In a pluvial period associated with Wisconsin glaciation the closed basin of the Estancia valley in New Mexico held a lake which, at its maximum extent, was 150 feet deep and had a surface area of 450 square miles. This basin, with an elevation of about 6,000 feet, has at present an annual precipitation of about 16 inches.

Estimates have been made of the Pleistocene precipitation necessary to maintain this pluvial lake. Instead of the present annual average of 14 inches, it has been variously estimated that the precipitation must have been 20 to 24 inches. Lakes existed during Pleistocene time in many places in Western United States which are now true deserts. There is evidence in many places in this area that early man lived on the shores of these lakes. He must have adapted himself to the increasing aridity. Some of the forms of this adaptation can be seen even at present in the form of flood-water farming practices highly developed by the Hopi Indians.

A gradually changing climate is only one, and not the most important, of the conditions to which man must gradually adjust in his use of water. The changes in his own culture, and in population density, are usually even more important determinants of man's use of and attitude toward his water supplies. In a desert area of Central Arizona, near Florence, there have been mapped and partially excavated the remains of irrigation systems developed by the aborigines to irrigate the valley with water diverted from the Gila River, which was at that time perennial. Though irrigated agriculture was not practiced nearly so extensively in the arid portions of the United States as in Persia, India and many Mediterranean countries, neither was the general culture so highly developed by indigenous American tribes. Even in the simple cultures of the American Indians a pattern of adjustment to a changing climate and to a changing culture and population level can be discerned. The patterns of such adjustment include, however crudely, the development of irrigated agriculture, flood-water farming, water storage for both stock and community use, spring development and even efforts at rain-making through the offices of prayers, rattles and dances. These same patterns, more complex to be sure, have characterized the adjustment of modern culture to the limited water supplies in arid climates, even including the prayers and rattles.

One aspect of the development of American culture in the arid areas is probably typical and may have a counterpart in certain of the now underdeveloped areas in other parts of the world. The local civilization of the arid climate usually does not develop to a very high level in situ. The indigenous cultures are usually transfused with new bursts of energy and knowledge by the incursion of other cultures which develop in other climes.

Luna B. Leopold

The cultural advances in the fertile crescent of Mesopotamia was influenced by barbarian invasion, which added much to, as well as detracted from, the locally developing society. So also the spurt of civilization which has characterized the arid parts of the United States since 1846 was determined by the super-position of a culture from the eastern United States on the essentially Spanish culture which had been developing since the initial exploration in 1630.

Up to the time of the American occupation in 1846, the preceding 200 years had seen the establishment of a highly developed irrigated agriculture based primarily on temporary diversion dams rather than on carryover storage. The remarkable part of this irrigated culture was not so much the engineering works of canalization and the brush and rock diversion dams, but the social order of villages revolving around the necessity of operation and maintenance of the diversion works and the canal systems.

The mayor domo de la acequia, or ditch master, was one of the foremost citizens in the village for it fell upon him to placate every farmer who felt that he did not get his share of water, and to prod each irrigator to contribute his share of the labor necessary for maintaining the system. But this social order, highly dependent on subsistence irrigated farms, was equally dependent on the grazing resource in the adjacent non-arable hills and in the forested highlands. The livestock industry was the source of those animal products—wool, hides, meat and draft-power—needed to supplement the agricultural products: beans, melons, corn and chili.
The mid-19th Century marks the beginning of the rapid changes which took place in the arid southwestern United States. When this great expanse extending from New Mexico to California was ceded to the American government the real conquest of the West began. With settlement came a marked increase in irrigated agriculture, mining and commerce. Impetus to this expansion was given by the discovery of gold in California, again later by the completion of a transcontinental railroad and by the Homestead Act. Under the latter legislation, a settler could gain private ownership of a block of the public domain by settling on and developing the land.

Though there had been dense concentrations of grazing animals around certain of the old Mexican villages, the cattle industry reached its apex in the 1880s. The first decades of arid land development fortuitously included some extreme weather conditions. Extended dry periods were punctuated by years of extraordinarily heavy precipitation. The weather records indicate also that during this decade a change occurred in the relative frequency of small and large rainstorms. Between 1850 and 1880 a relatively large number of heavy rains occurred. Intense single rainstorms, years of exceptionally high rainfall and concentration of livestock coincided with, and presumably initiated, a period of intense erosion, specifically characterized by the development of deep trenches or arroyos in the alluvial valleys.

