir.

Salinity

Increased evaporation from reservoirs leads to a concentration of total dissolved solids as compared to prior river conditions. The diversion of impounded water for irrigation usually accentuates this effect, since there are large increases in the salinity and hardness of return flows from irrigation. The projects on the Colorado River provide an exceptionally dramatic example of these processes. The river's salinity increases from about 50 parts per million in the headwaters to over 1,000 parts per million by the time the river flows into Mexico after passing through numerous man-made reservoirs (Holburt and Valantine, 1972). Evaporation and irrigation are both implicated in the changes in salinity, and these changes are expected to continue. Even at present, the concentrations of dissolved solids have reached the point where agricultural use of Colorado River water can damage fields in the lower reaches of the system.

A totally different process may also produce salinity changes in delta areas downstream from certain projects. Artificially reduced water flows sometimes permit salt water to intrude upstream from receiving waters into areas where agriculture traditionally has depended on low-salinity river water, as in the delta area of San Francisco Bay.

Solution and Precipitation

Mineral solution and precipitation also alter levels of total dissolved solids, especially where the materials of reservoir beds are soluble substances such as gypsum and limestone. Solution processes usually dominate during reservoir filling. The previously mentioned landsliding in Lake Mead resulted from mass dissolution of the limestone cap on the Temple. In this same reservoir, huge amounts of gypsum bed materials dissolved in the decade following dam construction (Howard, 1954).

Mineral precipitation processes result largely from the increased photosynthetic activity that develops in reservoirs. Marl can form in reservoirs, for instance, when algae and aquatic macrophytes alter the equilibrium of dissolved inorganic carbon in water. The marl can then decrease, in turn, the concentrations of certain plant nutrients (e.g., inorganic phosphate) and of dissolved organic substances through adsorption to its surface (Wetzel, 1975).

Nutrients

The stratification of acidity, oxygen, carbon dioxide, and inorganic nutrients in reservoirs resembles that of deep natural lakes (Symons, 1969). Biological autotrophic processes in the upper layer and decomposition processes in the lower layers result in the following changes with increasing depth: lower pH, lower oxygen levels, higher carbon dioxide levels, and higher concentrations of inorganic nutrients (phosphorus and nitrogen-containing ions, in particular).

Often, filling a reservoir produces a transitional period during which the decomposition of submerged terrestrial vegetation and the dissolution of newly covered soil materials lead to an increase in dissolved nutrients. This pulse of nutrients diminishes as reservoir water moves downstream and aquatic vegetation assimilates the nutrients. Exchange of inorganic and organic materials on the surfaces of silt particles also modifies the water chemistry of reservoirs, the direction and magnitude of this influence depending on details of silt composition, silt inflow rates, density currents, reservoir volume, and water retention time. Release of materials from silt trapped in the reservoir sometimes leads to continuously increasing availability of dissolved nutrients. The attractiveness of reservoirs to waterfowl also can lead to nutrient enrichment via decomposition of the fecal matter of flocks of ducks and geese (Neel, 1966).

Decomposition processes in the hypolimnion may lower oxygen and redox potential to the point where reduced forms of sulfur, iron, and manganese are produced in large amounts. These reduced substances are extremely soluble and are toxic at high concentrations. Water discharged from hypolimnetic levels thus can contain large concentrations of plant nutrients and of materials toxic to more complex forms of life. On the other hand, water discharged from the epilimnion has been stripped, to varying extents, of dissolved organic nutrients. Regardless of the discharge layer, the process of discharge often ensures that the released water is well oxygenated.

BIOLOGICAL CONSEQUENCES

Plankton

Replacement of a river system with a reservoir leads to conditions favoring denser phytoplankton growth. The quieter waters permit deeper penetration of light as suspended particles contributing to turbidity settle out. Nutrients become available through leaching from silt, from newly inundated bed materials, and from submerged terrestrial vegetation, as outlined in the previous section, and temperatures in the illuminated portions are higher. All of these conditions favor higher growth rates and larger standing crops of phytoplankton. Slower turnover times of the reservoir water, compared to the previous river system, ensure that relative losses of phytoplankton biomass to downstream areas will be slow, particularly when withdrawals are from below the photic zone. Immediately after inundation, a time when, as we have seen, nutrient availability becomes maximal, productivity pulses can result in massive phytoplankton development (Coche, 1974).

