

WATER AND THE ARID ZONE OF THE UNITED STATES

by

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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 a mean elevation of about 6,000 feet, has at present an annual precipitation of about 14 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 between 20 and 24 inches. Lakes existed during Pleistocene time in many places in the western United States that are now true deserts—with a precipitation of less than 4 inches—and there is abundant evidence that early man lived on the shores of these lakes. He must have adapted himself to the increasing aridity; this adaptation can be seen even at present in the form of floodwater farming practices, which have been highly developed by the Hopi Indians, particularly in northeastern Arizona.

A gradually changing climate is only one, and not the most important, of the changing conditions to which man must gradually adjust in his particular relation to the use of water. The changes in his own culture in conjunction with changes 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, the remains of irrigation systems developed by the aborigines to irrigate the alluvial valley floor with water diverted from the Gila River, which was at that time perennial, have been mapped and partially excavated. Irrigated agriculture was not practised nearly so extensively in the arid portions of the United States as in Persia, India, and many Mediterranean countries, nor was the general culture of indigenous American tribes so highly developed. Even in the simple cultures of the American Indians patterns of adjustment to a changing climate and to a changing culture and population level can be discerned. These patterns include,

however crudely, the development of irrigated agriculture, floodwater 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, can be seen to have characterized the adjustment of modern culture to the limited water supplies of the arid climates, even including the prayers and rattles.

An aspect of the development of American culture in the arid areas is probably typical and may have a counterpart in certain of the underdeveloped areas in other parts of the world at the present time. 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 have developed in other climes. The cultural advances in the Fertile Crescent of Mesopotamia were gradually influenced by the barbarian invasion, which added much to, as well as detracted from, the locally developing society. Similarly the spurt of civilization which has characterized the arid parts of the United States since 1846 was determined by the superposition of a culture from the eastern United States on the essentially Spanish culture which had been developing since the initial exploration of the southwestern desert 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 carry-over 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 these works and systems.

The *major-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 labour 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—necessary to supplement the agricultural products, beans, melons, corn, and chili.

The mid-nineteenth century marks the beginning of the rapid changes which took place in the arid southwestern portion of the 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, by the completion of a trans-continental railroad and by the Homestead Act, under which 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 with individual years of extraordinarily heavy precipitation. Detailed analyses of the weather records indicate also that during this decade a change occurred in the relative frequency of small and large individual rainstorms. Between 1850 and 1880 a relatively large number of heavy rains occurred compared with later decades. Intense individual rainstorms, individual years of exceptionally high precipitation, and concentration of livestock coincided in time 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 soil erosion wrought important changes in the economy, not only because of a qualitative degradation of the grazing resource but also through the effect of the eroded debris 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 practised by the construction of simple diversion structures was no longer possible without engineering works too complex for the local inhabitants to build. The erosion epicycle and the degradation of the range so increased the hazard of stockraising 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 twentieth century the construction of a series of large dams to stabilize and promote irrigation. It was irrigation that built the centres of population in the semi-arid states, though mining, stockraising, 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 important adjunct to this legal doctrine is the dissociation of a given parcel of land from a given water right. Later it could develop 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 groundwater rather than to surface streams for their 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 for resource use. 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 groundwater was developed to serve population centres where a surface supply was either not available or was already appropriated. But the speed, location, and type of development were dictated by an evolving interaction between social and economic factors.

Then came the second world war. 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 favourable 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 pre-war 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. Pertinent water rights were needed both for the urban growth and for the industrial expansion. Therefore near centres 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 gradual decrease in the cost of power and the availability of new equipment made it possible to draw groundwater in larger volume and from greater depths than had ever been possible prior to the widespread use of the centrifugal pump.

The national policy relative to farming in general also had an important impact on water-resource development. In order to provide more stability to agricultural enterprise, prices of certain crops were guaranteed by the government. These artificially high prices made, and continue to make, certain agricultural crops profitable which would not be so without a federal subsidy. In some areas, for example where cotton is the principal crop, groundwater can be pumped from considerable depths at a financial profit, whereas without price support for the product the pumping lifts would make cotton-raising in the area uneconomic.

The post-war development, characterized by industrialization and urbanization, similarly demonstrates that water development was dictated in location, amount, and kind by the economic and social forces extant. 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 in the physical sense. In other words, all the available water is being put to use and, furthermore, in many areas the present use of groundwater cannot continue indefinitely because withdrawal is already exceeding recharge. On the desert fringes of some larger urban centres, home sites are being built in large numbers even where no water is available. Some home sites are self-supplied with wells tapping groundwater reserves emplaced during late Pleistocene time and for which the present recharge is negligible.

The history of water development in semi-arid areas in the United States exemplifies how problems evolve. One of the problems comes about 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 which are near and surround areas of urban expansion before more isolated upstream areas are developed either for intensive agriculture, industrialization, or urbanization. If the water supply is limited, upstream areas may be effectively prevented from reaching maximum potential owing to the fact that water passing through or origi-

nating on the upstream areas has previously been appropriated.

