1. THE MAN-MADE LAKE ECOSYSTEM

Among the many ecosystems of which man is a part, the man-made lakes present in sharp outline the difficulties and opportunities of tracing out basic relationships and of shaping public policy to deal effectively with social goals and environmental change. When man throws a dam across a stream to create an impoundment he generates a complex net of impacts. These spread through human, biologic, hydrologic, atmospheric, and earth crustal components of the environment.

The initial action of a dam usually is abrupt. The transformation from terrestrial and riverine to aquatic and lacustrine conditions is rapid and grossly evident. The full consequences, insofar as they are identified, reach not only far over the earth's surface but far after in time. Although much less than one percent of the continental land area now is covered by artificial lakes, they claim the attention of policy makers at national and international levels because of their strong ties to potential economic growth and of their capacity for highly visible environmental and social disruption. They are symbols of economic advancement and also of dismay. They provoke issues of public judgment likely to appear wherever drastic changes are made in an ecosystem. Thus, they embody the kind of complex relationships and choices that are involved when land and water are severely altered by drainage, cultivation, pesticides or other massive human treatment.

In considering the significance of man-made lakes to society, it is important to ask why they are undertaken, whether they are the best methods for achieving the desired aims, and, thereby, what the alternatives are to building them. This leads to the questions of how they differ from natural lakes and from place to place, and how man functions as a part of the new ecosystem as it goes through its several stages of development.

Alternatives to Man-made Lakes

Man creates lakes to store water for power generation, flood control, irrigation, navigation, and urban water supply and waste disposal, and for sport and commercial fishing, hunting, and recreational uses of the reservoir itself. A large experience documents the benefits that have accrued from building storage reservoirs of one kind or another, and especially in helping improve the conditions of life in some areas. They are an accepted part of man's technological arsenal for developing and controlling the natural world to his advantage. It could well be argued that some reservoirs are among our best examples of enlightened manipulation of environment to enhance its quality. Unfortunately, with reservoirs as with most other major modifications, only a few careful assessments have been made of the full range of impacts of their construction.

For most efforts to enhance human welfare by building dams, there ordinarily are alternative ways of meeting the social need. Building an impoundment is not necessarily the most desirable alternative. Power may be generated from fuel sources; flood losses may be reduced by other means, such as channels or land-use
change; water may be transported directly by aqueducts from sources to places of demand rather than stored until needed; and so on.

Sometimes impoundment is chosen because it seems the only physically feasible and economical means of reaching a goal. Generally an artificial lake is judged to be economically preferable to other alternatives. It appears to accomplish a variety of benefits in a tidy way at low cost. However, many a dam is built without genuinely considering the other possibilities. It should not be assumed that a dam — large or small — necessarily is desirable; however, it would be equally erroneous to assume that the appraisal of alternatives is an easy task.

All such efforts logically hinge on the prior definition of social goals. These set the framework within which alternatives will be examined and impacts will be discovered and reconciled. Both goals and methods change over time and differ among nations. Whereas economic efficiency may be a primary goal in one place, regional development may predominate in planning water management in another area, and in other places a large dam is in part a display of national autonomy and strength.

Projects as massive as many man-made lakes involve much more than efforts to increase real economic output. By design and by accident, they alter the relative abundance or power of different productive factors and thereby shift the range of economic opportunity in the area affected. In a developing country they may set in motion profound readjustments such as the transition from subsistence to market-oriented economic life. In an industrial country they may shape the pattern of heavy manufacturing or of new recreation. The speed and direction of those changes may be critically important in determining the relative weight of economic gain against the disruptive social effects.

Any major environmental change is likely to produce substantial redistributions of wealth, income, and employment opportunities. The redistribution effects will hit different groups of people with different impacts. Even a project promising to be highly efficient in an economic sense may involve such gross inequities in distribution effects, as in the costs of relocation, as to require other measures to compensate the losers.

Whatever the circumstances, reservoir construction never is warranted without prior examination of the other possibilities. An adequate comparison requires scientific knowledge to assess likely effects. These are judged on social and economic grounds, and, man being man, the political factor ultimately will be decisive. The impacts stretch 1) downstream, 2) to distant consuming areas for water and power, 3) to upper parts of the watershed, 4) in the case of very large impoundments, throughout the political and economic life of the nation, and 5) within the immediate area of the reservoir and the adjoining lands. It is primarily the latter impacts, which may be defined as the biotic and socio-cultural community and the nonliving environment as they function together, that create the man-made lake ecosystem. In dealing with it we thus examine only one sector of the impact of water management.

