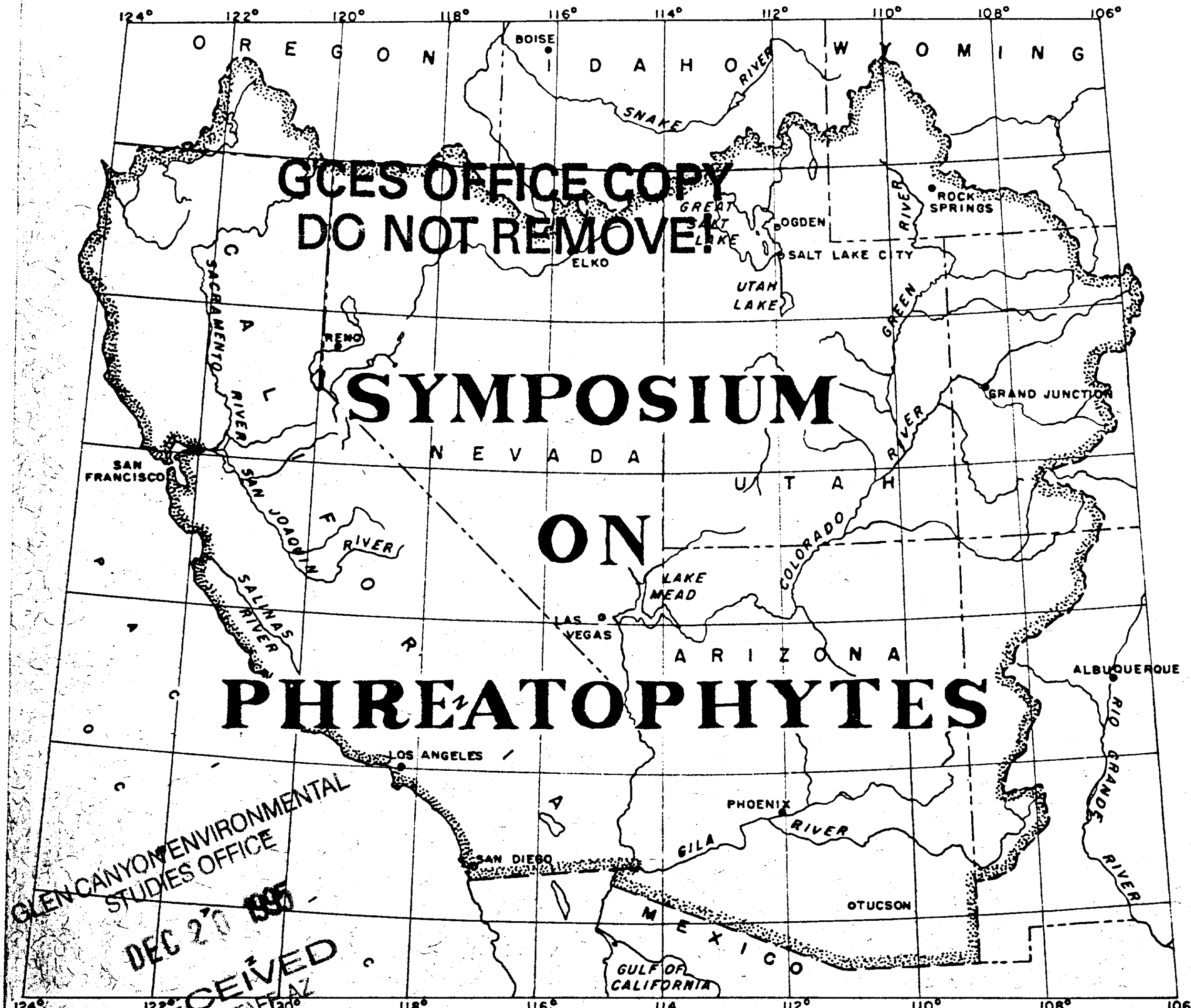
SYMPOSIUM ON PHREATOPHYTES



PACIFIC SOUTHWEST REGION

PHREATOPHYTE SUBCOMMITTEE OF PACIFIC SOUTHWEST INTER-AGENCY COMMITTEE

Presented at Pacific Southwest Regional Meeting
American Geophysical Union
February 14, 15, 1957, Sacramento, California

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ABSTRACT

Phreatophytes, plants that depend on groundwater for their water supply, adversely affect the water supply of arid regions. In Western United States these plants waste large amounts of groundwater that would otherwise be available for irrigation or municipal use. Some species, because of their dense growth along stream channels, are a flood hazard. Most species of phreatophytes are indigenous to the United States, although a few have been introduced from the Old World. The most notable of these, saltcedar (Tamarix sp.), has created a serious problem in Southwestern United States through its high rate of water consumption, its dense growth, and its aggressiveness in spreading along stream channels and in flood plains. Much time, effort, and funds have and are being expended to control and eradicate the plant in order to salvage water and to maintain floodways. The two common methods used to control the plant, by mechanical means and by spraying with herbicides, have not been entirely successful and are expensive.

In densely overgrown streamways, such as the Rio Grande, channelization and drainage have been effective in salvaging groundwater. In order to evaluate the amount of salvage following clearing operations it is necessary to know the rate of use by the plants under undisturbed conditions of growth. One promising line of research in determining plant use of water is the relation of pan evaporation to evapotranspiration under field conditions. In the laboratory, transpiration rates of potted plants (eucalyptus and tamarisk) have been measured by the infrared gas analyzer. There is promise this instrument can be adapted for field use. Salvage of water can be accomplished by substituting plants of economic value for the unbeneficial phreatophyte plants. Research is needed to find adaptable plants for this purpose.

THE PHREATOPHYTE PROBLEM

By T. W. Robinson 1/

ABSTRACT

The phreatophyte problem is a water resource problem of special concern to the arid and semiarid regions of the Western United States, where large quantities of groundwater are consumptively wasted by phreatophytes. In the Western United States there are about 80 species of phreatophytes--plants that depend upon groundwater for their water requirements. These plants, which cover nearly 17 million acres in the Western States, reduce the water available to man by an estimated 25 million acre-feet a year. Water use by the plants is greatest where the water table is shallow, the climate warm and the growth dense. Consumptive waste, which is defined as that part of consumptive use that is without considerable benefit to man, may be salvaged by converting consumptive waste to consumptive use.

Some phreatophytes pose a flood hazard and induce sedimentation because of the reduced velocity caused by dense growth that chokes river overflow channels and floodways. Dense growths immediately above a storage reservoir may act as a desilting agent and prolong the life of the reservoir, but the cost in terms of both water loss and flood hazard may be excessive.

Ten questions dealing with the phreatophyte problem are listed for which research should be continued and expanded.

* * *

The phreatophyte problem, in brief, involves the consumptive waste of groundwater by a group of plants known as phreatophytes. It is a water resource problem of particular concern to the arid and semiarid regions of the Western United States, particularly the Southwest. It involves the discharge by evapotranspiration of large quantities of groundwater by phreatophytes of low, or negative, economic value. Since about the beginning of World War II the phreatophyte problem has been growing in magnitude, and during the past decade it has been brought into sharp focus by three unrelated developments. One is the prolonged drought of the Southwest beginning in 1942, the second is a fast-growing population, and the third has been the rapid spread of a phreatophyte, salt cedar, throughout the stream valleys of the Southwest. This combination of increasing water requirements and a decreasing water supply has naturally been viewed with concern and has focused attention on possibilities for the conservation and salvage of water.

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The problem is better understood and appreciated through some knowledge of phreatophytes, their relation to other desert plants, and the manner in which they affect the water supply. The name "phreatophyte" was given by Meinzer (1923, p. 55) to a group of plants that tap groundwater and habitually depend on it for their water supply. The name is derived from the Greek and means "well plant". This is a very apt description, for each plant may be thought of as a miniature pump, supplying its daily needs from the groundwater reservoir.

Not all the plants that occur in arid regions, however, are phreatophytes. There is another large group called xerophytes (meaning "dry plants"), which differ from phreatophytes in that they obtain their water supply exclusively from soil moisture. The distinction between phreatophytes and xerophytes with respect to their sources of water supply under natural conditions is shown in Figure 1. It is important that this distinction be kept in mind when dealing with the phreatophyte problem. Phreatophytes are commonly found lining the banks of streams, on flood plains, or in valley bottoms--places where the water table lies at shallow depth. Xerophytes, on the other hand, grow where the water table lies at depths beyond the reach of their roots.

The manner in which phreatophytes affect the water supply of an arid region is best shown by referring to the hydrologic cycle, illustrated in Figure 2. In the endless cycle of water movement, through the atmosphere to the land and back to the atmosphere again, water moves as a vapor and as a liquid through a maze of overland and underground routes. In its earthbound passages, water may percolate to the groundwater reservoir through the soil column as soil water excess, or it may seep directly from lakes and streams. Water as soil moisture is not available to man in liquid form, for he cannot extract it from the soil. It is available to xerophytes, which extract it from the soil, and in so doing reduce the soil moisture and any soil water excess. Groundwater, on the other hand, is available to man, for he can extract it as a liquid by means of wells, tunnels, or ditches. It is available to the phreatophytes also.

Phreatophytes, by virtue of their direct root connection with the water table, have first call on the water. Unlike xerophytes, phreatophytes are not forced to limit their water consumption because of an insufficient water supply, but draw freely from the groundwater reservoir to the extent of their needs throughout the growing season. In Figure 2, depletion of the reservoir by evapotranspiration is shown by a reduction in the volume of groundwater in storage. As most phreatophytes are plants of low economic value, the water consumed by them produces little that is of benefit to man. Its use by phreatophytes is therefore termed consumptive waste. A reduction in the amount of water consumptively wasted will conserve and make available for man's use a perennial supply of water equal to the reduction. In the arid regions of the United States, the water consumptively wasted by phreatophytes is one source of potentially reclaimable water.

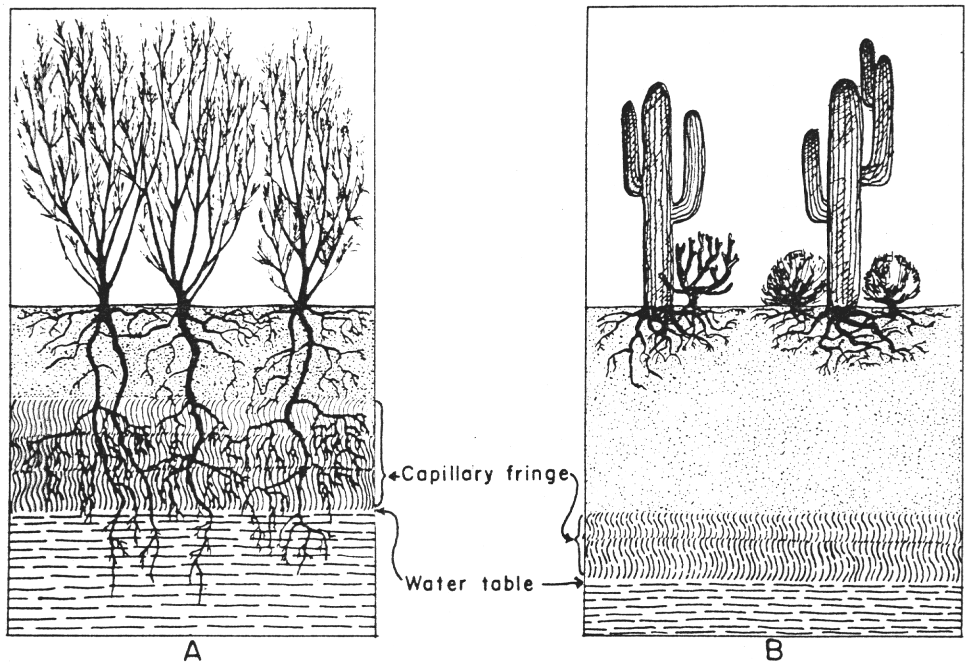

Figure 1.– Distinction between phreatophytes (A) and xerophytes (B) shown by their occurrence with respect to the water table.

