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SYMPOSIUM ON PHREATOPHYTES

PHREATOPHYTES AND THEIR RELATION TO WATER IN WESTERN UNITED STATES

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Abstract--Phreatophytes, plants that depend on ground water for their water supply, cover about 15 million acres in the 17 western states, and may waste as much as 20 to 25 million ac ft of water into the atmosphere annually. There are many variable factors that affect the growth and use of water by the plants, but present-day knowledge of them is limited. The water used by these plants probably represents the largest source of reclaimable water in the arid western United States. Although it appears feasible to salvage a part of this water, methods for doing so have not passed the experimental stage. In Nevada, it is estimated that it would be practical to salvage about 25 pct of the water wasted annually, or about 400,000 ac ft. This would be sufficient to irrigate about 133,000 acres of alfalfa having a crop value of $10,000,000.

In the arid and semiarid regions of western United States, the close association of certain plants with areas in which the water table is at shallow depth is well known. MEINZER [1927] gave the name "phreatophytes" to this group of plants. He defined phreatophytes as "plants that habitually grow where they can send their roots down to the water table, or the capillary fringe immediately overlying the water table, and are then able to obtain a perennial and secure supply of water." The term was derived from two Greek roots and means a "well plant."

It may be desirable to point out here that phreatophytes do not belong to any particular genus or even any one family of plants. Indeed, they are made up of many species belonging to different plant families. They have only one common characteristic and that is their typical dependence on ground water for their water supply. The list of known phreatophytes is quite long and, although probably not complete, includes about 50 plant species and several times that number of subspecies. The most important and widespread species are saltcedar, baccharis, greasewood, rabbitbrush, saltgrass, willow, cottonwood, mesquite, and alfalfa. Of this group only alfalfa is important in agriculture. The rest are all indigenous to the United States, with the exception of saltcedar which is a native of the Mediterranean region, whence it was imported to this country about 35 years ago.

Through transpiration these plants discharge large quantities of ground water into the atmosphere. In areas where the water table is so shallow that the capillary fringe extends to the land surface, there is discharge of ground water by evaporation from the soil also. Transpiration and soil evaporation are so closely associated that it is difficult to determine separately the quantity of water discharged by each. For this reason the two are commonly referred to as a single process, evapotranspiration.

Phreatophytes may be contrasted with xerophytes (from the Greek root meaning "dry plant"), desert plants that are not associated with the water table and do not depend on it for their water supply. Xerophytes maintain themselves on the small amount of water that gets to them from infrequent rains. During prolonged drought periods they are nearly dormant.

Phreatophytes use many times the quantity of water used by xerophytes. Unfortunately, however, most of the ground water, except that used by alfalfa, is not beneficially used or is only slightly so. In western United States the area of phreatophytes, excluding alfalfa, is reckoned in millions of acres. The water used by these plants probably represents the largest source of reclaimable water in that region. It is to the economic interest of this region that, where feasible, at least a part of the ground water now virtually wasted be utilized efficiently. This is especially true in this day of high water costs.

The quantity of water used by the different species varies widely. As an example, WHITE [1932] estimated from experimental data that the annual ground-water discharge by an association of greasewood, rabbitbrush, and shadscale in Escalante Valley, Utah, where the water table was 8 to 30 ft below the land surface, was about two inches per year. At the other extreme, it was estimated from experimental data that the annual discharge by saltcedar growing in areas of shallow water table under very favorable conditions, in Safford Valley, Arizona, was about seven feet per year [GATEWOOD and Others, 1950].

Therefore, before attempts are made to salvage or to utilize more efficiently the water discharged by phreatophytes it is important to know within reasonable limits the quantity of water used by the plants annually in the area concerned. The determination of this quantity is based upon two primary factors, namely, the annual rate of use by the different phreatophytes and the area covered by the plants. The area usually is not difficult to ascertain, but the annual rate of use varies not only with the species but with variable factors that control the growth of the species.