Response to Uncertainty

Man has no early prospect of being able accurately to judge all possible effects of a new lake. Whereas some of them, such as the influence of water depth on
lake bed vegetation in given physical conditions, may be predicted with guarded confidence, many of the relationships are barely recognized, let alone sufficiently well understood to permit prediction. Moreover, the time dimensions of the processes at work differ greatly. The response of certain populations, such as plankton to the new water body may be almost instantaneous, while the formation of lake bottom soils or, indeed, of the whole lake system goes on over decades or centuries.

Faced with such uncertainties over a wide range of time horizons, a public agency responsible for new man-made lakes can take one of several postures. At one extreme, it can push ahead with the primary purpose of construction, such as hydroelectric power, and deal with side effects as they arise or are perceived, hoping that they do not prove to be unduly serious or intractable. At the other extreme, it can halt all new construction until long and painstaking research has established sufficient knowledge of facts and method to permit some minimum confidence of prediction. Between are a variety of positions involving efforts to make further studies, to prepare for certain contingencies, and to hedge against major disruptions.

Robert Bridges once wrote that «stable conduct lies in masterful administration of the unforeseen». In this sense, any thoughtful attempt to design and carry out the creation of a man-made lake is a search for stable conduct. It is a search that requires large flexibility not only at the outset but throughout the entire life of the enterprise.

**Natural and Man-made Lakes**

A man-made lake is a combination of terrestrial and riverine ecosystems becoming a natural lake ecosystem. However, it never arrives at that relative state because it always is subject to human manipulation of outflow and water levels. Likewise, reservoirs are often constructed by damming the outlets and raising the shoreline of natural lakes. For the purposes of this report we see man-made lakes as fresh water bodies created or enlarged by the building of dams, barriers or excavations. They are subject to continuing human maintainance and operation. Where any of the factors that comprise the basic water balance is significantly altered or controlled it is counted as man-made.

The resulting ecosystem is thereby more or less different from that of a natural lake. Involved are the new physical environment, the aquatic and terrestrial communities, and the changing web of human interactions in those communities. It is easy to delimit the maximum lake level, but difficult to draw a line around the areas affected by the organisms, and especially man, which are related to the new habitat. Somewhat arbitrarily, we designate as parts of the lake basin ecosystem the lake area, the immediately adjoining terrestrial communities, and the human communities within the upland areas, other than the main stem of the stream, draining directly into the lake. Difficulty is encountered in delimiting boundaries of the physical and biological impact area which varies according to the elements or species concerned. This definition excludes more distant communities influenced by the new habitat and its products, as when land animals roam across a watershed, when electric power is transported to a city, or when political maneuvering for the dam affects the national political balance. It includes the populations directly affected by the artificial lake. It excludes the downstream effects which in many instances are profound. Changes in flood peaks may induce channel silting.
lization of stream flow may provoke bank cutting and may disturb the feeding and reproducing mechanisms of organisms associated with the periodicity of water level fluctuations. For example, in the lower Paraná and Amazon basins the increase of upstream storage might cause a shift from present pool and prairie landscape toward a swamp condition. Such downstream effects are excluded.

A Recent Widespread Phenomenon

Although small lakes have been constructed over many centuries, as recorded in the ancient tanks of Ceylon and the mill ponds and fish ponds of Europe, the era of creating lakes of more than 100 km² in surface area did not begin until after 1915. Early in the 1900's the changes in earth moving and concrete technology made feasible large and relatively inexpensive structures. Since then, reservoirs of large size have been constructed in tropical and temperate zones on all the continents (see Figure 1.1). Unlike some other products of modern technology, they are as common per unit area in many developing countries as in high income countries. At least 40 with water surface exceeding 1000 km² and 260 with surfaces of 100-1000 km² are now in operation (Fels, 1970). In volume, the more than 4000 km³ stored in those lakes would equal roughly one-third of the water in the atmosphere.

The largest number of big reservoirs (1000 km²) is in the USSR with Canada, China, India, and the United States all having major structures (see Figure 1.2). In Ghana the Volta River reservoir inundates more than four percent of the total land area. Some of these as well as other countries have built many small reservoirs of less than a few square kilometers. Thus, Japan has .05 percent of its land area in such use, and Rumania, with 1200 small projects, has at least 0.2 percent. The Machakos area of Kenya and most of Rhodesia is sprinkled with small dams. In North America, small reservoirs are widely used for regulated domestic water supply, flood control, waterfowl production, and recreational fishing, and for these reasons are widely recognized as a useful way of improving natural environments. In Western United States alone at least 1,000 small dams for stock watering purposes are being constructed each year.