This epicycle of erosion wrought important changes in the economy, not only because of a degradation of the grazing resource but also through the effect of the eroded débris on stream channels. The larger irrigated valleys downstream suffered from channel sedimentation and widening. Drainage of irrigated land was impaired by the rising level of stream beds as well as by higher water tables resulting directly from irrigation. Flood hazards were increased in the lower valleys. In the trenched alluvial valleys upstream, irrigation formerly practiced by the construction of simple diversion structures was no longer possible without engineering works too complex for the local inhabitants to build. The degradation of the range so increased the hazard of stock raising as a stable economic enterprise that agriculture and commerce forged ahead.

An expanded irrigated agriculture, associated with the increasing population, required carry-over storage, and thus the cost of irrigation-farming increased. There followed in the second decade of the 20th Century the construction of a series of large dams to stabilize and promote irrigation. It was irrigation that built the centers of population in the semi-arid states, though mining, stock raising and lumbering were industries closely allied in the expanding economy.

Another important influence was the legal doctrine governing water, premised on the Spanish custom that longevity of beneficial use determined the right to water. An adjunct to this doctrine is the dissociation of a given parcel of land from a given water right. Later it developed that a water right could be acquired and the water led elsewhere for beneficial use. The development of communities dissociated from local irrigated agriculture accompanied the expansion of commerce and of mining. Such communities were forced to look to ground water rather than to surface streams for the supply of this essential resource.

This brief history of development before the Second World War is characterized by water-resources development responding to social and economic needs circumscribed by a legal doctrine of appropriated rights, but unguided by regional or even local planning. Nor could it have been otherwise under the democratic institutions of free enterprise and economic entrepreneurship.

In summary, water was used first where it was immediately available in communities more or less economically isolated. With the increase of commerce, surface waters were stored for use at various places downstream, and ground water was developed to serve population centers where a surface supply was either not available or already appropriated. But the speed, location and type of development were dictated by interaction between social and economic factors.

Then came World War II. An important part of the aircraft industry had already grown up in California. The tremendous expansion of aircraft work tended to be even more marked in the semi-arid West than in other parts of the country. The warmth and clear skies were particularly favorable for the development of airfields, training bases and manufacturing. Many other industries were similarly expanded to meet the demands of war. Although many of these operations were curtailed when war ended, the facilities and trained personnel gave impetus to a more rapid rise in industrial activities than had been seen in the prewar years. Thus, for the first time the water needs of industry began to loom large.

The population increase of the whole country was also an influence. The equable climate of the semi-arid lands promoted the growth of Southwestern cities not only for general living but for recreation. Land formerly used for irrigated agriculture could be turned over for a handsome profit for residential or industrial use. Water rights were needed both for urban growth and for industrial expansion. Therefore, near centers of population, urban and industrial development proceeded at the expense of irrigated acreage. Yet the increasing values of irrigated crops could justify expansion of reclamation activities into areas uneconomic in earlier years.

The gradually lowering price of power and the availability of new equipment made it possible to draw ground water in larger volumes and from greater depths than had ever been possible prior to the widespread use of the centrifugal pump.

The national farm policy also had an important impact on water-resource development. In order to provide more stability to agricultural enterprises, prices of certain
crops were guaranteed by the government. These artificially
high prices made, and continue to make, crops profitable
which would not have been so without federal subsidy.
In some cotton growing areas, ground water can be
pumped from considerable depths at a financial profit,
thanks to the price support.

Thus postwar development, characterized by industriali-
zation and urbanization, likewise demonstrates that water
development was dictated in location, amount and kind by
economic and social forces. Obviously these circumstances
have led to more complete development in certain areas
than in others, and there are now many places where
local and even regional water supplies are fully developed.

This history of water development in semi-arid areas in
the United States shows how problems evolve. One of them
derives from the fact that the economy of various portions
of an arid area will develop at different rates. With a legal
doctrine of appropriated rights based on beneficial use,
water rights may be acquired for downstream areas near
areas of urban expansion before more isolated upstream
areas are developed, either for intensive agriculture, in-
dustrialization or urbanization. If the water supply is
limited, upstream areas may be effectively handicapped
because water passing through or originating in them has
already been appropriated.

A potential danger in any arid area lies in the inherent
variability of the water resources. During a decade of
relatively high water yield, water will be put to beneficial
use in downstream areas and an initial right to water will
be established. In succeeding decades of deficient precipita-
tion all of these rights cannot be fulfilled. There has been
an overexpansion of irrigated agriculture that cannot per-
manently be sustained.