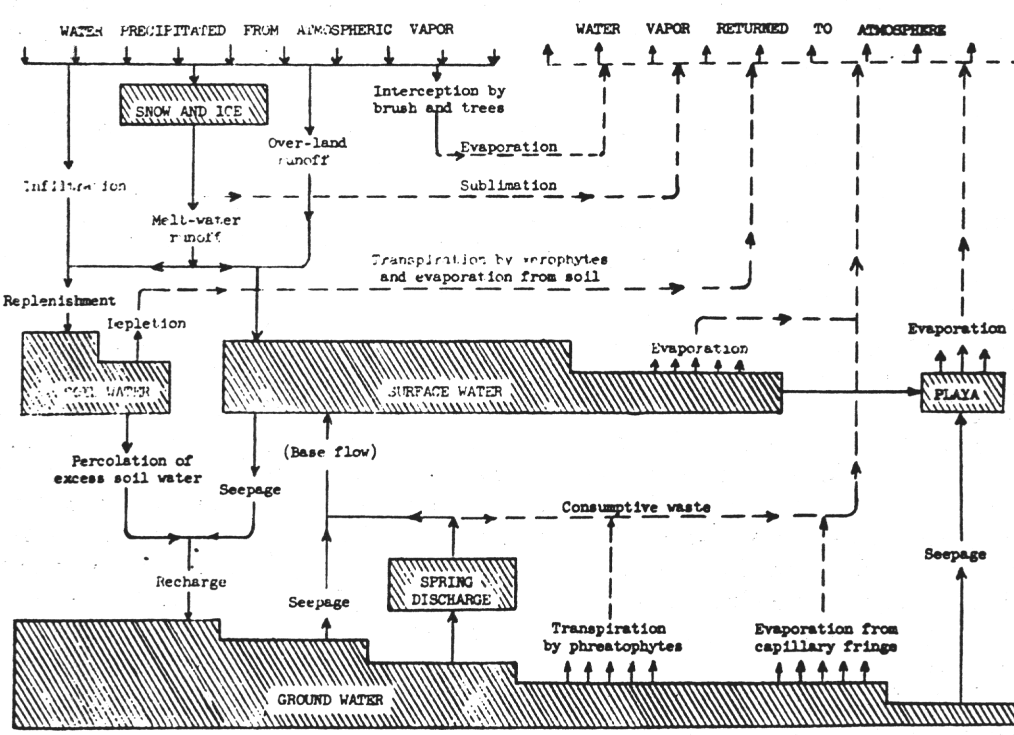

Figure 2. The hydrologic cycle for an undeveloped closed basin in an arid region. (Shaded areas represent water in storage; solid lines movement as liquid; broken lines as vapor).

There are about 80 species of plants in the Western United States that have been identified as phreatophytes. This group of plants does not belong to any one genus or family, but represents many genera and many species. They have only one characteristic in common--their dependence on groundwater when growing under natural conditions. Although most phreatophytes are plants of low economic value, some are not. Alfalfa, for example, is an important forage-producing plant.

Of the 80 species, about 10 at the present time are considered problem plants. The most notable among these are saltcedar (Tamarix pentandra) formerly known as (T. gallica), willow (Salix sp.), mesquite (Prosopis sp.), and cottonwood (Populus). Other important phreaophytes of little economic value, most of which are quite widespread, are batamote, or baccharis (Baccharis sp.), greasewood (Sarcobatus vermiculatus), rabbitbrush (Chrysothamnus sp.), saltgrass (Distichilis stricta), arroweed (Pulchea sericea), and alder (Alnus sp.).

Saltcedar is largely responsible for the present phreatophyte problem of the southwestern states. It is an aggressive, rapidly spreading, vigorous plant that grows densely along virtually every stream of consequence in the Southwest. The annual rate of water consumption by saltcedar is greater than that by any other phreatophyte. Saltcedar is not a native of this country, but is an exotic plant that was introduced into the Southwest from the Old World. The largest concentrations of growth are in the southwestern states, although in the past few years saltcedar has been observed spreading into other states, notably Wyoming, Colorado, Utah, and Kansas.

It has been estimated that there were about 16-3/4 million acres of phreatophytes of low beneficial use (Robinson, 1953, p. 111) in the 17 Western States. At the same time it was estimated that the annual evapotranspiration by these phreatophytes was of the order of 25 million acre-feet--more than twice the average annual flow of the Colorado River at Lees Ferry.

The annual rate of water use by phreatophytes ranges widely, according to the plant species and to local conditions. Under the same conditions some species consume large quantities of water, others much less. The rate of consumption for a species may vary from one locality to another, according to the following factors: (1) depth to the water table, (2) climatic conditions, and (3) density of growth. The use is greatest when the growth is dense, the climate arid and hot, and the water table shallow. According to Lee (1942, p. 272), air temperature is the most influential factor in controlling the rate of transpiration. As the Southwest has, on the average, a higher temperature than the rest of the Western United States, it would be expected that the water use there would be higher. This was borne out during studies of the use of water by saltcedar on the Gila River in Safford Valley, Arizona, where it was observed that the use of water paralleled changes in temperature, increasing as the air temperature increased and decreasing as it decreased.

The effect on evapotranspiration by saltgrass of differences in the depth to the water table and in air temperature during the growing season is shown in Figure 3. The curves in this figure are based on experimental data obtained at five locations in the Western United States where the depth to the water table ranged from less than 1 foot to nearly 5 feet, and where the average temperature during the growing season ranged from 54° to 70° F. The increase in use with decreasing depth to the water table is shown in Figure 3A. The temperature effect is shown clearly in Figure 3B. There three curves showing the use values for depths of 1, 2, and 3 feet at the localities given in Figure 3A have been plotted against the average temperature during the growing season, and show an increased use with increased temperature. The curve for the 2-foot depth indicates that with a 16° F. increase in air temperature, from 54° F. to 70° F. during the growing season, the water requirement increased about 100 percent; or, stated in another way, the water requirement at 70° F. is about twice that at 54° F.

The use of water is affected not only by the density of growth, but also by the size of the plant, and, hence, the amount of foliage. In describing growth conditions a value of 100 percent is assigned to the maximum possible growth and zero to essentially no growth. Then the variations in density and size of the plants may be evaluated as a percentage in terms of areal density and vertical density and expressed as a product of the two, called volume density. Studies in Safford Valley, Arizona (Gatewood, Robinson, Colby, Hem, and Halpenny, 1950, p. 27), have shown that the use of water by phreatophytes is proportional to the volume of foliage, being greatest where the growth is large and dense and least where it is small and scattered.

Data on the annual rate of water consumption by phreatophytes that are considered problem plants are scant and have been obtained for only a few localities. With one exception, all the localities are in the Southwest. The available data, for 7 different species growing at 9 different localities, are given in Table 1.

Table 1. Annual rate of water use by some common species of phreatophytes in the Western United States, including precipitation

Species	Acre-Feet Per Acre	Volume Density (Percent)	Depth to Water (Feet)	Locality and Remarks
Alder	5.3	-	-	Santa Ana River Drainage Basin, Calif.
Batamote	4.7	100	6	Safford Valley, Ariz.
Cottonwood	6.0	100	6	Safford Valley, Ariz.
Cottonwood	5.2	100	4	San Luis Rey River, Calif.
Cottonwood	7.6	100	3	San Luis Rey River, Calif.

Species	Acre-Feet Per Acre	Volume Density (Percent)	Depth to Water (Feet)	Locality and Remarks
Mesquite	3.3	100	10	Safford Valley, Ariz.
Saltcedar	7.2	100	7	Safford Valley, Ariz.
Saltcedar	6.0	-	-	Pecos River, N. Mex.
Willow	4.4 1, 2/	-	2	Santa Ana, Calif.
Willow	2.5 1/	-	1.1	Isleta, N. Mex.
Saltgrass	0.8 to 4.0 1/	-	0.5 to 5.0	See Figure 3

1/ For plants grown in tanks
2/ Tank isolated; not in natural environment.

The importance of the phreatophyte problem stands out more sharply when expressed in terms of man's everyday water needs. For example, it was found in the Safford Valley, Arizona, that the average use of water by a 3-year-old cottonwood tree during the growing season was 10.3 gallons a day and for a saltcedar plant of the same age, 13.5 gallons a day. In terms of man's needs, 14 young cottonwoods or 11 young saltcedars in Safford Valley consumed each day as much as the average city dweller (145 gallons, according to MacKichan, 1951, p. 4), two rural dwellers having running water (80 gallons), or 14 rural dwellers not having running water (10 gallons). Expressed in terms of livestock need, each young cottonwood tree or saltcedar plant consumed a little more water than a steer, a horse, or a mule, nearly as much as a milk cow, and about the same as 3 hogs, 4 sheep, or 4 goats.

In describing the water used by plant life, the term "consumptive use" has come into general use to denote the water transpired and evaporated from a cultivated area. It is considered synonymous with the term evapotranspiration. The term "consumptive waste" has been proposed (Thomas, 1951) and used (Robinson, 1957) to describe the water used by plants that have little utility for man. Under this condition, consumptive waste is defined as that part of consumptive use that is without considerable benefit to man. It connotes the opposite of beneficial consumptive use and becomes synonymous with nonbeneficial consumptive use.

The water that is consumptively wasted by phreatophytes may be conserved and salvaged. Salvage, as here used and applied to the phreatophyte problem, means converting consumptive waste to consumptive use. Basically, salvage may be accomplished in two ways: one by reducing the consumptive waste, and the other by increasing the efficiency of water consumption by beneficial plant life. For either method a knowledge of the occurrence of phreatophytes and their annual rate of water consumption is necessary.

Consumptive waste may be reduced by taking the water away from the plants and using it elsewhere. This may be done by pumping from

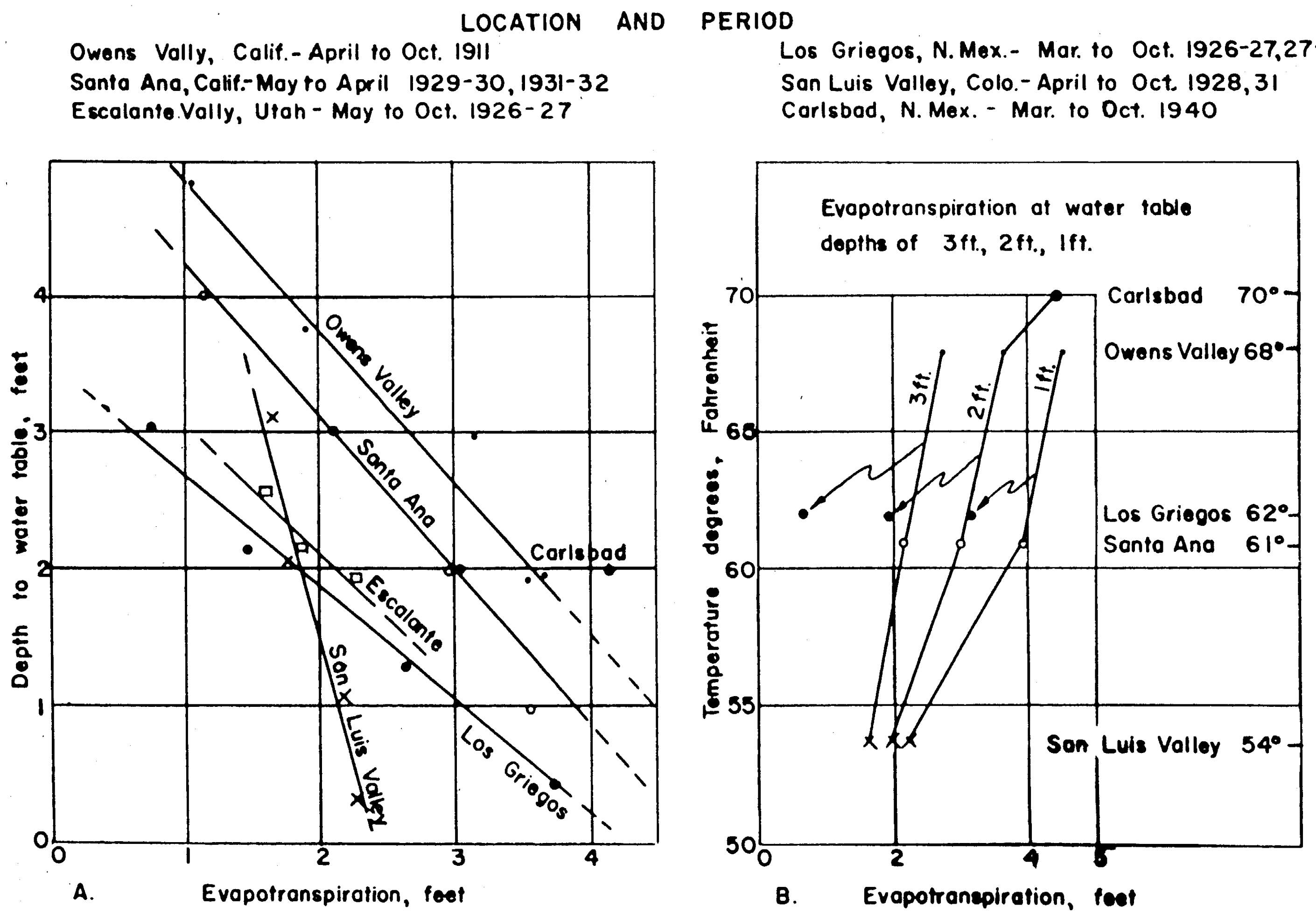

Figure 3 Relation of evapotranspiration by saltgrass, grown in tanks, to depth to water table and to the average temperature during the growing season.

wells, by drainage, by intercepting the groundwater upgradient from the area of plant growth, or by preventing it from reaching the plants by lining stream channels. The efficiency of water consumption may be increased in two ways: one by replacing the low-value phreatophytes with plants of higher economic value, and the other by developing a higher economic use for the existing phreatophytes. Replacement makes it necessary to clear the area of existing vegetation, not always an easy task.