Large vs. Small Lakes

There is no obvious lower limit for the size of a man-made lake. Even in their hydrologic influence, as in their contribution to streamflow control, an aggregate of small lakes may be as important as a large one. Indeed, in countries such as Bulgaria, Hungary, Japan, and Spain, water resource management and inland fishery development are based on hundreds of small reservoirs.

Although similar basic physical and biological processes are at work in large or small water bodies, there are profound differences in limnology and management of ponds as opposed to small lakes, and of small lakes as opposed to large lakes. The transition from ponds to small lakes is commonly associated with mean depth greater than about 3 metres or area greater than 10 km²; the transition from small lake to large lake is traditionally associated with mean depth greater than 10 metres or area greater than 100 km². With greater depth and area there is characteristically a thermal stratification and the development of a complex dynamic physical struc-
Fig. 13 - Distribution of Man-made Lakes with Surface Area of Basis 100 sq mi

- Surface Area: sq mi
- Storage Capacity: cu ft

- Canada
- USA
- Latin America
- Europe
- USSR
- Africa
- India
- Other Asia
- Australia
ture. There may be changes in natural productivity as depth and area decrease, with associated changes in ecosystem functioning. Large lakes or reservoirs are thus mostly separable from small lakes and reservoirs on biological bases.

From the viewpoint of power generation and major water storage, only relatively large and deep reservoirs are economically attractive. One horsepower is generated by dropping one cubic foot of water per second through a height of 11 feet (see Figure 1.3). Thus, there are obvious advantages to constructing power

dams with as much "head" as possible. Similarly, for water storage, the approximately parabolic shape of most lake basins ensures that with each increase in height of a dam there are progressively greater storage benefits. In consequence, major reservoirs are usually made as extensive as possible, tending to put them in a large-scale range. The social correlates of size are highly variable. A pattern of small reservoirs poses a quite different set of social considerations from a single large reservoir.

For these several reasons, we direct attention in this review chiefly to the larger types of reservoirs with areas greater than 100 km². Although this may seem arbitrary, it is a useful line of demarcation between two somewhat different patterns of human ecosystem impacts.

In terms of the public responsibility for the disruptive effects, the large reservoirs most often claim attention. However, aggregates of many small reservoirs may have environmental impacts just as profound.
Temperate vs. Tropical Lakes

It will be observed from Figure 1.2 that Western Europe has very few large lakes, and that the larger ones are widely distributed over the land surface of the globe. Unlike certain other facets of modern technology, man-made lakes are numerous among the developing countries. Although relatively more numerous in semi-arid zones, they have been built in humid zones such as the lower Ganges-Brahmaputra and in very arid areas traversed by exogenous streams such as the Nile.

The disparity in energy balance conditions for man-made lakes of the temperate and tropical climatic zones makes for some fundamental differences in water balance conditions, temperature regimes, and biological processes. Most of the serious human population dislocations have occurred in tropical situations, partly because large displacement would be political suicide in some temperate areas such as France. However, there are enough properties in common so that they may be treated as a group, recognizing the salient differences at critical points.

Why Focus on Man-made Lakes?

Large dams are hailed in many areas as milestones of technological advancement of human welfare. In some other areas they are lamented by certain groups as ecological catastrophes. An examination of what is known and not known about reservoirs thus has significance as an inquiry into scientific and policy issues raised by massive human intervention in the environment, as well as an aid to management of present and future reservoirs.

Attention is focused on this one ecosystem because it provides a conveniently delimited and observable set of relationships over time. The initial transition is usually a matter of a few years. The total area directly affected is relatively discreet.

The number of studies of large reservoirs is great by comparison with numerous other ecosystems. The highly visible reservoir suddenly brought into reality attracts more interest than less obvious works such as swamp drainage, agricultural land use alterations and highway construction. Thus, there were major interdisciplinary investigations in cooperation with the United Nations Development Programme (UNDP) on lakes Kainji, Kariba, Kossou, Nasser and Volta which began essentially as salvage operations by the countries when the likely impacts became apparent. These have been interdisciplinary studies in which aquatic biologists, fishery specialists, economists, engineers, geographers, public health scientists, sociologists and many others have collaborated. They built on earlier work preceding the dam construction, of which the Volta River investigations were perhaps the most searching. The UNDP activity led to the preparation by the Food and Agriculture Organization (FAO) of a general guide to planning for studies of man-made lakes (Lagler, 1969).