A potential danger in any arid area results from the inherent variability of the water resource. During a decade of relatively high water yield, i.e., favourable precipitation, water will be put to beneficial use in downstream areas and an initial right to water will be established. In succeeding decades of deficient precipitation all of these rights cannot be fulfilled owing to lack of sufficient resource. There has been an over-expansion of irrigated agriculture that cannot permanently be sustained. Little recognition is paid to the fact that one of the attributes of an arid area is the variability of the water resource.

As a result, areas which have the most junior or youngest right to water will seek all possible means to guarantee the production of water to fulfil those rights even during years of low precipitation. Various schemes for increasing water yield will therefore be promulgated. In the semi-arid states experiments are now being conducted to try to increase the total downstream yield of water by the decrease of evapotranspiration losses in upstream areas. Some headwater areas are being cleared of native woodland vegetation which consists of species of pine and juniper. When the woodland species have been eliminated by poisoning, burning, and grubbing, the area is seeded to grass in the hope that the grass will, over a period of time, cause a smaller evapotranspiration loss than did the woodland. Other techniques include selective logging or controlled burning of headwater forests with the multiple 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 desired by some groups even before research has demonstrated the efficacy of the practice. Woodland clearing is also desired for improved grazing forage. Introduced grass would supposedly have a local advantage in increasing the total available forage.

The manipulation of native vegetation poses certain difficulties. For example, there is the question whether an artificial plant association introduced by man under particular circumstances can, over a long period of time, continue to be both stable and productive. There is also a problem caused by the fact that in the semi-arid parts of the United States the highland areas, which are the sources of water yield, have a particular value for watershed protection and for recreation. The native vegetative cover was so disturbed by grazing and fire that erosion had become an important land-use problem by the turn of the present century. Whether under a condition of altered vegetation, sediment production could be controlled is open to question. In addition to the possibility of serious sheet and gully erosion in upstream areas, the change in rainfall run-off 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 increased rates of sediment deposition.

Problems posed by the differing rates of development of various portions of a drainage basin are illustrated 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 downstream 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 economically feasible to develop the share allocated to the downstream users. But with the passage of time and the mounting water demand, all terms of the compact are not entirely clear. Estimates of available water tend to change with longer records. Whereas the compact dealt principally with average conditions, an unresolved problem of growing importance is an equitable sharing of the consequences of periods of deficient streamflow. The interplay of these factors led to legal action in an attempt to resolve the difficulties.

Another problem of considerable importance has developed 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, for the prevention of 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 soil 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 affect 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 that is not characteristic of certain other extensive areas of the arid zone. Except in the true desert, which constitutes only a relatively small proportion of the arid portions of this country, much of the semi-arid area is characterized by a basin and range topography. Relatively high mountains jut out of extensive plains. The main features of such topography are determined by fault blocks which, when downthrown, comprise the alluvial basins and when upthrown, comprise the mountain ranges.

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 in areal extent, 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 run-off from elevated mountain regions pose quite different problems. In the latter type of physiography it is a reasonable and practical philosophy that the most economical use of water would be to use it locally rather than in downstream areas. That is, in the absence of perennial streams rising in mountain ranges water falling sporadically on arid areas might best be used as soil moisture to grow vegetation or to support stock on or near the areas where the precipitation fell. In such areas evaporation losses tend to be high, transmission losses are usually important, and thus the storage of such moisture in surface reservoirs tends to be inefficient.

This conclusion was apparently reached by nearly all primitive people living in such areas, for we see the remnants of elaborate systems of water-spreading and local sediment control. The purpose of such structures was to control the run-off from local storms, leading it to deposit sediment either where it would do some good or where it 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 run-off was led into underground cisterns after having gone through structures designed to eliminate most of the sediment load.

At the present time there is a tendency in several countries to take a somewhat different view, i.e., that storm run-off 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 latter 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 and soil units which may not be the best from the standpoint of plant production. However, a much larger amount of water can actually be applied to useful ends when applied locally.

It can be seen 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. The downstream user finds it difficult to believe that he gets no water yield from these sporadic local storms. The status of research is such that quantitative evaluation of the alternatives is not possible. Nor has research shown how various conditions of topography, vegetation, and rainfall affect the disposition of precipitation.

To summarize, the major part of arid and semi-arid areas of the 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 centred 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 of development was both enhanced and aided by a legal doctrine of appropriated rights based on the longevity of beneficial use.

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

Two problems of outstanding importance accompanied this pattern of development. These are sufficiently general that they can probably be seen with minor differences in many arid areas.

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 where and when social and economic forces make such development practical. As a result, expansion of water demand may occur during a few years of favourable 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 below average 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 favourable periods and is unprepared for extended droughts without serious economic and social dislocations.

Second, groundwater storage is used with little consideration of the long-term relation of recharge to withdrawal. Adequate hydrologic investigation is time-consuming and thus facts are usually not available to form the basis for planning. As a result, development of groundwater proceeds as with surface water, wherever need exists and economic forces make water development financially feasible. Groundwater 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 groundwater reserves as a buffer to tide over the dry periods when a deficiency of surface water occurs. In contrast, groundwater storage reserves are used with the same impunity as are the fluctuating surface water reserves.