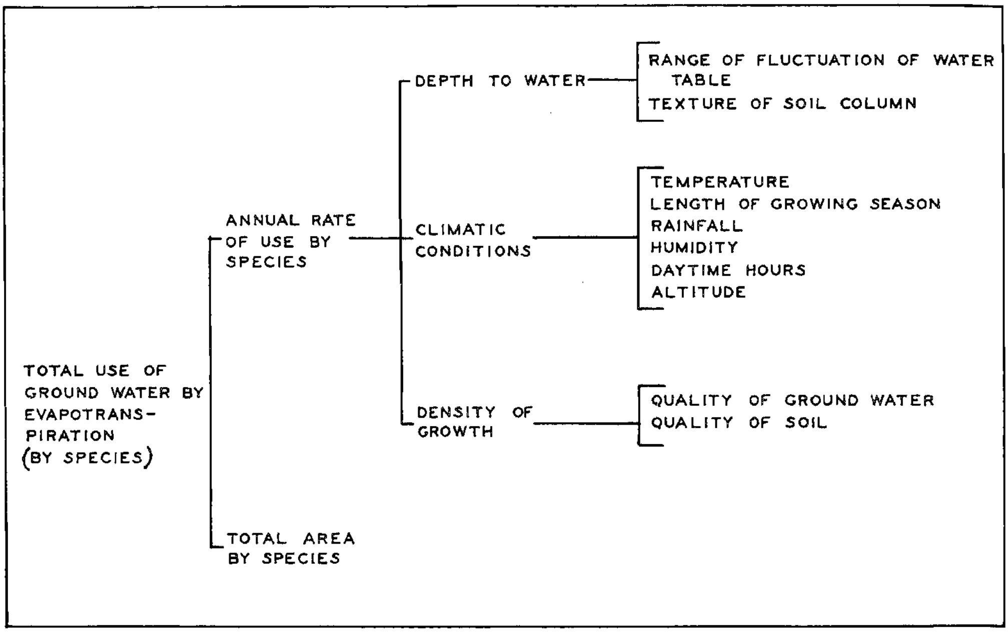

Fig. 1--Factors that may affect the evapotranspiration of ground water for each species of phreatophytes

Figure 1 is an attempt to show graphically the factors that may affect discharge of ground water by evapotranspiration in areas of phreatophyte growth. The following discussion will outline briefly the effects of these factors as they control or influence the growth of plants and the use of ground water by them. Not all the species, however, are necessarily affected by all the factors. Present knowledge of these factors is limited and, although some progress has been made, a great deal remains to be learned.

In general, the greater the depth to water the lower the rate of water use. For some species the depth of the water table is the controlling factor in the growth of the plant. Tules grow only in water or where the water table is shallow, usually less than one foot below the land surface. Saltgrass, as a rule, does not thrive where the depth to water exceeds six to eight feet, although it has been observed growing where the depth was 11 to 12 feet [BLANEY, 1933, p. 150]. On the other hand, deep-rooted plants such as mesquite and alfalfa have been known to send their roots 40, 50, and in a few instances more than 100 ft in search of ground water. Greasewood usually thrives best where the depth to water does not exceed 15 ft, although it grows in some places where the depth is greater. An extreme depth of 80 ft was noted in Goshute Valley, Nevada, where greasewood was observed growing. Saltcedar, baccharis, willow, and cottonwood appear to prefer localities where the depth to water does not exceed 20 ft. Although no surveys have been made, observations indicate that the bulk of the ground water discharged by phreatophytes occurs in areas where the depth to water is less than 20 ft, and possibly less than 15 ft.

In areas where the water is shallow the texture of the soil affects the rate of evaporation from the soil by controlling the height of the capillary fringe. In soils of fine texture the height of the capillary fringe is greater than in soils of coarse texture. Thus for a given depth to water the capillary fringe may extend to the land surface where the soil texture is fine but fail to do so where the texture is coarse. All other factors being equal, the opportunity for evaporation from the soil is greatest where the soil texture is fine.

Climatic conditions exert a controlling influence on the occurrence of some species but not of others. Saltcedar, for instance, prefers a moderate to low altitude and a warm climate and is confined almost entirely to southwestern United States. It thrives best south of the 37th parallel and below 5000 ft. Saltcedar plants several years old in the vicinity of Carson City and Fallon, Nevada (lat. 39°N, and altitude a little over 4000 ft), are not aggressive in spreading over the land, nor do they exhibit the vigorous junglelike growth so common to the plant in the valleys of central and southern Arizona and New Mexico. Yet at this locality in Nevada the ground-water conditions are otherwise favorable for saltcedar growth. Other phreatophytes, particularly cottonwood, willow, saltgrass, and greasewood, grow abundantly.

In addition to saltcedar, mesquite and baccharis also do not grow much farther north than the 37th parallel or at an altitude above 5000 ft. In contrast to these three plants is greasewood, whose southern limit of growth is at about this latitude. Species that apparently are relatively unaffected by climatic conditions include cottonwood, willow, saltgrass, and alfalfa. In western United States, from Canada to Mexico, where ground-water conditions are favorable these plants thrive at altitudes ranging from 8000 ft to sea level.

The other climatic factors that affect rate of use of ground water are length of growing season, daytime hours, rainfall, and humidity. It has been found that the draft on ground water is greatest when the growing season and daylight hours are long, when the rainfall is scanty, and when the relative humidity is low.