Symposia at London (Lowe-McConnell, 1966), Accra (Obeng, 1969) and Knoxville (AGU, in press) have drawn together much of the international experience. At Knoxville in 1971, for example, members of the concerned disciplines joined in plenary discussion of the major scientific issues. Each of these symposia has assembled a
large part of the available information about the reservoirs of the world. The information so far collected has not been synthesized in a way to enable formulation, without further analysis, of a useful guide for setting detailed policy for new reservoirs. Such a lack of synthesis is not a reflection on the symposia of their participants. Rather, it mirrors the state of most reservoir investigations. With the exception of the salvage studies, the tradition is to examine small segments of water impoundment experience. There have been only a few sustained investigations of such new water bodies in the USSR and in the U.S. national research programs on environmental factors relating to success or failure of major fish species.

If governments and scientists are troubled by the outcome of some reservoirs (and research projects thereon) it is in part because the scientific waters are muddy. Mainly because of the educational and institutional barriers and the limitations in available training, much remains to be done at both national and international levels in order to foster cooperative efforts among the physical, biological, and social disciplines concerned.

*Man in the Ecosystem*

Basic to the choice of appropriate policy is the public view of the significance of man's act in building a dam. One widely held view is that man has the power and responsibility to manipulate natural systems to serve human ends, and that the test of the wisdom of his action is in the short-term monetary returns. If a hydroelectric project returns the payments on the investment and stimulates regional growth, it is good.

A somewhat different view is that of man as intervening in a natural ecosystem: he disturbs existing systems, creates new ones, and tries to balance the favorable and unfavorable effects. If a calculation in advance of construction shows that the total social benefits exceed the total social costs for specified groups of beneficiaries over a specified time period, the intervention in the ecosystem is judged to be warranted: the so-called natural system is viewed as somehow independent of, but controlled by man.

A view which we find more suitable is that of man as the dominant species in ecosystem earth, who by building dams adds to his long-demonstrated capacity for technological change, and who seeks beneficially to integrate that skill with an on-going process of interaction among human and other elements of the ecosystem. With inspiration and skill, he may mold a better world for his descendents. Under this view the dam is only one among numerous and continuous interactions: a simple «before-and-after» model of change is not sufficient to describe the impacts. Long-term shifts in diversity and stability take on greater importance. While it is essential to try to assess the likely effects at the stage when the feasibility of a new structure is being decided, the process of assessment is a continuing part of human life in the system.

The continuing interaction with other systems makes it desirable that the management of a man-made lake be carried out in close association with activities upstream, downstream, and in areas that are linked by physical or social impacts. Reservoir management is part of a larger regional responsibility.
It is important to state two theoretical problems. The first concerns the conceptualization of man as a part of an ecosystem; the second concerns the nature of the socio-cultural system. Whereas it is relatively easy to analyze the lake basin human population as part of the man-made lake ecosystem it is more difficult to include those government agencies which are responsible for planning and executing dam construction and lake basin development. In one sense they are external agents although they are of course part of a wider ecosystem just as the human species is part of a global ecosystem.

The second problem relates to the nature of a socio-cultural system. Certainly it is a system in that there is an interrelationship between component human actions and premises. However, social and behavioral scientists are finding unsatisfactory the applications to human affairs of analytical models which have been borrowed from the physical and biological sciences. These include organismic models and equilibrium models, neither of which is particularly useful in dealing with the multi-disciplinary features of man-made lakes. Yet one of the characteristics of man in society is a capacity radically to change the rules of the game through the generation of new ideologies and programs of social action. Examples include not only the appearance of world-wide religions like Buddhism, Christianity and Islam, but also within the past 100 years of new political ideologies.

It is not that we reject the utility of equilibrium analysis, for example, since in the hand of an ecologist or economist this can be a powerful tool in dealing with certain limited types of problems and can be extended to deal in a broad way with survival strategies. Rather, the concept of equilibrium as developed by classical ecologists was not intended to come to grips with the complex interrelationships between man as a social, culture-bearing animal and other components of the ecosystem. Whereas it is not our task in this report to attempt to generate new theory or models, it is clear that there is yet no unified theory that relates to social change or to ecological change where man is viewed as an integral part of the ecosystem. It is obvious that detailed long-term studies of continuity and change within complex man-made ecosystems are essential if theoreticians are to have the data against which to generate and test increasingly complex models. Meanwhile, in this report the model used is a rather simple one that views human societies primarily as coping systems making creative responses to stress.