As a result, areas which have the youngest, or most
junior right to water will seek all possible means to
secure the presence of water to fulfill those rights during
dry years. Various schemes for increasing water yield
will be devised. In the semi-arid states at present experi-
ments are being conducted to increase the total downstream
yield of water by the decrease of evaporation losses in up-
stream areas. Some headwater areas are being cleared of
native woodland vegetation species of pine and juniper.

When these have been eliminated by poisoning, burning
and grubbing, the area is seeded to grass in the hope that
the grass will eventually cause a smaller evaporation loss
than did the woodland. Other techniques include selective
logging or controlled burning of headwater forests with
the aims of improved timber and forage production as well
as increased water yield.

There is pressure to expand these efforts to increase
water yield beyond mere experiments. Large-scale changes
in native vegetation are demanded by some groups even
before research has demonstrated the efficiency of the prac-
tice. Woodland clearing is also desired for improved graz-
ing forage. Introduced grass would supposedly increase the
total available forage.

Such manipulation of native vegetation poses difficulties.
There is a question, for example, whether an artificial
plant association introduced by man under particular cir-
cumstances can, over a long period of time, continue both
stable and productive. There is also a problem that in the
semi-arid United States the highland areas, the sources of
water yield, have particular value for watershed protection.
By the turn of the present century, the native vegetative
cover was sufficiently disturbed by grazing and fire that
erosion had become an important land-use problem.

Whether under a condition of radically altered vegetation,
sediment production could be controlled is open to ques-
tion. In addition to the possibility of serious sheet and gully
erosion in upstream areas, the change in rainfall-runoff
relations poses the possibility of important alterations in
the stability of downstream channels. To the extent that
an altered vegetative cover increases the sediment content,
downstream channels tend to aggrade, flood hazards are
increased and the life of storage reservoirs is impaired by
higher rates of sediment deposition.

The problems posed by the differing rates of develop-
mont of various portions of a drainage basin is illus-
trated by an interstate agreement relative to the water of
the Colorado River. In the early 1920s the various states
concerned with the water of the Colorado basin agreed
to a division of water between the upstream and the down-
stream states. This compact arrangement was an effort to
reserve for the upper states the right to develop their
share of the water at some time in the future, long after
the needs of the downstream states had made it econ-
onomically feasible to develop the share allocated to them.
But with passage of time and mounting water demand,
not all terms of the compact are entirely clear. Estimates
of available water tend to change with longer records.

Whereas the compact dealt principally with average con-
ditions, an unresolved problem of growing importance is
an equitable sharing of the consequences of periods of de-
cific streamflow. The interplay of these factors led to
legal action.

Another problem of considerable importance has de-
veloped as a result of the combination of free enterprise,
governed principally by local economic factors and by the
legal doctrine of appropriated rights. In an attempt to
improve forage conditions for grazing, to prevent erosion,
or for recreation, upstream users have developed over a
period of time small surface-water reservoirs, tanks or
ponds. By land management practices upstream users have
also attempted to utilize soil moisture as completely as
possible for improvement in the vegetative cover. Research
results are too incomplete to forecast the effects of such
measures on water yield downstream. Downstream users fear that the installation of such small reservoirs and the manipulation of vegetal cover will decrease the total amount of water yielded to downstream areas. Therefore, they have attempted in several ways to forestall the construction of small upstream reservoirs and even the construction of works designed primarily to control sediment production and prevent erosion.

It has been the view of ecologists that the water from small local rains does not appreciably contribute to the water yield to downstream areas. The water from small and local rains tends merely to moisten the surface layers of the soils and this moisture returns to the atmosphere by direct evaporation or by the transpiration of local vegetation. In this view, increased use of soil moisture by improved local vegetative cover would have no adverse effect on downstream water yield.

Many of these problems come about from a basic attribute of the arid and semi-arid lands in the United States which is not characteristic of certain other extensive arid areas. Except in the true desert, which constitutes only a relatively small proportion of the arid portions of this country, much of the semi-arid region is characterized by a basin and range topography. Relatively high mountains jut out of extensive plains.

In such topography the main sources of water are from the precipitation which falls on the elevated mountain areas; but the low-lying alluvial basins constitute the areas topographically best suited to water utilization. Water eventually reaching the flat-lying areas downstream is derived principally from winter snows in the mountains. Both the mountain areas and the alluvial basins are characterized in summer by rainfall of the thunderstorm type which tends to be local, high in intensity, and therefore capable of producing flash floods high in sediment load.