Beginning about 1948 considerable time and money have been expended on the problem, much of it on experimental programs in clearing areas by eradication of the plants. Most of the work has been on saltcedar, although some has been done on willow, mesquite, and cottonwood. The methods investigated include the use of chemicals (herbicides), mechanical means (uprooting or cutting), and burning of the plants. In the case of saltcedar no wholly satisfactory method had been found. So far, a combination of clearing of the mature growth by mechanical means followed by spray treatment of the regrowth with herbicides has proved to be most effective.

The cost of eradicating undesirable phreatophyte growth varies with the method of treatment, size of area treated, terrain, and plant species. The unit cost for large areas is generally less than that for small areas. Cost data show that for large areas of saltcedar, 4,000 acres or more, the cost of treatment by mechanical means ranged from about $3 to about $11 an acre. For smaller areas of a few hundred acres, as much as $35 an acre was spent, and for riverbank clearing in units of less than 100 acres where the slopes are steep and access difficult, the cost was slightly in excess of $100 per acre.

Clearing operations are for two general purposes. One purpose is that of conserving groundwater; the other is flood prevention, which may be achieved by keeping overflow channels and floodways clear of vegetation. In this operation conservation of groundwater is a secondary consideration.

A prerequisite to the evaluation of groundwater salvage, whether by clearing or by other conservation measures, is data on the use of water by the phreatophytes before the start of any treatment. This information is necessary and forms the basis for determining the amount of salvage. It is the basis also for determining the economics of the conservation measures, and in the planning of any water conservation program involving control of phreatophytes. With adequate water use data, the economic feasibility of a proposed salvage operation may be estimated in advance. However, at the present time, information for this purpose is very limited.

An important aspect of the phreatophyte problem--that needs consideration--is the relation to floods and sedimentation. Some species grow so densely on flood plains that they choke overflow channels and floodways, form a partial barrier to flood flows, and thus cause floodwater to spread and inundate areas that otherwise would not be flooded. Saltcedar is the worst offender in this respect. Streams in which it has been found necessary to take corrective measures in order to reduce the flood hazard resulting from phreatophyte growth include the Salt and Gila Rivers in Arizona, the Pecos River in New Mexico, the Colorado River, and the Rio Grande in New Mexico, in Texas, and along the International Boundary.

Floodwater nearly always carries a high silt load, and as the velocity of the water is reduced by the ponding effect of the dense phreatophyte growth, sedimentation occurs in the area of growth. Sedimentation of this nature is prominent in the flood plains of the Pecos and the Rio Grande in New Mexico and the Gila River in Arizona. In the delta on the Pecos above Lake McMillan, New Mexico, dense saltcedar growth has acted as a desilting agent to reduce the amount of silt entering the reservoir. In this respect the growth has been quite effective, as shown by reservoir surveys. Before the dense saltcedar growth developed on the delta, some 41,000 acre-feet of silt was deposited in the reservoir during a 21.5-year period, whereas in the 25 years after the dense growth developed, the reservoir deposition amounted to only about 9,800 acre-feet. Thus, the saltcedar growth has reduced the annual rate of silting by four-fifths.

The example of Lake McMillan suggests the possibility of using phreatophytes as a desilting agent to prolong the life of reservoirs. The cost in terms of water, however, may be excessively high. During a 6-year period, the streamflow depletion by the 12,000 acres of dense saltcedar growth on the McMillan delta was estimated as 54,000 acre-feet a year, which was about one-fifth of the streamflow entering the area of growth. One year's streamflow out of each five may prove to be a high price to pay for increasing the life expectancy of Lake McMillan five times.

The phreatophyte problem poses many questions, some of which are partially answered, but most are unanswered. The research that has been done so far, although enlightening, has been limited. It should be continued and expanded to cover every facet of the problem. In 1927, Meinzer (p. 14-15) listed 17 questions dealing with phreatophytes that deserve further study. Most of these questions still remain unanswered. Phases of the phreatophyte problem on which research should be started, continued, or expanded, and which include some questions originally posed by Meinzer, are as follows:

1. Determination of annual evapotranspiration rates by species for different climatic conditions and for different depths to water.

2. Depth of root penetration--in effect, determining the maximum and minimum limits of depth to water within which the different species will live and flourish.

3. Relation of the occurrence, growth, and use of water by species to the chemical character of groundwater.

4. Determination of the limits of tolerance to alkaline and saline soil conditions.

5. Methods for salvaging groundwater consumptively wasted by phreatophytes.

6. Development of economic uses for phreatophytes presently of little or no value.

7. Continued research on methods of eradication of phreatophytes.

8. Research on groundwater plants of economic value that may be substituted for the low-value phreatophytes for various conditions of climate, depths to water, soils, and qualities of water.

9. Evaluation of the economics of phreatophytes as a desilting agent.

10. Development of standards as a guide to areal and density mapping of phreatophytes.

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INTRODUCTION AND SPREAD OF THE UNDESIRABLE TAMARISKS IN THE PACIFIC SOUTHWESTERN SECTION OF THE UNITED STATES AND COMMENTS CONCERNING THE PLANTS' INFLUENCE UPON THE INDIGENOUS VEGETATION

By Curtis W. Bowser 1/

ABSTRACT

The _Tamaricaceae_ family is a relatively small group of plants consisting of four genera all endemic to Africa, Europe, and Asia. Only members of the genus _Tamarix_ are found abundantly in the United States and of these the species _T. pentandra_, commonly called "saltcedar", grows so vigorously to have infested many natural drainage channels and waste areas. Introduction of the undesirable tamarisks into North America is not of firm record.. Specimen plants could have been brought in by the early explorers, by settlers, or later by exchange of plants between horticulturists. Regardless of the date that the plants were introduced, their spread since 1915 has been phenomenal which has resulted in a gradual transition of the characteristic indigenous willow, poplar, arrowweed, and baccharis communities to that of saltcedar in many drainage systems throughout the Southwestern and South Central sections of the United States. The tamarisk plants, in addition to creating a hazard by congesting the natural drainageways thereby creating a flood problem, also consume large quantities of water in a nonbeneficial manner. The usefulness of saltcedar for soil erosion control, as wildlife habitat, or for wood and pulp products is extremely limited. At elevations above 6,000 feet, and in the Pacific Northwest, the species is not rapidly gaining a strong foothold and it does not appear to have the ability to spread with rapidity so characteristic of plants at lower elevations. Nevertheless, there are reports of the species growing at elevations from 9,000 to 11,000 feet above sea level, and as the plant has escaped cultivation from coast to coast it indicates that undesirable tamarisks will become widely distributed and eventually will be regarded as an objectionable species of no economic value in many of the natural drainageways throughout North America.

* * *

The family _Tamaricaceae_ is a relatively small group of low-growing arborescent plants consisting of four genera which are endemic to Africa, Europe, and Asia. The genus _Tamarix_ first was described by Tournefort in 1719 and the first description of one of the 70 or more recognized species was made by Linnaeus in 1753. One derivation of the name stems from the report that tamarisk plants abound in the vicinity

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of the Tamaris River (now Tambro) in the Pyrenees. Another possibility is that the name derived from the Hebrew word "tamarik" meaning cleansing because the twigs and small canes were used in Biblical times to make brooms. From ancient times tamarisk plants have been mentioned in literature. H. N. Moldenke's treatise on plant references in the Bible states that some translations of the word "tree" and "grove" imply tamarisk. This is supported by the fact that tamarisks are reported to have grown for centuries in the Jordon River Valley. Tamarisk is a tree of classic lineage often referred to by the early epic poets and it has been written that against the tamarisk tree Archilles laid his spear before he plunged into the OEnanthus to pursue the fleeing Trojans.

There have not been any special reasons for anyone to have extensively studied the genus Tamarix as very little commercial use is made of either the wood or fiber products of the represented plants. Mention is made in various texts that the plant has been used in production of tannin, the pliable canes for making brooms in Chinese Turkistan, and throughout the area of the plant's native habitat its wood is used as a source of charcoal and the small twigs and branches have been collected for basketry and wattle work. The bark of some tamarisk plants allegedly has certain medicinal properties as a tonic, astringent, and diuretic, and it is reported that the foliage and twigs have been used in the preparation of a crude beer. A moot question has been whether or not in Biblical times the manna utilized by the Israelites in their journey out of Egypt to the Holy Land was a honey dew secreted by a scale insect feeding upon Tamarix mannifera, or the manna liken which is distributed over a wide area in Asia, Southeastern Europe, and Northern Africa. The latter explanation is most commonly accepted.

Introduction of plants belonging to the family Tamaricaceae into North America is not of firm record. Two of the four genera of the family, i.e., Tamarix and Myricaria are found in the United States, but species of the latter-mentioned genus are believed to be confined to ornamental plantings and have not escaped from cultivation. Practically all the described species of the genus Tamarix have been introduced. However, the phytographer in charting distribution of Tamarix is confronted with a problem of identification as the flower and vegetative characteristics, especially of several species, are so similar that differentiation is difficult. The early reports frequently do not define species but refer to the plants as tamarisks, false cedar, and even tamarack or larch which is not a close relative.

The record indicates that tamarisks could have been established in Mexico and the South Central United States at an early date, but subsequent migration through the drainageways has not been recorded. It is known that the early Spanish explorers and conquistadors who invaded Mexico and made expeditions into the United States between 1540 and 1750 were accompanied by armies and entourages of thousands of men with supporting wagons, farming equipment, and livestock. This media could have been the transporting agent for a plant or perhaps one minute pappused tamarisk seed from its original habitat to North America and then into the United States. Also, the early colonizers could have transported plants to America to beautify the grounds of a mission or farmstead.

It is significant that early contributions to the botany of the Southwestern sections of the United States do not mention tamarisks. However, seed and nursery catalogs, particularly from California firms, listed Tamarix, species not indicated, for distribution as early as 1856, and quite possibly the vegetative material made available through these sources for homesite planting for parks and gardens throughout the country provided the stock whose progeny were planted in such widely scattered localities as the District of Columbia; Brooking, South Dakota; Biltmore, North Carolina; San Francisco, California; Highland Park, New York, etc.

With the exception of the evergreen athel, Tamarix aphylla Karst, all other species are deciduous. The athel was introduced successfully in 1909 by Professor J. J. Thornber, Botanist, University of Arizona, in cooperation with Dr. Trabut of Algeria, the native home of the species. This species is not known to reproduce by seed, and is found only as an ornamental planted widely in the Southwest for shade and windbreak purposes. Of the deciduous species T. pentandra has become naturalized and is creating a problem in certain sections of the United States.

The first reliable herbarium record indicates that a collection of Tamarix was made by J. F. Joor in 1884 on the San Jacinto River, Harris County, Texas, and at that time the species was naturalized completely in that area. In 1877 a specimen identified as Tamarix gallica was collected in Fairmont Park, Philadelphia. Heller and Hapeman collected specimens of this species along the ocean near Corpus Christi and Galveston, Texas, in 1894, but other collections of the species were made only infrequently until 1915. After that widespread collections of tamarisk were made in the tributaries to most drainage channels throughout Southwestern United States indicating that the plants were then established widely in the plant communities. Complete invasion of these nonendemic plants now is evidenced along many natural water courses.