Immediately downstream from the dam, algal development is also usually higher. Releases from the epilimnion provide a large source of phytoplankton directly, and releases from the hypolimnion provide levels of inorganic nutrients sufficient for fast phytoplankton growth, although turbid discharges may have the opposite effect. Mixtures of discharges from these two levels lead to proliferations that can exceed those in the reservoir itself. Further downstream, plankton levels drop and, because of nutrient stripping and algal sedimentation, often fall below levels reached prior to dam construction (Neel, 1966).

Aquatic Macrophytes

The same conditions favoring high phytoplankton growth lead to the invasion of reservoir areas by aquatic macrophytes, particularly in shallow parts not subject to much turbulent water motion. These water weeds can cover entire bays, and the freely floating forms may spread over the majority of the reservoir surface. Water hyacinth is the chief offender in warm regions of the earth. Submerged macrophytes are a more serious problem in the United States, the most troublesome being <u>Ceratophyllum</u>, Egeria, Elodea, Myriophyllum, Najas, and Potamogeton (Holm, Weldon, and Blackburn, 1971).

Heavy infestation of macrophytes has many ramifications. Water is lost through transpiration, and both water flow and navigation are obstructed. Fishing and other possibilities for recreation are diminished. Massive developments can sometimes clog water inlets or outlets, and the plants serve as habitats for vectors of serious disease, particularly schistosomiasis and malaria. Chemical, biological, and mechanical means of control sometimes are effective if considered in the planning stages of the project. These macrophytes do have potential value as food or soil supplements, but economic problems associated with harvesting, processing, and transportation preclude their use except perhaps on a local basis.

Benthic Organisms

Benthic biomass in the reservoir itself can be expected to increase with higher plankton productivity, but little research is available to confirm this. A shift in species composition accompanying the deposition of finer-grained sediments can also be anticipated.

Downstream from the dam, irregular discharges discourage benthic development. Aquatic insects with a flying stage are least affected by the altered hydrography, whereas sedentary organisms have the greatest difficulty surviving (Neel, 1966). Cold hypolimnetic releases containing low oxygen levels and high levels of toxic reduced substances such as sulfides decrease benthic faunal productivity. Muddy discharges produce several opposing effects, any of which may dominate; for example, silt-laden water decreases phytoplankton development and availability by increasing turbidity, but it may also bring a net increase in the food supply in the form of organic material adsorbed to the surfaces of particles.

Further downstream, the combination of lower phytoplankton productivity, lower annual silt load, and delta recession often entails decreased benthic production.

Fisheries

Hydroelectric dams usually preclude the continued existence of anadromous fish species, serving as effective barriers against migration to spawning grounds. Certain projects have special structures that permit passage of fish; more frequently, downstream hatcheries are constructed to propagate the anadromous species. In California, however, temperature variations, water quality, and disease have rendered salmon and steelhead hatcheries much less effective than originally planned (Hagan and Roberts, 1975).

Altered temperature structure in the reservoir itself produces a shift in species composition, usually to warm-water species. The production of anoxic conditions in the hypolimnion through organic decomposition forces fish to seek oxygen in the warmer epilimnion, where temperatures may exceed the tolerances of the original species. Anoxic conditions in the hypolimnion are ameliorated by placing generator intakes below the expected thermocline depth. Anoxic water then is flushed out preferentially, and the hypolimnion can also serve as a habitat for fish.

The production of game fish may increase after reservoir formation, but the high numbers observed during the first years are not sustainable. These large initial populations develop in response to the pulse in phytoplankton productivity, which, as we have seen, slowly subsides as the reservoir ages. Later conditions favor the reproduction of competitors, which are not as suitable for sport fishing. Though conditions often favor an increase in such food supplies as mosquito larvae, the size of these supplies depends on unpredictable features such as the extent of macrophyte development.

Despite these uncertainties, the total standing crop of the fish community does gradually increase as the reservoir ages, probably in response to the increased fertility and area of benthic and littoral environments (Stroud, 1966). But evaluating the change in the composition of the fish community and in the potential fish harvest is extremely difficult (Holden, 1969).