Modes of Social Assessment

In theory, every public or private decision triggering a major change should follow on the heels of careful assessment of the full range of likely impacts, and the analysis should be repeated as conditions change. In practice, this rarely happens. Indeed, the state of the art of defining and measuring impacts is so primitive and the object measured so unstable that a firm appraisal at any one time would be impossible. Yet, some estimate must be made, if only to provide a basis for comparing the tentative project with other alternatives.

One common mode of analysis is to estimate the cost effectiveness of a dam by comparison with other possible measures. This assumes that the primary aim is desirable and that the remaining question is whether or not a particular combi-
nation of engineering and auxiliary works would be the cheapest way of reaching the goal.

More frequent is benefit-cost analysis, with its attempt to place a value on each expected future stream of benefits and costs. The total benefits are then compared with total costs.

A third formulation is to ask what is socially the most desirable investment of the available capital. This would involve choice among sectors of investment, such as water control vs. roads. It does not question the particular design of the water-control works or the roads, although, like benefit-cost analysis, it involves assessment of their net social outcomes.

In both cost-effectiveness and benefit-cost analysis a genuinely comprehensive evaluation would search out every possible impact and try to attach a value to it. A series of troublesome issues inevitably arise in that effort. Many of the effects of a dam and reservoir — for example, changes in gene stock or in species combinations of fishes — cannot be identified readily. Even when they can be recognized, they may defy accurate monetary measurement. And for those impacts that lend themselves to quantitative expression there are the questions of what is a suitable time horizon and what is an appropriate rate for discounting the future. These decisions have a powerful influence on feasibility calculation and rest finally upon judgment as to the financial constraints for undertaking a project and as to the long-term role of the action in maintaining a viable world.

No thoughtful attempt to understand the consequences of setting in motion new ecosystems can ignore the complexities of making social and economic assessments of the foregoing sort. Considerations of the discount rate, multiplier effects, and the like cannot be dismissed, for even if explicitly ignored they enter inevitably into any estimate of prospective changes. The contrary also is evident: judgments as to environmental aspects cannot be made casually just because solid grounds for quantitative measurement are lacking. Wise resource use is thus coincident with the best possible contemporary evaluation, being neither superficial for reasons of expediency, nor paralyzed by anxiety. Equally important are clear-minded appreciation and statement of the inadequacies of current techniques of evaluation, and the determination to improve them by learning from past experience. If the attempt is to produce constructive findings for the guidance of new research and of public policy there will need to be a good deal of humility on the part of both natural and social scientists as to the limits of current knowledge and as to the difficulties of evaluating change.

Four Stages in Creating the Ecosystem

The making of the man-made lake ecosystem proceeds in four stages (Figure 1.4). Oftentimes the most crucial is the period of feasibility studies when the groundwork is laid for a decision as to whether to build the structure. Second comes the period of final design and construction. Third, as soon as the dam is closed, a stage of reservoir filling and instability begins. Fourth, after the initial ecological instability, gradual adjustments take place during a more or less stabilized stage throughout the remainder of the reservoir's life.

In these circumstances planning is not a single act of investment, however long
and deliberate may have been the studies leading to the construction decision. It is a process which if properly carried out includes monitoring, mechanisms for preserving options, and alternatives for the timing, sequence, and scale of sub-projects that may alter the direction of change in the last stage.

Reservoirs going through these four stages pose essentially the same problems of understanding as other ecosystems. They comprise an interacting entity of physical factors of environment, a complex web of biological production, and a skein of effects of human manipulation. They differ from many other ecosystems chiefly in the degree to which man causes a gross and sudden shaping of their physical
structure and ensuing regime. In addition to having the usual dynamics of natural ecosystems, they have a) extremely unstable and transient initial conditions, and b) a long-lasting, somewhat more predictable structure largely determined by initial design and by subsequent water discharge manipulations. For abruptness of initial transition in the third stage there is no terrestrial counterpart save perhaps after such catastrophes as a forest fire or volcanic eruption. For human manipulation, the character of structural design and of regulation of water levels is a continuing element in ecosystem functioning.