The following comments pertain to the species of Tamarix which have adapted themselves to our climatic and soil conditions to be of importance from a standpoint of choking natural drainage channels and in the nonbeneficial utilization of enormous quantities of water. The colloquial term "saltcedar" often is applied to these plants. It is interesting that these plants also commonly have been referred to as the French or Russian tamarisk, and it was not until about 1915 that the expression "saltcedar" came into popular usage. Undoubtedly the origin of this term stems from the fact that the small scale-like closely appressed leaves in general appearance resembled the cedar, and the solid residue and the deliquescent moisture that collects upon the foliage distinctly are salty, giving rise to the popular exemplificative term "saltcedar".

At the present saltcedar is growing in almost every drainage system throughout the Southwest, as shown on the attached map. Plants are thriving vigorously along the Colorado River near Grand Junction, Colorado, at elevation of approximately 3,800 feet, near Casper and Riverton, Wyoming, in North Dakota, Idaho, Kansas, Nebraska, Missouri, and along the coast in Louisiana. Saltcedar is not confined to the western portion of the United States, but is found widespread throughout the country in waste places and roadside thickets in the Southern States, and as a casual escape from cultivation from Wisconsin to Indiana and Massachusetts. Slow invasion of tamarisks into the upper watersheds and montane areas of the United States is being evidenced with plants reported in Nevada to be growing in the mountains near 9,000 feet elevation. Although the plants do not spread aggressively at the higher elevations, neither altitude nor temperature is considered the limiting factor. Saltcedar is not subject to attack by any insects or diseases which materially retard growth or vigor. The plants produce viable seed prolifically. One small plant has been estimated to bear over 600,000 seeds and each minute seed with its tuft of hair is most efficient to be transported by water and wind. These factors in addition to the inherent ability of the plant to thrive under most adverse conditions are indicative of its potential spread. It cannot be construed that the undesirable saltcedars, which are influenced primarily by edaphic conditions, will not thrive or that they will not spread over favorable areas in the more temperate climatic sections of the United States. Of course the domination by this species over the native vegetation to a point of achieving complete invasion will depend upon the balance exercised by Mother Nature as may be influenced by the regulation imposed by civilization.

* * *

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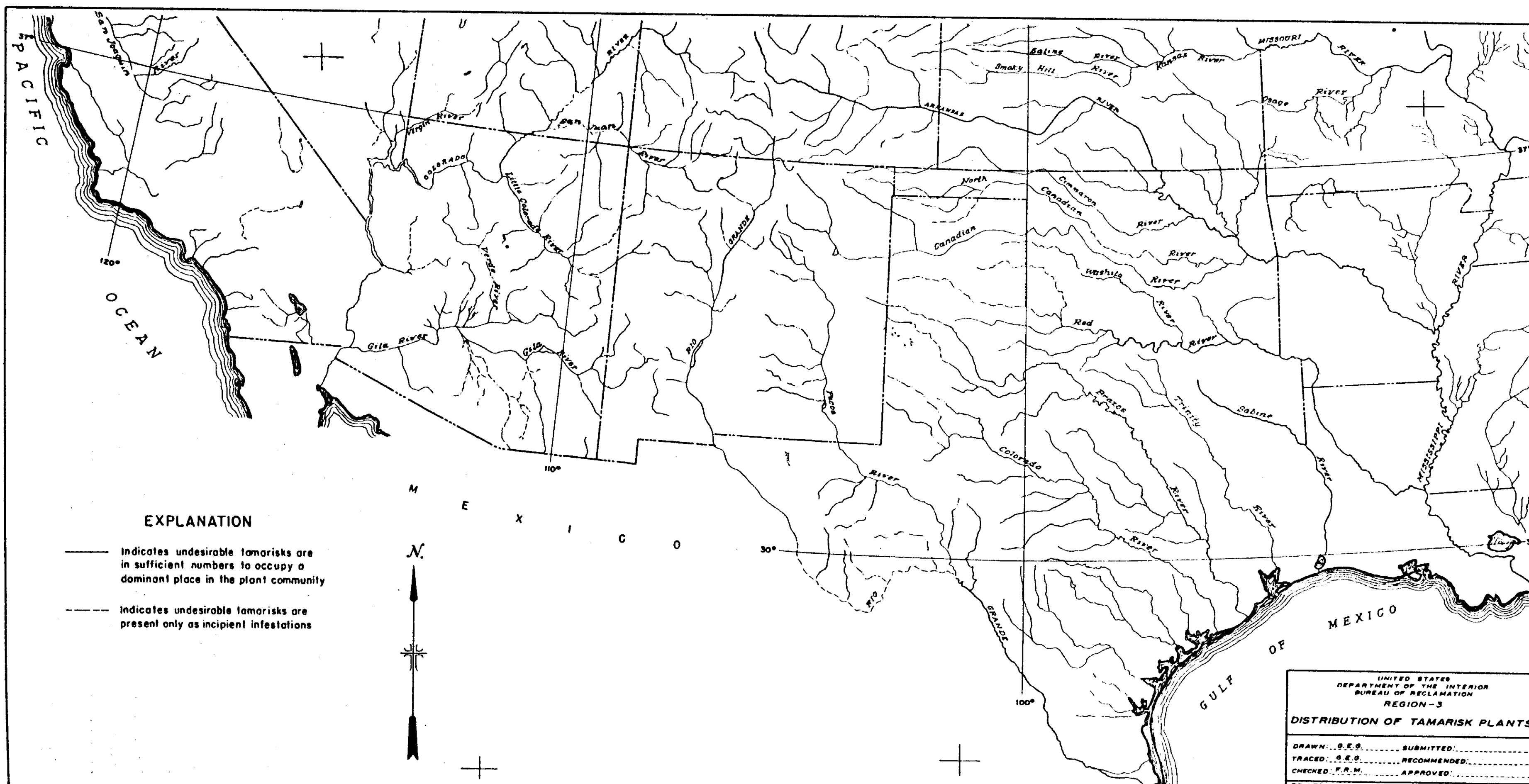
PACIFIC
OCEAN
MEXICO
GULF OF MEXICO
San Joaquin River
Virgin River
COLORADO
Little Colorado River
Verde River
Gila River
San Juan River
RIO GRANDE
Pecos
Colorado River
ARKANSAS RIVER
Saline River
Smoky Hill River
Kansas River
MISSOURI RIVER
Osage River
North Canadian
Cimarron River
Canadian River
Washita River
Red River
Brazos River
Trinity River
Sabine River
MISSISSIPPI RIVER
120°
110°
100°
30°
37°
N.
EXPLANATION
Indicates undesirable tamarisks are in sufficient numbers to occupy a dominant place in the plant community
Indicates undesirable tamarisks are present only as incipient infestations
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
REGION-3
DISTRIBUTION OF TAMARISK PLANTS
DRAWN: G.E.G.
SUBMITTED:
TRACED: G.E.G.
RECOMMENDED:
CHECKED: F.R.M.
APPROVED:
BOULDER CITY, NEV. 3-17-62
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INCREASE IN AREA AND DENSITY OF SALTCEDAR GROWTH IN NEW MEXICO

By C. B. Thompson 1/

ABSTRACT

Saltcedar (Tamarix pentandra) was first reported growing in New Mexico south of Mesilla Park about 1910. In 1914 it was reported in the Lake McMillan delta area of the Pecos River. Growth in the Middle Rio Grande Valley now totals approximately 52,000 acres and in the Pecos Valley about 42,500 acres. During the last five years a sum of approximately $506,000 has been spent for eradication and control in these two river valleys by the New Mexico State Engineer and the U. S. Bureau of Reclamation. Measures used have been chemical sprays, discing, burning, lowering the water table, and others.

Saltcedar growth was first confined to the lower valleys of the Pecos River and Rio Grande but is now spreading to the higher tributaries and to other stream systems such as the San Juan, Canadian, and Gila. It is believed that in the near future, if uncontrolled, it will be flourishing in every watershed in the State.

Due to its excessive water consumption and the fact that it constitutes one of the major operation and maintenance problems on irrigation and flood control projects, not only in New Mexico but in the entire Southwest, it is recommended that Congressional legislation be enacted to establish a program to find a more effective means of eradication. Such a program could be similar to that used to combat halogeton in the western states during recent years.

* * *

Introduction.--In the years after the introduction of saltcedar (Tamarix pentandra) in New Mexico, growth spread rather slowly and was almost unnoticed by man. Fifty years ago it had not yet become sufficiently established to be mentioned in the records and was first reported in the area south of Mesilla Park about 1910. In 1914 it was reported in the Lake McMillan delta area of the Pecos River. Infestations are now spreading at an ever-increasing rate into the watersheds of the San Juan, Canadian, and Gila Rivers. Figure 1 is a map of the State showing the extent of this vegetative invasion to 1956.

The Rio Grande and Pecos River Valleys, and especially the delta areas of Elephant Butte and McMillan Reservoirs, afford ideal growing conditions for saltcedar. This plant has a bushy structure and spreads out close to the ground. It is deciduous with minute leaves. Its physiology is such that it is very tolerant to both saline and alkali soils, grows

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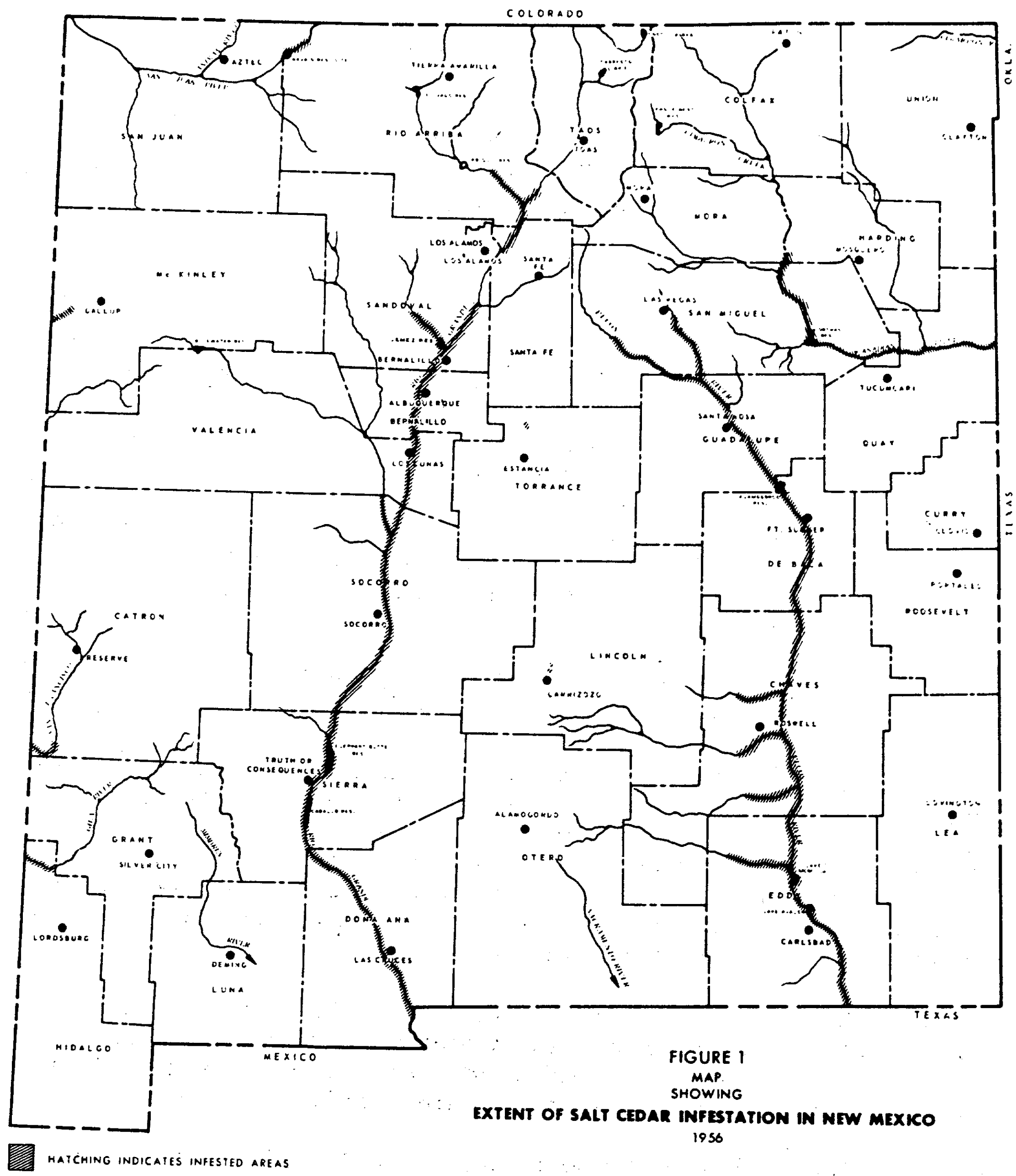


FIGURE 1
MAP
SHOWING
EXTENT OF SALT CEDAR INFESTATION IN NEW MEXICO
1956

rapidly when subjected to a high water table and a warm climate, and will survive long periods of inundation of root crowns. On the other hand it will also withstand extreme drought conditions and can survive comparatively severe winters. Water consumption of the plant varies with the available supply, density, and other factors, but has been reported to be from 3 to 11 acre-feet per acre per year.