Nitrogen supersaturation of water downstream from the dam sometimes occurs when air is entrained into water during the discharge process. This increases the dissolved nitrogen concentration of body fluids in fish, and interior bubbles may form when they move into the lower pressures and higher temperatures of the upper water layers. Death often ensues. Nitrogen supersaturation is a common effect in widespread reaches of the Columbia River at certain times of the year (Smith, 1972).

The net effect of dam construction on downstream fish populations is as variable as the discharge patterns, water quality, temperature, and turbidity downstream from the dam site. Scouring by clear discharged water and sedimentation of silt by muddy discharges both inhibit spawning activity. Macrophyte development, however, in waters receiving regular nutrient-rich discharges provides increased cover and foraging possibilities.

In delta and bay areas, a decrease in fishery production often reflects a decrease in the mean annual load of nutrients borne by the river far from the dam site. A drop in eastern Mediterranean fish harvests has been attributed to construction of the Aswan High Dam on the Nile River (George, 1972).

Wildlife

Reservoir formation of course submerges habitat for terrestrial wildlife, although the larger shoreline increases the carrying capacity for certain species. Opportunities for waterfowl such as ducks and geese to establish themselves also improve. Depending on the species composition and the populations of the original terrestrial community, the loss in harvestable protein may be greater or smaller than the yields of reservoir fisheries. Areas rich in game fauna, such as the Gwenbe Valley, which was flooded by Lake Kariba, generally have a higher faunal productivity than the fisheries established after inundation (Balon, 1974). Attempts to transfer wildlife out of an inundation area have been ineffective; Operation Noah at the Lake Kariba project was an example (Goldman and Hoffman, 1975). In the case of endemic or rare species, care must be taken to ensure that transplantation results in viable populations being established before the onset of inundation.

The increased sedimentation of suspended matter because of dams threatens wildlife dependent on downstream beaches for survival. The future of certain rare or endangered Central American waterfowl that use portions of Caribbean beaches for nesting could be threatened by a proposed dam on the Honduran Rio Humuya (Goldman, 1972). Green turtles use sandy areas of these same beaches for breeding, areas that could be altered by the dam's discharge pattern. A complete wildlife and bird census is necessary to recognize the problems peculiar to any particular hydroelectric project.

Agriculture

Losses of any agricultural land during inundation are compensated for somewhat by increased opportunities for irrigation and control of flooding downstream. However, a major difficulty accompanies each of these two potential benefits. Declining water quality, especially due to the increases in salinity by evaporation and increases in toxic metals by hypolimnetic water releases, may render long-term damage to agricultural fields. Saltwater intrusion caused by reduced flows may be especially detrimental to agriculture on downstream deltas. In addition, periodic floods deposit nutrient-rich silt on agricultural lands, inundations that may be a major factor in maintaining soil fertility. A number of complicated economic impacts (Hagan and Roberts, 1975) also may result from the sudden changes in agricultural practices caused by building a dam.

Recreation and Scenic Values

Boating and swimming activities, insofar as they are not hampered by aquatic macrophytes, often increase in reservoirs. Larger fish populations do not compensate for loss of wild game, most warm-water fish species being unsuitable for angling. Beach erosion can hinder coastal tourism, but the larger shoreline encourages aquatic recreation upstream.

Loss of "wild" river systems through dam construction has occurred to such an extent that remaining pristine areas have become valuable aesthetic resources to large numbers of people. Reservoirs are common, and any scenic value they offer is certainly not unique. On the contrary, the denuded strip of land caused by drawdown, the increase in macrophyte populations, and the coloring of clear waters by phytoplankton development are an unsightly alternative to the magnificent lotic systems that reservoirs sometimes replace.

CONCLUSION

Forming reservoirs changes the patterns and extent of human use of the project area. The problems of erosion, sewage disposal, fertilizer runoff, and so forth ultimately make themselves felt through the quality of water in the reservoir and downstream. These problems are similar to those accompanying any urbanization process, but it is impossible to estimate their magnitude without carefully studying the conditions unique to any hydroelectric development. As with the more direct effects of constructing a dam, each water system deserves its own specialized study of climatological, geological, and limnological conditions to make acceptable projections and plan proper mitigating procedures.