Density of growth is a controlling factor in the use of water by phreatophytes. Field studies in Safford Valley, Arizona, in 1943-44, indicated that there are two variables with respect to density of growth, areal density and vertical density, and their product is termed "volume density." Areal density relates to the numerical density of the plants in a unit area with respect to the maximum possible, and vertical density relates to the vertical depth of fronds with respect to the maximum possible. As plant growth is a function of sunlight, density of growth and depth of frondage are apparently limited by the amount of sunlight that penetrates to the most remote foliage. It was found in the Safford Valley that use of water by saltcedar, cottonwood, and baccharis varied directly as the volume density. The amount of water used by phreatophytes, then, depends upon the thickness of growth and the amount of foliage on individual plants.

Data obtained in the Safford Valley indicate also that the quality of the water has an effect on plant growth and rate of use of ground water. In general, plants tend to use less water and to grow less vigorously as the mineral content of the water increases. Some species of phreatophytes, particularly willow, cottonwood, rabbitbrush, and alfalfa, do not grow where the mineral of the water is high. On the other hand, saltcedar, greasewood, and saltgrass have a high tolerance for mineralized water.

An inventory of the water resources of a region to be complete must include the discharge of ground water by evapotranspiration. In order to include it a working knowledge of the factors discussed is necessary. The process of evapotranspiration affects the flow of the streams and the storage of water in underground reservoirs. It is a well-known fact that during the growing season there is a daily fluctuation in the flow of western streams not affected by diversion or other regulation. These fluctuations are a measure of the rate at which water is withdrawn from the stream during a 24-hour period by riparian vegetation. In ground-water studies the quantity of water discharged by evapotranspiration is especially important. In closed basins the quantity so discharged marks the upper limit of the average annual amount of water that may be safely recovered from the valley. In open basins it is an index to the quantity that may be salvaged in addition to that which may be recovered by pumping that reduces the surface outflow or underflow from the basin.

Until 1948 no attempt had ever been made to obtain an overall picture of the area covered by phreatophytes or of the use of water by them in the 17 western states. In the autumn of 1948 the writer assembled all available data for this purpose. In 1951 estimates for two States, California and Utah, were revised on the basis of later information. The estimates are incomplete; nevertheless, they are believed sufficient to show the order of magnitude of the quantities involved. For the most part the figures for the quantity of water discharged by evapotranspiration are based on knowledge of the area, the plants, and the limited data on rate of use. These were compiled by men of the U. S. Geological Survey who were familiar with conditions in the various states. In this survey only those phreatophytes known to have a low beneficial use were included. Alfalfa, which has a high beneficial use, was excluded. The available estimates summarized by States are shown in Table 1.

Table 1--Data on occurrence of phreatophytes

State	Area	Annual use
	ac	ac ft
Arizona	400,000	1,375,000
California[a]	317,000	1,150,000
Colorado[a]	737,200	1,056,200
Idaho	500,000	1,000,000
Kansas	No data	No data
Montana	1,600,000	3,200,000
Nebraska[a]	515,000	709,000
Nevada	2,801,000	1,500,000
New Mexico	441,000	870,000
North Dakota	1,035,000	1,660,000
Oklahoma	No data	No data
Oregon[a]	40,800	21,200
South Dakota	850,000	1,240,000
Texas[a]	262,000	436,500
Utah	1,200,000	1,500,000
Washington	No data	No data
Wyoming	No data	No data
Totals approximate[a]	10,700,000	15,700,000

[a]Partial data.

It must be emphasized that the data in the table are incomplete. For about one-fourth of the States there are no data and for another one-fourth only partial data. As a result, the grand total is a minimum that may be in error on the low side by 50 to 75 pct. Probably the total area of phreatophytes is of the magnitude of 15,000,000 acres. If this figure is reasonably correct, the total use of water may be estimated. Assuming that the ratio of acres to acre-feet in the grand totals is representative, then the total use would be between 20 and 25 million acre feet annually. In order to visualize a little more clearly the magnitude of this amount of water, it may be stated in terms of flow or volume. It is equivalent to about twice the average annual flow of the Colorado River at Lees Ferry for the 25-year period 1921-45, or, expressed in another way, it is equivalent to about 75 pct of the total storage capacity of Lake Mead.

In the arid and semiarid regions of western United States, where water is the ''bread and butter'' of the land, the virtual waste of this immense quantity is certainly ''food'' for thought. What, then? Obviously it is not possible to salvage all the water wasted, but the potentialities and the rewards of success are sufficient to warrant a thorough investigation and study of the problem of ground-water salvage.

Here again is a dearth of information. As far as the writer is aware, it is only within the last five years that attention has been given to developing practical methods for salvaging on a large scale the ground water lost in areas of phreatophyte growth. Salvage operations may be divided into (1) reduction of waste, (2) increased efficiency of use, and (3) a combination of these methods. Each has its problems.