Saltcedar is very difficult to eradicate. The New Mexico State Engineer Office and the U. S. Bureau of Reclamation have spent approximately \$506,000 during the past five years in the Rio Grande and Pecos Valleys in a cooperative control program which included repeated sprayings, discing, burning, lowering the water table, and other measures. However, every year a healthy crop of saltcedar appears, either by means of regrowth from old roots or from seed.

<u>History and Development in the Rio Grande Valley</u>.--In 1918 the New Mexico State Engineer directed a topographic and land use survey of the Middle Rio Grande Valley from San Marcial to Cochiti, a distance of approximately 150 miles. No saltcedar was mapped in 1918 nor was its presence even mentioned in the survey report.

In 1924 a valley cross section was made at milepost 1006+1864 on the Atchison, Topeka and Santa Fe Railway near San Marcial. Although other vegetation is noted on this cross section, no saltcedar is mentioned as having been present.

In 1926 the Middle Rio Grande Conservancy District conducted a land classification survey and again there was no mention of saltcedar.

In 1936 the vegetation in the Middle Valley was mapped by the U. S. Department of Agriculture, under the direction of Mr. Fred Scobey, as a part of the Rio Grande Joint Investigation. Although no separate classification was established for saltcedar, it was included under the heading of brush and trees and was specifically noted on the field sheets. At the time of this survey the infestation in the Middle Valley amounted to approximately 3,510 acres.

In 1947 the U. S. Bureau of Reclamation made a vegetative density survey of the Middle Rio Grande Valley under the direction of Mr. E. L. Draper. This survey showed an infested area of approximately 34,825 acres which is nearly a tenfold increase since 1936.

In 1954 the Atchison, Topeka and Santa Fe Railway filed suit in the U. S. Court of Claims for damage suffered as a result of aggradation of the channel of the Rio Grande in the general vicinity of San Marcial. It was alleged that the aggradation was caused by the impoundment resulting from the construction of Elephant Butte Reservoir. The Bureau of Reclamation contends that the aggradation was caused by the infestation of saltcedar and initiated a survey of the Middle Valley to investigate the spread of this phreatophyte. The results of this survey are contained in a report dated October 1955. The report indicates that between 1947 and 1955 the volume-density of saltcedar in the reach between Bernardo Bridge and San Marcial increased by more than 3,000 acres in equivalent area, or by slightly more than 50 percent of the 1947 density. Total estimated areal coverage of saltcedar in that reach in 1955 was 52,000 acres.

At this point an explanation of the volume-density method of vegetative surveys may be in order. This method was developed in the Safford Valley in Arizona by the U. S. Geological Survey and the Phelps-Dodge Corporation and is explained briefly as follows: areal density is the ratio of area covered by all plants to the total ground area, vertical density is the ratio of the vertical depth of foliage on a plant to the maximum possible depth on the species, and volume-density is the product of the areal and vertical densities. The volume-density of a species varies with latitude. For instance, a stand of saltcedar in Sonora, Mexico, might be 25 feet in height and have a volume-density of 100 percent while a corresponding stand in Wyoming with a 100 percent volume-density might be only 12 feet high, the difference being due to climatic factors.

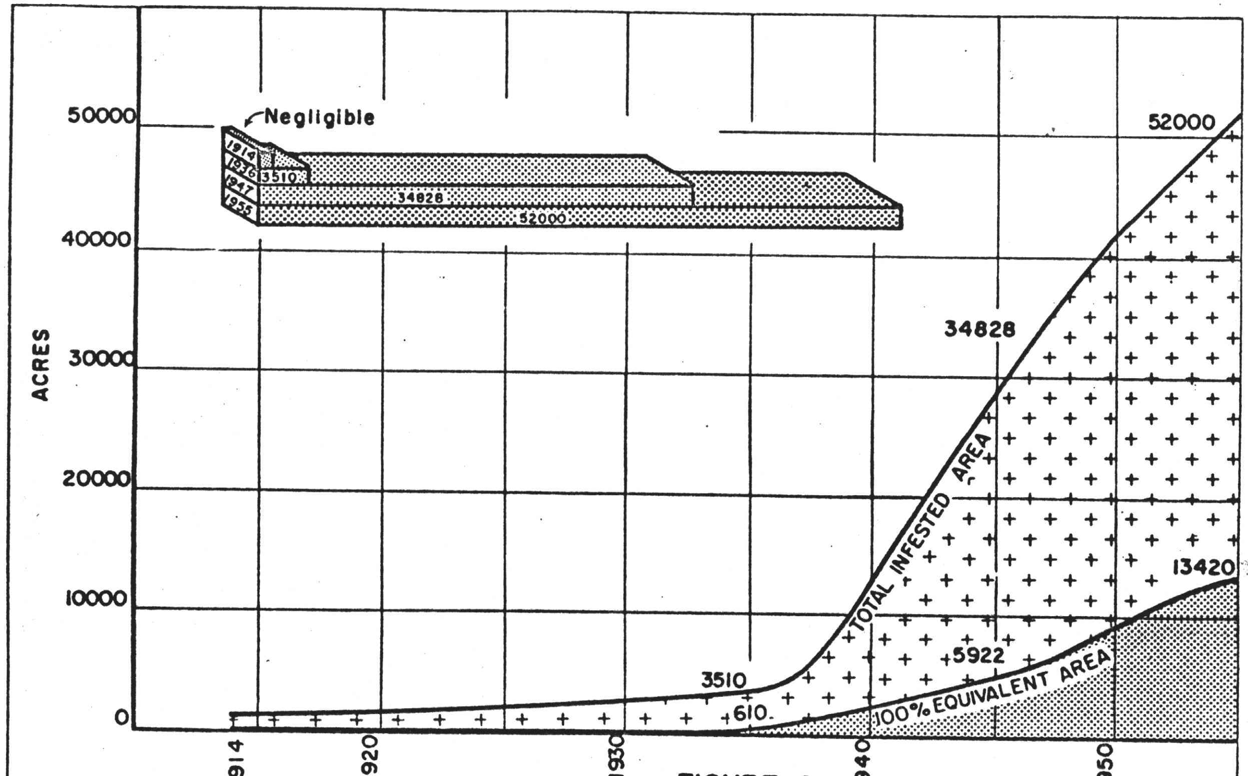
Equivalent area is an area of 100 percent volume-density which would contain the same volume of foliage as the area in question.

Figure 2 portrays graphically the increase in infested acreage and volume-density in a reach of the Middle Rio Grande Valley from San Marcial to Bernardo for the period 1914 to 1955.

From Elephant Butte to the Texas line the river is channelized and, outside of a sizeable concentration in the delta of Caballo Reservoir, saltcedar growth has probably reached its maximum areal extent along the valley and in the river channel. However, the Elephant Butte Irrigation District, the International Boundary and Water Commission, and the Bureau of Reclamation are waging a constant battle to keep saltcedar from stealing valuable irrigation supplies and rendering distribution works inoperative.

Tributaries of the Rio Grande such as the Rio Puerco and the Jemez Rivers are affected by scattered growths which will undoubtedly continue to spread. During the last five years several dense infestations have developed along the Rio Galisteo, and during the summer of 1956 seedlings were observed growing at the confluence of the Rio Ojo Caliente and Rio Chama, some 12 miles upstream from Espanola. It is believed that in the not-too-distant future saltcedar will invade all of the tributaries of the Rio Grande.

<u>History and Development in the Pecos River Valley</u>.--Saltcedar was first reported in the Lake McMillan delta of the Pecos River in 1914, and in 1915 the infestation was estimated to cover 600 acres. As in the Rio Grande Valley, extensive growth was not observed until the early thirties.



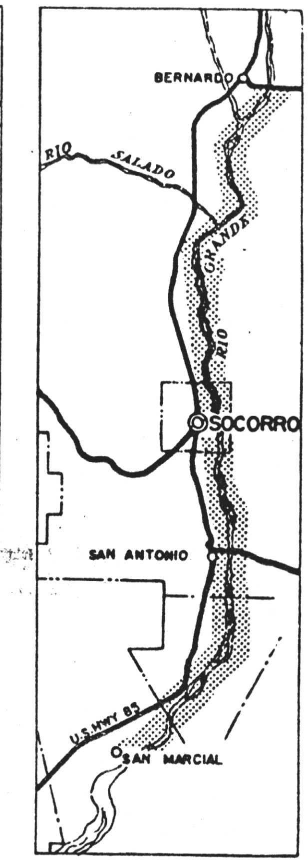


FIGURE 2

INCREASE OF SALT CEDAR AREA, RIO GRANDE VALLEY, BERNARDO TO SAN MARCIAL, N. M.

Thereafter the plant became well established and in 1939 coverage was estimated at 15,230 acres in the reach from Alamogordo Reservoir to the Texas state line.

In 1946 surveys indicated that the coverage had infested about 26,255 acres of valley land. Four years later the total had risen to 31,820 acres and to date it is estimated that areal coverage is about 42,500 acres.

Volume-density data for the Pecos River Valley are available to a limited degree. In 1947 the Pecos River Commission authorized a volume-density study in the McMillan delta area. This survey extended upstream to a point 3 miles from the Artesia Bridge. The balance of the river valley was classified from aerial photos as light, medium, or dense. The results of this study indicated a volume-density in the reach from Alamogordo Dam to the Texas-New Mexico state line of 14,634 acres in equivalent area by the end of 1950.

Figure 3 illustrates graphically the rather phenomenal growth of saltcedar in four reaches of the Pecos River in the period from 1937 to 1953.

The most significant recent development of saltcedar is in the delta area of Alamogordo Reservoir where there is a rapidly expanding growth of approximately 5,000 acres. As this infestation increases in both area and density, more and more valuable water will be consumed and will thus be unavailable for use by the Carlsbad Irrigation District.

While it is believed that the rate of areal growth of infestations in this basin will approach a static condition within the next decade or so, it is felt that volume-density will continue to increase for many years.

Development in Other Areas.--Figures 2 and 3 show rather vividly how the spread of saltcedar has taken place in the Rio Grande and Pecos River Valleys. However, the plant is by no means limited to these two areas and it is believed that, due to similar climatic conditions, extensive development may take place in other valleys of New Mexico and in the other states as well.