Despite the difficulties of estimating even the direction of a reservoir's effect, let alone its magnitude, this brief report makes one fact clear. Reservoir construction produces large-scale ecological changes, many of which are undesirable. While reservoirs may not have the immediate polluting effects of fossil fuels or nuclear reactors, their indirect effects on water quality, surface geology, human health, and aesthetic appeal weigh heavily against their unrestricted development. The notion that hydroelectric power is a "clean" and dependable alternative to other, more obviously polluting energy sources is not a viable one.

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3 ECOLOGICAL CONSIDERATIONS OF THE SOLAR ALTERNATIVE

by Mark Davidson, Donald Grether, and Kenneth Wilcox

Solar energy offers hope for a future with energy that is plentiful, virtually inexhaustible, nearly cartel proof, and available to large segments of the world population. One of its main advantages is its promise of energy that is relatively benign environmentally when compared with other energy forms, offering relief to a world beset by the harmful and often disastrous activities of modern man. Some kinds of application and use may have an ecological impact, but solar energy will not degrade the environment in the manner of fossil and synthetic fuels, nuclear power, or other energy sources. It will rely heavily on conventional technologies and materials, at least for the present, and may prove to be more labor intensive than other energy technologies.

Included in the generic term "solar energy" are the following:

1. Solar thermal conversion to electricity
2. Photovoltaic conversion
3. Ocean thermal conversion
4. Wind conversion
5. Solar heating and cooling of buildings
6. Bioconversion
7. Direct agricultural and industrial process heat

The radiation on a square meter of area directly facing the sun would be 1.4 kilowatts if none of the energy were absorbed by the clouds, dust particles, and other constituents of the earth's atmosphere. The total solar energy falling on the earth's atmosphere is immense--about 0.167 quadrillion Btu (quad) per second. Even when atmospheric attenuation is

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taken into account, the amount of solar energy reaching the earth's surface in 12 minutes is enough to supply the total energy needs of the United States for one year.

The collection of most of this energy is not practical, of course; typical locations in the continental United States receive only 0.15 to 0.25 kilowatt on a square meter of horizontal surface over an average 24-hour period. Still, at a rate of 0.25 kilowatt per square meter and a conversion efficiency of 10 percent, an area of only 100,000 square kilometers (about 1.3 percent of the land area of the 48 states) would be required to provide all the energy needs of the nation (75 quads per year).

Solar thermal, photovoltaic, and bioconversion installations of a practical size will require the largest land areas and may significantly affect local ecosystems. Ocean thermal power units will not take up such large amounts of space but may, nevertheless, affect ecosystems over a large area. Wind converters will take up very little space but may run into aesthetic objections, with large arrays of very large wind turbines proving objectionable.

Each of the methods available for tapping the energy of the sun will have a distinctive impact on the environment, and studies of these effects should include the effect of pollution from the manufacture of all the building material and hardware required. This brief report will discuss in turn the main solar technologies, their direct ecological and environmental impacts, and their indirect effects.

THE MAIN SOLAR TECHNOLOGIES

Solar Thermal Conversion

Solar energy can be harnessed by using collectors with reflecting surfaces that focus solar radiation on a working fluid, producing heat for an engine that can either provide mechanical energy or drive an electric generator (Bockris, 1975; Selcuk, 1975; Killian _et al_., 1975; The Aerospace Corporation, 1974).

There are two main types of collectors, the parabolic trough and the central receiver. The first is a parabolic reflector that concentrates solar energy by focusing it on a pipe carrying the working fluid, say water, along the length of the trough. These units can be made with concentration ratios of 10:1 to 100:1 and can be rotated to track the sun. The central receiver consists of a large array of flat mirrors (heliostats) that also track the sun, reflecting solar energy to a central point where it can be used for the same purposes as a furnace fired with oil, coal, or gas, producing concentration ratios of 500:1 to 1,500:1. Although heliostats are more complicated to maneuver than parabolic troughs, because they rotate about two axes, they are favored for large-scale power generation because of the higher temperatures possible and the lower material requirements. Typical land areas for 100-megawatt (electric) intermediate-load power plants are about 2 square kilometers; the land area for a base-load plant is 3 to 4 square kilometers.

Study of Nuclear and Alternative Energy Systems

SUPPORTING PAPER 8

ENERGY AND THE FATE OF ECOSYSTEMS

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