In contrast, arid zones which are dependent mostly on local rainfall and not blessed with perennial runoff from elevated mountain regions pose quite different problems. In the latter landscape, it is a reasonable and practical philosophy that the most economical practice would be to use the water locally rather than in downstream areas. In such areas evaporation losses tend to be high, transmission losses are usually important, and thus the storage of such moisture in surface reservoirs is apt to be inefficient.

This conclusion was apparently reached by nearly all primitive people living in such areas, for we there see the remnants of elaborate systems of water spreading and local sediment control. The purpose of such structures was to control the runoff from local storms, leading it to deposit sediment, either where the deposition would do some good or would do the least harm, and as quickly as possible to infiltrate this water into the soil where it could be utilized as soil moisture. Some of this local runoff was led into underground cisterns after having gone through structures designed to eliminate most of the sediment load.

At present, there is a tendency in several countries to take the view that such storm runoff should be stored in surface reservoirs and led through pipes or canals to areas some distance from the catchment to be used for irrigation, industry or municipal supplies. The system has the advantage of being capable of supporting relatively large urban areas. Also the water can be applied to land best suited for irrigation. In contrast, the local utilization of water from infrequent storms requires a dispersed population and the application of water to topographic units and soil units which may not be the best from the standpoint of plant production. A much larger amount of water, however, can actually be applied to useful ends when it is applied locally.

It is evident that, in the United States, the philosophy of utilizing water at or near the place where it originated did not suit the local conditions. As a result of this heritage, it is now difficult for downstream users to accept the philosophy that some of the water, that which comes in small and local storms, might best be used locally. The downstream user tends to apply to the local sporadic rainfalls the same reasoning which applies to the general winter storms in the mountainous areas. He finds it difficult to believe that he gets no water yield from them.

In brief, the major part of arid and semi-arid United States is characterized by local mountain ranges which receive much higher total precipitation than the adjacent alluvial basins. The principal precipitation which leads to water yield downstream is that which occurs as low-intensity rainfall and snowfall in the winter months. The mountain masses produce perennial streams which, before the incursion of modern man, flowed long distances into the much drier alluvial valleys.

It developed, therefore, that both urban and irrigation
use centered in downstream valleys and depended upon water which fell as precipitation far upstream. The system of development was materially influenced by a national doctrine of free enterprise and, therefore, the extent and limit of water development was determined principally by economic feasibility. This general scheme was aided by a legal doctrine of appropriated rights based on the longevity of beneficial use.

It can be seen that under these circumstances it would be nearly impossible to apply any broad regional plan for the supposedly most economical development of the available water resources. Regional development has been orderly only in that water use has proceeded only as fast as economic and social conditions permitted.

Two problems of outstanding importance accompanied this pattern of development:

First, aridity is characterized by extreme variability of the rainfall. The consequences of this variability are usually submerged by excessive concern with averages and average conditions. In a democracy such as the United States water development is but little controlled by any general or regional plan, and proceeds wherever need exists and economic forces make such development practical. As a result, expansion of water demand may occur during a few years of favorable precipitation. But the economy is then quite unprepared for the stringency of succeeding periods of low precipitation which must, perforce, follow. Drought periods then have extraordinary consequences—economic recession, disruption of business, exodus of people from marginal lands and often deterioration of soil resources by wind erosion.

The experience in the United States underscores the necessity of devising, wherever possible, plans for water development which include practical and acceptable schemes for maintaining the stability of people and their economy during the inevitable periods of low precipitation. In this respect, I am thinking of plans beyond the mere provision of hold-over storage. Even in the western United States where water storage is highly developed, the economy is still singularly vulnerable to long periods of drought. It expands without curb during favorable periods and is unprepared for extended droughts.

Second, ground-water storage is used with little thought of the long-term relation of recharge to withdrawal. Adequate investigation is time consuming and thus facts are usually not available for planning. As a result, development of ground water proceeds as with surface water, wherever need exists and economic forces make water development financially feasible. Ground water is thus mined in many places with little concern for some future time when the pumping lift increases beyond the limit of economic feasibility or when the supply might be exhausted.

More consideration needs to be given to the use of ground water reserves as a buffer to tide over the dry periods when a deficiency of surface water occurs. At present, ground-water storage reserves are used with the same impunity as are those of the fluctuating surface water.