The presence of saltcedar has been no more than mentioned in reports in connection with the proposed multimillion dollar development along the San Juan River in New Mexico. Yet it has been identified and is already growing in this basin as indicated on Figure 1. It is believed that with the construction of Navajo Dam the river flow, which normally flushes the channel from the proposed location to the mouth of the Animas, will be greatly reduced. Thus the channel downstream, as well as the delta area which will form above the reservoir, will become an ideal location for phreatophytic growth, with attendant increased evapotranspiration losses and sediment deposition. This problem should be recognized

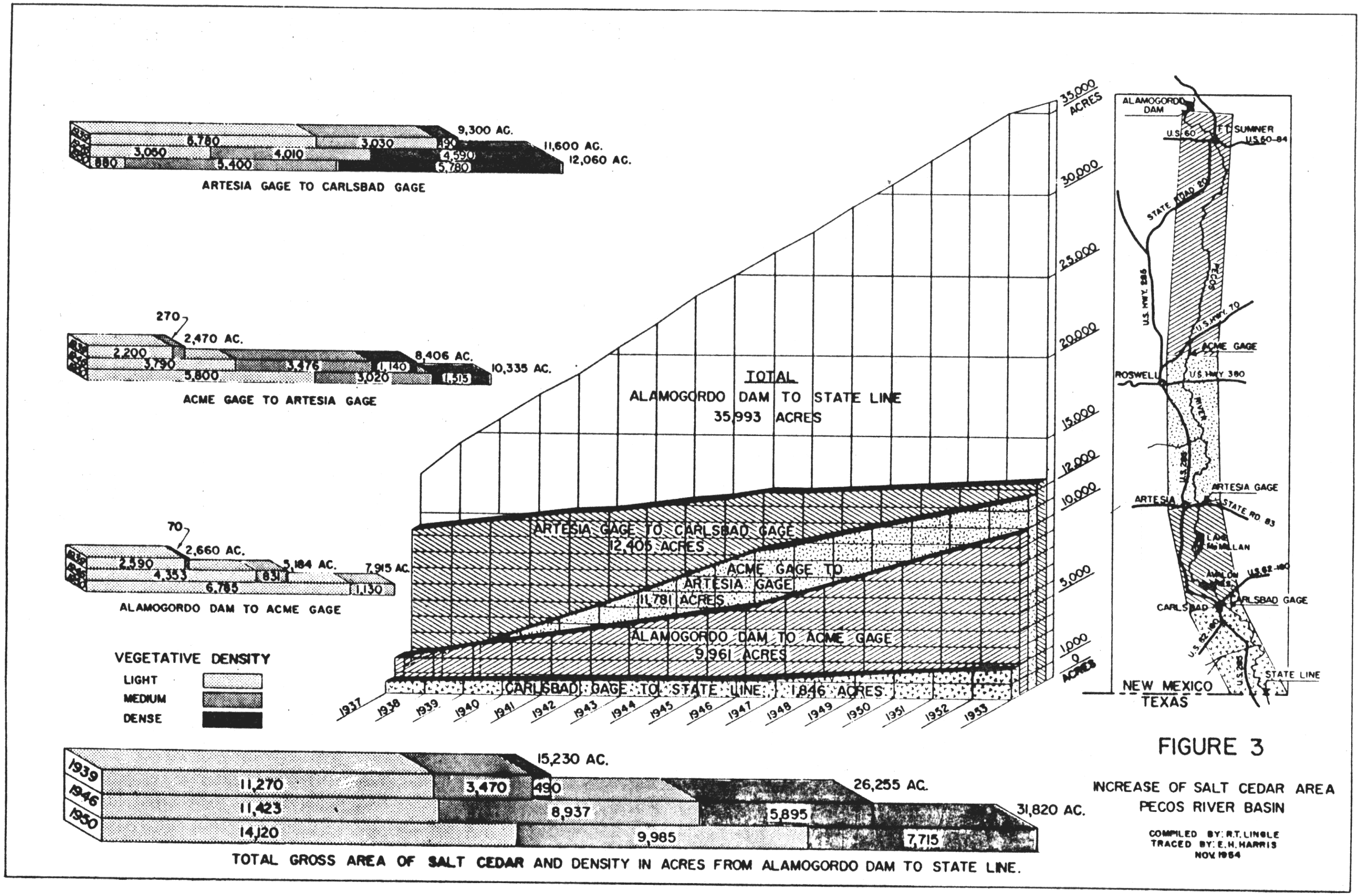


FIGURE 3

INCREASE OF SALT CEDAR AREA
PECOS RIVER BASIN

COMPILED BY: R.T. LINGLE
TRACED BY: E.H. HARRIS
NOV. 1954

in project planning and funds to attack it should be set up in the same manner as is done for operation and maintenance expenses. Undoubtedly saltcedar will eventually infest the San Juan and Animas River channels as it has the Rio Grande and Pecos.

In the Gila River Basin saltcedar has been reported in the vicinity of Redrock, New Mexico. This development has apparently taken place within the last few years and as yet does not constitute a serious problem. However, within a few miles downstream, in the vicinity of Safford, Arizona, and in the delta of Coolidge Reservoir, infestations are already of considerable concern to the San Carlos Irrigation District.

Dense growths have been observed below Conchas Dam on the Canadian River and are also developing upstream from the reservoir. These growths will undoubtedly spread to the canals and drains of the Tucumcari Project, necessitating a sizeable increase in the operation and maintenance costs for the Arch Hurley Conservancy District.

Recently a thin stand of saltcedar was observed along U. S. Highway 66 in a dry lake bed of the Estancia Valley. Undoubtedly careful field inspection would now reveal saltcedar growing in practically every watershed in New Mexico, and time alone is all that is needed to increase its volume-density, with attending water use, to astronomical proportions.

<u>Conclusion.</u>--It is apparent that saltcedar is rapidly becoming the predominant nonbeneficial vegetation in the lower river valleys of New Mexico where high water table and climatic conditions are ideal for its growth. It is further evident that this plant is becoming established in the higher tributaries and may be expected to invade all of the perennial stream systems of the State. It is therefore believed that, due to its extremely high water consumption and the fact that it constitutes one of the major operation and maintenance problems on irrigation and flood control projects, not only in New Mexico but in several other states, Congressional legislation should be enacted and funds appropriated in order to establish a program to combat "Public Enemy Number One" of the Southwest.

RELATIONSHIP OF PAN EVAPORATION TO EVAPOTRANSPIRATION BY PHREATOPHYTES AND HYDROPHYTES

By Harry F. Blaney 1/

ABSTRACT

Evaporation measurements from pans have been used for many years in connection with water supply studies to estimate evapotranspiration by phreatophytes. Usually, measurements of evaporation from U. S. Weather Bureau pans have been employed for this purpose. However, in some instances, evaporation from other types of pans and atmometers has been used. This paper presents some data observed in the Pacific Southwest on pan evaporation and evapotranspiration by saltgrass, saltcedar, cottonwoods, and other natural vegetation. Water consumption by these two important factors in the hydrologic cycle is compared and their ratios determined for the purpose of estimating evapotranspiration from evaporation pan records for areas where no water use measurements are available.

* * *

Water consumed by phreatophytes, such as saltcedar, cottonwoods, and willows, should be given careful consideration when making an inventory of the available water supply of river basins, such as the Rio Grande, Pecos River, and Colorado River (Blaney, et al., 1938, 1942, and 1952). As indicated by previous speakers, these uneconomic plants are spreading throughout the Southwestern States, especially along river channels and in areas of high water table.

The need for data on evaporation of water and evapotranspiration losses by water-loving vegetation has long been recognized by administrators and engineers in regions where water rights are in dispute, or where interstate water supply and water use are not in balance.

Measuring evapotranspiration under each of the physical and climatical conditions of any large river basin is expensive and time consuming. In water supply and irrigation investigations, engineers are called upon to make, within a limited time, estimates of probable past, present, and future evaporation and evapotranspiration losses from areas in river valleys. Many times no records of water consumption by vegetative growth are available. However, scattered throughout the Southwest, there are evaporation stations, some of which have been operated for many

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years. Evaporation from Weather Bureau pans has been used for many years by irrigation engineers of the U. S. Department of Agriculture in water supply studies to estimate evapotranspiration in regions where no measurements are available on water consumption by vegetation (Blaney, et al., 1938 and 1942).

Meteorological conditions influencing evaporation from water surfaces likewise affect evaporation from soils and transpiration from vegetation. Both evaporation and transpiration freely respond to changes in temperature, wind movement, and humidity so that evaporation from water may, under certain conditions, be used as an index of evapotranspiration losses for areas in which there is ample water to take care of evaporation and transpiration.

Studies which the author has made of water utilization in Rio Grande, Pecos River, and Colorado River basins, indicate that observed evaporation data from U. S. Weather Bureau pans may be used as a means of estimating evapotranspiration by water-loving vegetation when the relation of the two values is known for a particular area. This was accomplished in the Pecos River Joint Investigations (Blaney, et al., 1942) as illustrated in Table 1.

Table 1. Average Computed Rates of Annual Evapotranspiration by Phreatophytes Based on Pan Evaporation and Climatic Factors, Pecos River Basin, New Mexico and Texas

	Computed Evapotranspiration, Inches			
Location	Saltcedar Along River	Saltcedar Average	Brush Areas Away From River	Grass and Weeds Away From River
New Mexico				
Las Vegas	51.6	43.2	34.8	21.6
Fort Sumner	64.8	51.6	43.2	27.6
Roswell	67.4	56.4	45.6	28.8
Carlsbad	72.0	60.0	48.0	30.0
Texas				
Barstow	71.8	58.8	46.8	30.0
Balmorhea	72.0	60.0	48.0	30.0
Fort Stockton	72.0	60.0	48.0	30.0

Evaporation from Weather Bureau pans is being used in the San Francisco Bay Investigations for estimating evaporation and evapotranspiration (Blaney and Muckel, 1955).

The relation between pan evaporation and evapotranspiration is not always constant during the growing season yet it provides a means of making comparisons of evapotranspiration, not only from year to year, but between adjacent localities. The relation may vary from month to month, reaching a maximum in summer and a minimum during the cooler months of the growing season. Since water use becomes less with increased depth to groundwater, its relation to evaporation is partly governed by the position of the water table. Studies made on evapotranspiration by native vegetation, with water tables at different depths, in San Luis Rey Valley, California (Muckel and Blaney, 1945) in coastal climate, indicate a relationship of water use by tules, cottonwoods, brush and grass to evaporation from a Weather Bureau pan. Observations at Victorville (Blaney and Taylor) under arid climate show a similar ratio between tule use and pan evaporation. Results are summarized in Table 2.

Table 2. Comparison of Annual Evapotranspiration by Native Vegetation Growing With Water Table at Different Depths to Evaporation From a Weather Bureau Pan, San Luis Rey Basin and Victorville, California

	San Luis Rey, Calif.			Victorville, Calif.		
Classification	Depth of Water Table	Annual Water Consumption	Ratio Water Use to Evaporation	Depth of Water Table	Annual Water Consumption	Ratio Water Use to Evaporation
	Ft.	Ins.		Ft.	Ins.	
Pan Evaporation	0.0	60.8	1.00	0.0	82.5	1.00
Tules	0.0	57.5	0.95	0.0	78.5	0.95
Cottonwoods	3.0	92.7	1.52	--	--	--
Cottonwoods	4.0	62.3	1.02	--	--	--
Brush-Grass	4.7	45.4	0.75	--	--	--
Grass	12.0	14.0	0.23	--	--	--

The relation of monthly evapotranspiration by cottonwoods growing in tanks with water table at different depths to monthly pan evaporation in San Luis Rey Valley, California, is shown in Table 3.

Other studies in Arizona, California, Colorado, Nevada, New Mexico, Utah, and Texas indicate observed pan evaporation may be used as a means of estimating evapotranspiration by phreatophytes and hydrophytes (Young and Blaney, 1942).

Studies conducted at Rothamsted Experiment Station, England, show that annual evapotranspiration by grass, with a water table, is about 75 percent of evaporation from a water surface (Penman, 1948). This percentage ranged from 60 percent in midwinter to 80 percent in midsummer.

Table 3. Relation Between Evapotranspiration by Cottonwoods in Tanks to Evaporation From United States Weather Pan, San Luis Rey Valley, California

Month	Evapotranspiration Cottonwoods (ET) 1/	Pan Evaporation (E)	Ratio (ET)/(E)	Evapotranspiration Cottonwoods (ET) 2/	Pan Evaporation (E)	Ratio (ET)/(E)
	Ins.	Ins.		Ins.	Ins.	
Apr.	7.01	5.61	1.25	5.15	4.52	1.14
May	10.55	7.53	1.40	6.93	6.96	1.00
June	11.88	7.52	1.58	8.98	7.89	1.14
July	16.49	9.55	1.73	10.28	9.00	1.14
Aug.	14.24	8.58	1.66	10.41	8.18	1.27
Sept.	9.84	6.70	1.47	8.16	6.73	1.21
Average			1.51			1.15

1/ Year 1940; water table 3 feet.
2/ Year 1943; water table 4 feet.