One obvious way of reducing waste would be to destroy the vegetation. Destroying some species of vegetation, however, is not a simple task. In the Safford Valley of Arizona attempts were made to destroy saltcedar by burning, using flame throwers. The operation was successful in killing the trunk and limbs but not the root, for by midsummer of the following year new growth had attained a height of five to six feet. Uprooting also was tried, using heavy mechanical equipment to rip the plants out of the ground. The operation would have been successful if all the roots could have been removed. This was not the case and soon new growth appeared from the end of each severed root, so that two plants grew where one had grown before. In one test plot the saltcedar was cut off just above the ground. Three months after cutting the new growth had reached a height of 2 1/2 ft. Experiments by the Bureau of Reclamation in 1948 and 1949 above McMillan Reservoir in New Mexico were quite successful. They involved spraying tracts of salt cedar with the chemical 2, 4-D. Thus this method is a promising and inexpensive one for destroying saltcedar, and perhaps willow also, which is similar to saltcedar in resisting destruction.

Even when the plant is successfully destroyed there is a question whether a saving of water will be effected under certain conditions. In areas where the capillary fringe is at or near the land surface the rise of the water table resulting from the decrease of evapotranspiration may bring the water so close to the surface that the discharge by soil evaporation will increase and possibly equal the former discharge by evapotranspiration. On the other hand, where the water table is sufficiently deep that the capillary fringe does not extend to the land surface and the plants intercept only a part of the ground water as it moves down gradient to a point of ground-water discharge, the method should be quite successful.

Lowering the water table in the area of evapotranspiration discharge either by pumping or by drainage is another method of reducing waste. To be successful, however, the drainage should be rapid so that the plants will die for lack of water; otherwise, the plant roots will keep pace with the declining water table and keep the plant alive until conditions are again stable. In materials of low permeability, where drainage is slow, it is doubtful if this method would be successful, although the draft by the plants would be reduced.

Intercepting ground water up gradient from the area of plant discharge also reduces waste. In fact, this method is unwittingly practiced in some of the closed valleys in Nevada. In many of these valleys, where the lowest part of the valley floor is covered with phreatophytes, the soil is too alkaline for agricultural development. Up slope from the area of phreatophytes, where the soil is suitable for the raising of crops, wells have been drilled and the water pumped for irrigation. As the ground water migrates from the sides toward the lowest part of the valley, some of the water that would otherwise have been discharged by the plants is thus diverted for irrigation. In Nevada, this practice is quite recent, and has resulted from a desire to put more land under irrigation, but with no realization that it was also a salvage operation. Although limited to areas where conditions are favorable, this method holds a great deal of promise.

The efficiency of use of ground water may be increased by substituting, in the area of discharge, plants having higher economic value. Generally this means substituting one phreatophyte for another. Forage crops, particularly alfalfa and grasses, seem best adapted for this purpose. In the Escalante Valley of Utah, alfalfa was successfully substituted for an association of greasewood, rabbitbrush, and saltgrass. There are doubtless other areas, particularly on the flood plains of some rivers and on the floors of open valleys, where the method would prove successful. The advantage of this method lies in the fact that, once the substituted plant has established itself, irrigation cost becomes negligible for the plant pumps its own water.

An indication of the economic value of salvaging the ground water wasted by non-beneficial vegetation is provided by the State of Nevada. The estimate of evapotranspiration discharge in Nevada is 1,500,000 acre feet per year. Of this amount about 25 pct, or 400,000 acre feet, is estimated to be salvageable. If this water were utilized in growing alfalfa, which has an irrigation requirement of about three acre feet per acre per year, it would be sufficient to irrigate about 133,000 acres. It is conservatively estimated that the average yield of alfalfa in Nevada is about three tons per acre. At the average price of $25 per ton, prevailing for the past three years, the gross value of 400,000 acre feet of water is $10,000,000.

In Arizona, where it is estimated about 700,000 acre feet of water is salvageable, and where crops of higher value may be grown, the gross value of the salvageable water could easily be 20 to 25 million dollars. Much the same situation exists in the other western states. It seems that the reward for salvaging at least a part of this wasted water would justify intensive effort involved.

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DETERMINING EVAPOTRANSPIRATION BY PHREATOPHYTES FROM CLIMATOLOGICAL DATA

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Abstract--Before the available water resources of a drainage basin in arid and semi-arid regions can be satisfactorily ascertained, careful consideration must be given to the consumptive water requirements of phreatophytes (or water-loving vegetation) and other types of natural vegetation and agricultural crops. The moisture requirements of natural vegetation are usually satisfied before water becomes available for irrigation and other purposes. Although evapotranspiration (consumptive use) by phreatophytes has been measured at various times and places during the past 40 years, very little data are available