One way of suggesting the character of the changes that take place is given in Figure 1.4. This indicates the evolution of impacts of a lake over time, with different elements in the ecosystem taking on or losing importance as the development unfolds. In the stage of feasibility studies, the definition of social aims and of criteria for choosing among alternatives is crucial, although often this is treated only by unspoken assumption. At the same time, the appraisal of whatever prior knowledge has accumulated about the physical, biological and human characteristics of the area is essential to making estimates of impacts. In the planning and construction stage, much more detailed analysis and data collection are required within the agreed objectives of the project. Here, the shape of the reservoir and all its auxiliary human activity are designed. In the filling stage, the emphasis shifts to carrying out the plans and to observing change as a basis for later operations. In the lake management stage, there is continued interaction of reservoir discharge, biological systems and human activity, and the ecosystem may be expected to change as social aims, management techniques, and scientific understanding evolve together.

Major Components

Another way of outlining changes is to chart the principal lines of interaction among components of the ecosystem as shown in Figure 1.5. This is schematic at best but it helps identify the major groups of relationships. The diagram has the special weakness of being static and only two-dimensional, whereas the relationships in question are dynamic, and include the conventional third dimension plus a fourth, time.

In brief, the dam construction causes immediate relocation of people and creates a new water body. The artificial lake provokes seismic and micro-climatic changes, and becomes the habitat for aquatic and lacustrine populations. These interact in new production systems in which the socio-cultural systems may be altered only slightly, as when an impoundment covers and adjoins an unpopulated area, or profoundly, as when new fishing, recreational, and agricultural activities are generated. The effects are not a single perturbation moving through the several systems; they change and continue through time.

In the creation of a man-made lake, a previously riverine ecosystem is superimposed on a terrestrial one. The immediate result is an unsteady, not easily defined state, which with time becomes stabilized into a definable new ecosystem, with limited characters similar to those of a natural lake. It does not retain completely a riverine character neither does it reflect, in total, the features characteristic of a natural lake. The new ecosystem is a complex hybrid which demonstrates
a mixture of characters of the two parent ecosystems, both in physical terms as well as in behavior.

The terrestrial ecosystem contributes to the chemical character from its soils and geological structure. It affects the physical character as a result of the mold of the flooded basin. Its flooded vegetation contributes to the early stages of the organic sediments and fertility of the new ecosystem.

Fig. 1.5 - Components of a Man-made Lake Ecosystem

The river provides the material structure for the new ecosystem; its water supplies the new environment; its fauna and flora, the new community. The result of the interaction of these two systems in the initial stage, is an artificial lake ecosystem, with its own unstable limnochemical and physical characters, diversified populations of benthic periphyton, plankton, large invertebrates, vertebrates and plants, and its own energy-transfer patterns at various trophic levels.

When the artificial impoundment becomes stabilized, it does not automatically take on the character of a natural lake, the features of which may be due to factors
traceable into geological times. Generally, a reservoir lacks the characteristic morphology of natural lakes, and the stratification and profoundal deposits so characteristic of natural lakes may be markedly different. The reservoir will be deeper in parts than original maximum river depths but in some instances the limnetic zone may be virtually stationary and therefore may not support the biota normally associated with limnetic habitats. The resulting ecosystem generates far-reaching effects. Its conditions may for instance trigger a rapid growth of aquatic or semi-aquatic shoreline vegetation which in turn may have various effects on man and his actions in the vicinity of the created lake.

Thus, the general question of what are desirable interventions in the environment has different points of emphasis for man-made lakes than for numerous other ecosystems. These points change over time. The new lakes provide large and continuing opportunities for experimental manipulations of physical, biological and socio-cultural conditions. But offsetting this latitude for experiment, there is little opportunity for slow accumulation of experience. The reservoirs are not usually built by small increments to dam height (although to be sure the Aswan impoundment was constructed in three stages). Once the height is established there is little freedom to rescind it. Whereas there may be opportunities for large-scale changes in discharge operation schedules after construction if economic constraints permit, the major structure is determined only once, usually at great expense, and short of catastrophe will be on the scene for a long time.

In terms of total area transformed, man-made lakes do not bulk large. Their consequences loom higher on both the socio-economic and environmental skyline than does their combined surface on the geosphere, Nevertheless their symbolic importance is very great. Within their restricted areas they illustrate the immense difficulty of recognizing the on-going transformation that is generated by a single technological change with all of its auxiliary actions.