From long-period records of evaporation, temperature, and humidity in Pecos River basin (New Mexico and Texas) together with evapotranspiration measurements, empirical formulas were developed (Blaney, et al.) for computing evaporation and evapotranspiration when temperature and humidity data are available. Consideration of these results and the factors involved is shown in the expression:

$$u = ktp\,(114 - h) = kc \quad . \; . \; . \; . \; . \; . \; \mathrm{I}$$

in which "u" is the monthly evapotranspiration (or evaporation) in inches; "k" is the monthly empirical coefficient; "t" is the mean monthly temperature, $^{\circ}F.$; "p" is the monthly percentage of daytime hours of the year; "h" is the average monthly humidity; and "$c = tp\,(114 - h)$" is the monthly use index (climatic factor). The formula for annual evapotranspiration (or evaporation) in inches is:

$$U = K_aC = k_wc_w + k_sc_s \quad . \; . \; . \; . \; . \; \mathrm{II}$$

in which "K_a" is the empirical coefficient for the entire year; "C" is the use index for entire year; "k_w" is the empirical coefficient for winter period; "k_s" is the empirical coefficient for growing season or frost-free period; "c_w" is the use index for winter season; and "c_s" is the use index for growing season or frost-free period. The values of "k_w" and "k_s" may be computed from observed values of evapotranspiration, temperature, and humidity by the relation $k = u/c$.

Computed coefficients for winter and summer water consumption based on evapotranspiration, evaporation, temperature, and humidity measurements at Carlsbad, New Mexico, are shown in Table 4.

Table 4. Coefficients for Computing Water Consumption From Climatological Data, Pecos River Basin, New Mexico and Texas

Type of Vegetation or Land Use	Depth of Water Table	Empirical Coefficients k_w	k_s
	Feet		
Sacaton (saltgrass)	4	0.0044	0.0139
Sacaton (saltgrass)	2	0.0063	0.0154
Saltcedar (tamarisk)	2	0.0075	0.0216
Alfalfa	5	--	0.0174
Tules	0	--	0.0240
Evaporation, bare soil	2	--	0.0083
Evaporation, water surface	0	--	0.0174

* * *

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AN INFRARED APPARATUS FOR MEASUREMENT OF TRANSPIRATION

By John P. Decker 1/ and Janet D. Wien 2/

ABSTRACT

An apparatus was developed that recorded directly and continuously the transpiration rate of a single intact twig or leaf. A leaf was sealed in an illuminated, constant-temperature glass chamber that was ventilated at a known rate with dry air. Absolute humidity of air flowing from the chamber was recorded continuously by an infrared gas analyzer. Humidity multiplied by ventilation rate gave transpiration rate. Transpiration increased smoothly to a new constant rate when a leaf was illuminated, and it decreased smoothly when the leaf was darkened. When a twig or petiole was severed in air, transpiration accelerated briefly in a smooth surge before beginning a gradual decline. When a petiole was severed under water, transpiration slowed to a new constant rate. It surged briefly when the cut end was then exposed to air.

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Introduction. --Numerous attempts have been made to study transpiration by enclosing a part of a plant in a transparent chamber and measuring the resulting increase of humidity. According to Maximov (1929) the first such study was made by Guettard in 1748. More recent work has been reviewed by Crafts, et al. (1954). This method permits studies on undisturbed natural vegetation, but its use has been limited by lack of a practical means for measuring rapid changes of humidity.

Decker and Wetzel (1957) described an apparatus in which an infrared gas analyzer was used as a hygrometer. Their study showed that the closed-chamber type of apparatus was impractical for field use because of acute sensitivity to temperature change.

Because of the need for a method to measure transpiration in the field, a ventilated-chamber apparatus was developed and tested. It was not affected appreciably by temperature change. Some of its operational characteristics were tested in the laboratory in a study of the course of transpiration of five-stamen tamarisk (*Tamarix pentandra*) and of a eucalyptus (*Eucalyptus* sp.) during light-dark cycles and following cutting of twig or petiole in air or under water.

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Apparatus.--The apparatus consisted of a leaf chamber, a metered ventilation system, a sampling pump, and an infrared gas analyzer (Figure 1). A leaf or twig was sealed in the chamber and was ventilated at a known rate with dry air. Absolute humidity of air flowing from the chamber was recorded by the analyzer. Humidity, in milligrams per liter, multiplied by ventilation rate, in liters per minute, gave transpiration rate in milligrams per minute.

The leaf chamber was the top of a 9.3 cm Petri dish sealed to a brass base plate with modeling clay. The rim of the dish was notched to accomodate a twig and a thermometer. Air temperature in the chamber was controlled automatically within 0.5° C. with a thermoregulator consisting of an ordinary mercurial thermometer to which was attached a Thermocap relay. The relay controlled a pump that forced water through a loop of tubing soldered to the lower side of the base plate (not shown in Figure 1).

Ventilation was continuous. Dry air flowed into the chamber from a high pressure cylinder (commercially compressed and dried air) through a reducing valve and floating-ball type flowmeter. Outflow from the chamber was through a large orifice around the thermometer stem.

The sampling pump (Thiberg Model 1) withdrew air continuously at about 1,000 ml per minute from near the outlet orifice, passed it through the analyzer and returned it to the leaf chamber as shown in Figure 1.

The analyzer was a Liston-Becker Model 15A coupled with a recording milliammeter. Zero was set as the equilibrium reading for air recycled through a closed system consisting of the analyzer, pump, and a series of three drying tubes charged respectively with Drierite, Ascarite, and Anhydrone. Full scale was set as the equilibrium reading for air recycled through a bubbler of distilled water held at 20° ± .01° C. The analyzer was checked against these two standards several times during each day of operation.

Calibration.--Calibration of the analyzer did not depend on the usual humidity tables or reference standards. The calibration procedure was as follows: A small, stoppered flask containing about 2 ml of water was fitted with inlet and outlet tubes and inserted into the system between the analyzer and empty chamber. The sample stream of air passed through the flask before returning to the chamber. Humidity at the outflow orifice became stable within a minute. Ventilation was adjusted to attain one of five different humidities. The sampling pump was stopped, the flask was removed, and a weighed duplicate flask was substituted. The pump was run for 10.0 minutes, and the flask was removed and reweighed. Its loss of weight divided by the volume of ventilation gave average absolute humidity corresponding to that particular analyzer reading. With the chamber held at 34.5-35.5° C., duplicate observations were made at a series of five points and a calibration curve was drawn (Figure 2).

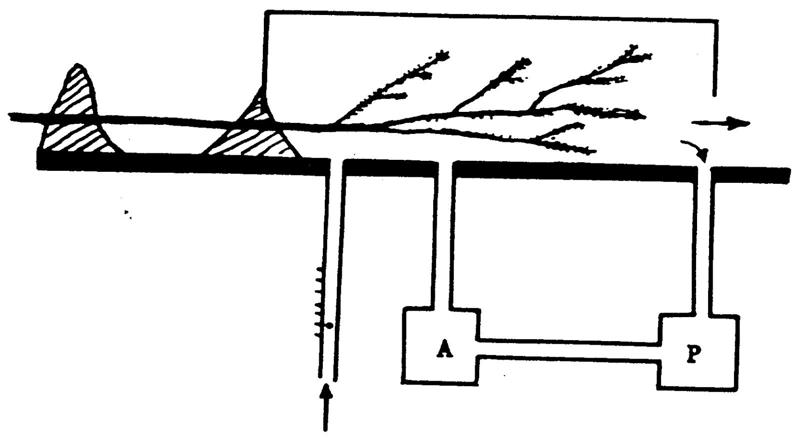

Figure 1. Diagrammatic vertical section through transpiration chamber showing tamarisk twig installed under Petri dish cover. Modeling clay cup at left of drawing was filled with water for certain experiments. Pump (P) and analyzer (A) are greatly simplified and reduced.

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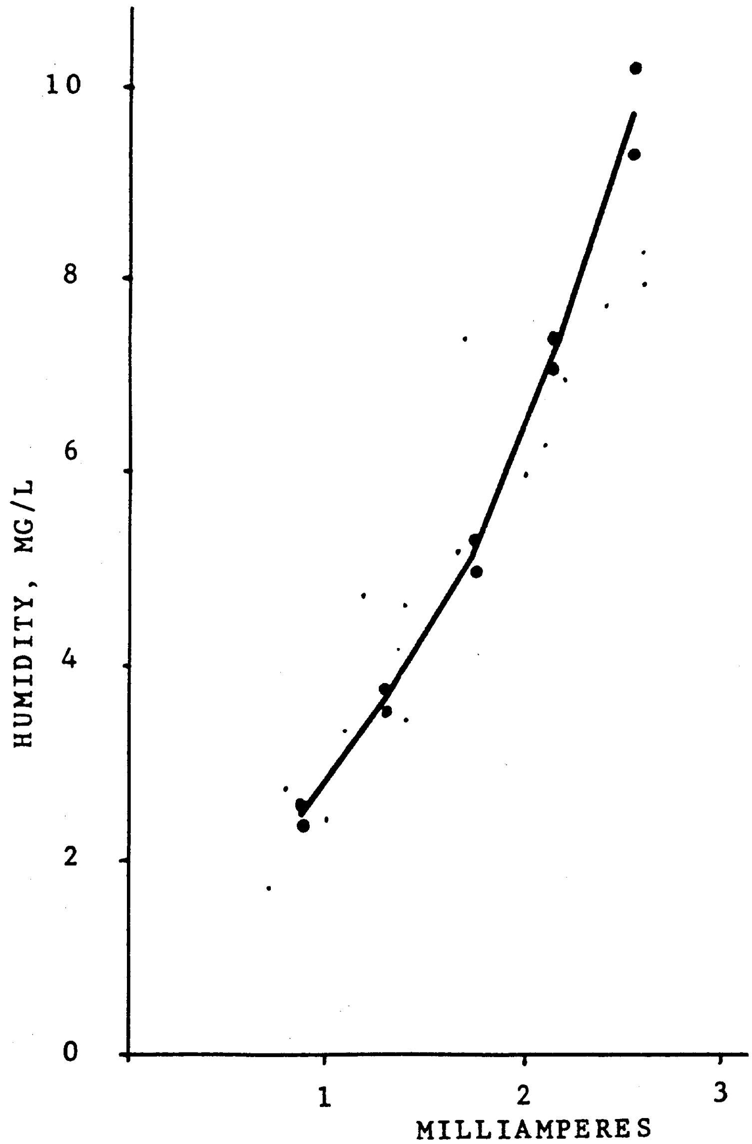

Figure 2. Calibration curve for infrared gas analyzer based on observations at 35° C. (large dots). Observations at 20° are indicated by small dots.

To test the effect of temperature on the present apparatus, the calibration procedure was repeated at another temperature (19.5-20.5° C.). Results are shown as small dots in Figure 2. The slight shift of the curve at the higher humidities is of no importance to the present work at constant temperature, but it does indicate the need for caution in calibrating an apparatus to be used over a range of temperatures, particularly at higher humidities.

Plants.--Ten potted seedlings of tamarisk and six potted seedlings of eucalyptus were used. The tamarisk plants were 80-100 cm tall and had grown in a greenhouse in one-gallon cans of clay soil. They were transplanted to the cans as small seedlings (10-20 mm tall) dug from the banks of the Gila River near Phoenix, Arizona. The eucalyptus plants were 80-120 cm tall. They were ornamental planting stock purchased from a commercial nursery.

Standard Procedure.--A twig of tamarisk or a leaf of eucalyptus was sealed in the chamber as shown in Figure 1 and was left under standard operating conditions (3,000 fc of light, 34.5-35.5° C.) until transpiration rate became constant. Ventilation was then adjusted to bring the hygrometer reading conveniently near midscale, and experimental treatments were applied. Soil was kept near field capacity throughout the experiments.

Dark-Light-Dark Cycle.--A well-known phenomenon, the change of transpiration rate with light and darkness, was used as a preliminary test of the apparatus. A tamarisk twig was arranged according to the standard procedure. The light was turned off until transpiration had dropped to a low and nearly constant rate. It was turned on until transpiration regained a constant high rate; then it was turned off again. Figure 3 is a photographic copy of a direct tracing of the milliammeter chart. The rapid changes of transpiration were similar to those reported by Andersson, et al. (1954) for other species. The procedure was repeated with eight other tamarisk twigs and eight eucalyptus leaves with similar results.

The changes of transpiration probably resulted primarily from changes in stomata rather than from changes of leaf temperature. In an earlier study with a similar leaf chamber, Decker (1955) found that a new stable leaf temperature was reached within the first 30 seconds of light or darkness, a change that is much too rapid to account for the relatively slow changes of transpiration observed here.

Twig or Petiole Cut in Air.--A tamarisk twig was arranged according to the standard procedure. It was then severed from the rest of the plant by cutting with a sharp razor just outside the chamber. Transpiration accelerated 13 percent above the previous constant rate and then declined (Figure 4). The surge was similar to that reported by Andersson, et al., for other species. The procedure was repeated with 29 other tamarisk twigs, with the cuts about 5 mm, 12 cm, or 25 cm from the chamber and

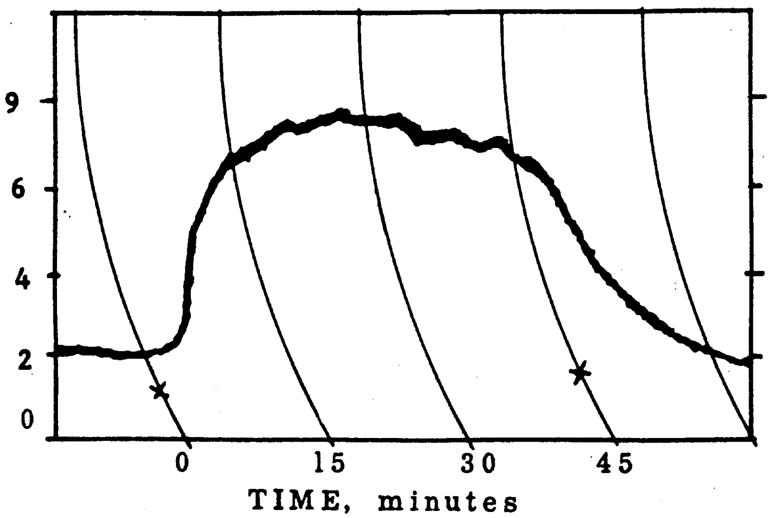

Figure 3. Direct tracing of milliammeter chart scaled to show transpiration rate of tamarisk in milligrams per minute at 3,000 fc and 35° C. Lights on at time 0, off at 45 minutes.

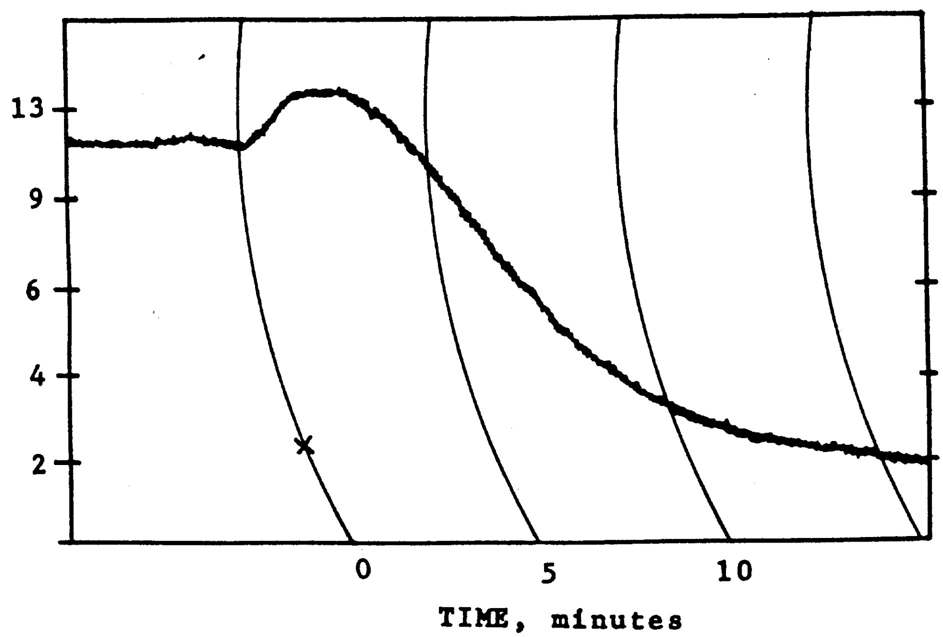

Figure 4. Transpiration rate of tamarisk twig in milligrams per minute at 3,000 fc and 35° C. Twig was cut in air with razor just outside the chamber at time 0.

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made with either a sharp razor or dull wire-cutting pliers. Surges ranged from none to 23 percent. No consistent relationship was apparent between height of surge and method or place of cutting. The procedure was repeated with 12 eucalyptus leaves and each showed a surge similar to that in Figure 4. Surges ranged from 5 percent to 30 percent above the previous constant rate.

Twig or Petiole Cut Under Water. --A eucalyptus leaf was arranged according to the standard procedure. A small cup was formed of modeling clay around the petiole just outside the leaf chamber. The cup was filled with water and the petiole was severed under water with a sharp razor. Transpiration declined to a new constant rate (Figure 5). The cup was then drained. Shortly after the cut end of the petiole was exposed to air, transpiration surged and declined (Figure 5). The acceleration was about 9 percent of the initial constant rate. The procedure was repeated with 9 other eucalyptus leaves. All showed a similar pattern, with surges ranging from 9 percent to 60 percent.

The procedure was repeated with 8 more eucalyptus leaves except that the petioles were crushed off with round-jaw pliers instead of being cut with a sharp razor. With one leaf the response was similar to that shown in Figure 5; with 5 leaves transpiration went into a continuous decline that was interrupted by a 9-26 percent surge upon exposure of the cut end to air; with 2 leaves, transpiration went into a continuous and uneventful decline that was not affected by exposure to air.

The procedure was repeated with 24 tamarisk twigs, using a razor. With 13 twigs, transpiration declined smoothly and uneventfully; with 6 twigs, it began to decline, recovered slightly (before exposure to air), then went into a continuous decline; with 5 twigs, the pattern was similar to Figure 5 with a 9-18 percent surge.

The decreased transpiration of eucalyptus and some tamarisk following cutting under water was similar to that reported by Andersson, et al., for other species. It may have resulted from a crushing and tearing of xylem elements that restricted lumina and increased resistance to flow of water. The surge when a cut was exposed to air may have occurred because air intruded more freely than water did into the damaged elements. The alteration of response with method of cutting suggests further that damage at the site of cutting was an important factor.

Discussion. --Because its calibration was not altered markedly by temperature change, the ventilated-chamber apparatus appears more adaptable to field studies than was the closed-chamber apparatus. Calibration of the hygrometer was made with direct reference to a primary standard (amounts of water weighed on an analytical balance) and is thus more reliable than the calibrations of other hygrometers that refer to hygrometric tables or vapor pressures.

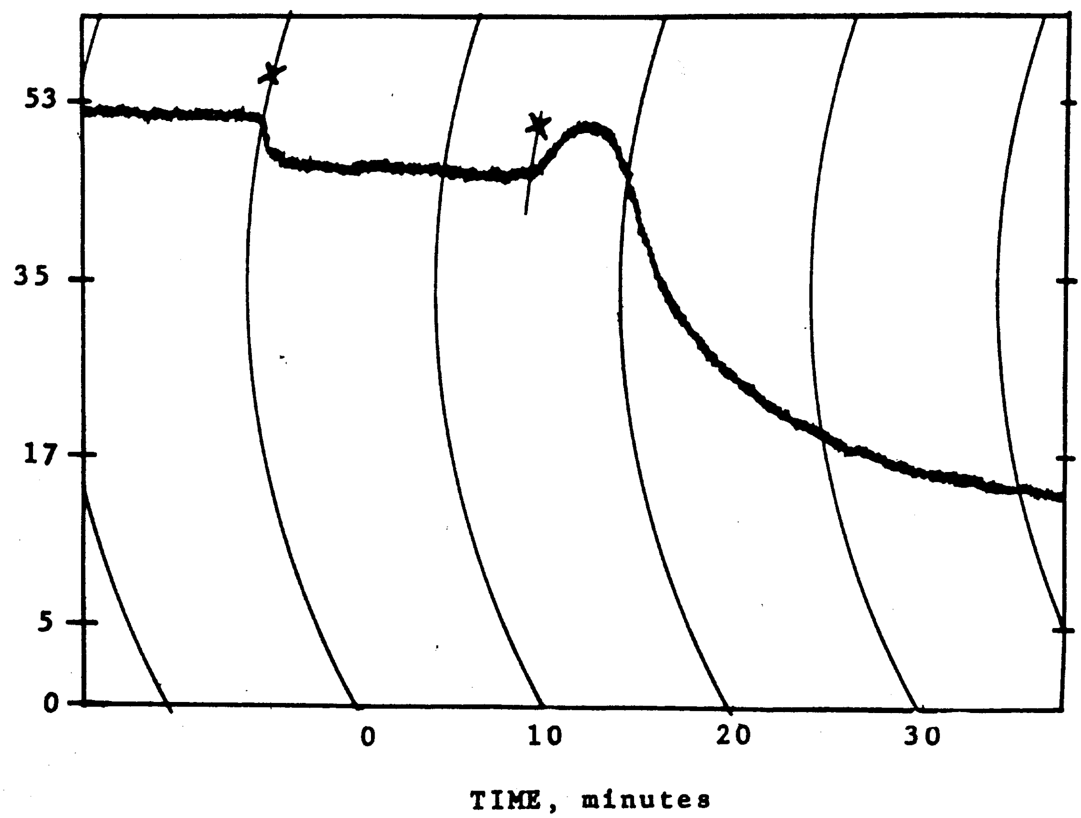

Figure 5. Direct tracing of milliammeter chart scaled to show transpiration rate of eucalpytus leaf in milligrams per minute per dm^2 of leaf area at 3,000 fc and 35° C. Petiole was cut under water with a razor at time 0 and was exposed to air after 15 minutes.

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Acknowledgments.--The work was done at the Tempe Research Center maintained in cooperation with the University of Arizona and Arizona State College. The Center is a part of the Rocky Mountain Forest and Range Experiment Station, headquarters at Fort Collins, Colorado, in cooperation with Colorado State University.

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ERADICATION AND CONTROL OF PHREATOPHYTES IN RESERVOIR DELTA AREAS AND REPLACEMENT OF GROUND COVER

By Henry J. Cremer 1/

ABSTRACT

Increasing agricultural water requirements and prolonged droughts have highlighted the necessity for considering all possible methods of water conservation. One of the newer conservation practices, about which there still remains much to be learned, is that of eliminating phreatophytic growth along water courses and in reservoirs. These noxious plants rob the groundwater basins of large quantities of water by transpiration.

The problems attendant upon controlling phreatophytic growths and of replacement plantings to deter infestation are being studied in several phreatophyte infested areas.

Both mechanical and chemical methods of phreatophyte control are being used with varying degrees of success. The phreatophyte problem cannot be solved simply and must involve a long-range program of planned inhibition until phreatophyte growth in infested areas is controlled and beneficial replacement plantings have been established.

* * *

The chief purpose of eradication and control of brush and noxious woody plants is to conserve groundwater and to improve land areas for agricultural purposes. In Southwestern United States, noxious plants, called phreatophytes, waste tremendous quantities of groundwater. Among major water-consuming plants are tamarisk (Tamarix), mesquite (Prosopis), greasewood (Sarcobatus), and cottonwood (Populus). Loss of water caused by transpiration of these woody plants reduces the underground water storage, and depletes the available water supply. Every phase of human activity demands the use of water, which is a vital necessity for homes, agriculture, and industrial purposes.

Agriculture is considered one of the most important factors in the economy and life of the Nation. The prolonged drought condition that has prevailed during recent years in Southwestern United States has caused decreased recharge of groundwater in reservoir delta areas. As a result, attention has been focused on the subsurface water storage problems and the eradication and control of large growths of phreatophytes in reservoir and channel areas.

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Deposits of sediments in delta areas and along streams and favorable seeding areas, especially where the groundwater table is shallow, appear to be the chief cause of noxious plant infestation. The seasonal fluctuation of the water surface is also a contributing factor to the spread and deposit of seeds along the shores of reservoirs and flood plains of streams and channels.

The task of eradication and control of phreatophytes for the conservation of underground water is enormous. The replacement of a suitable ground cover for erosion control and agricultural use presents an equally important problem. Cover crops or grasses with significant agricultural and soil stabilization values can best replace phreatophytes. To this end plans showing sedimentation deposits, phreatophyte infested floodway areas, and depth of the water table, are essential. Studies should also be made to determine the treatment for prevention of noxious phreatophyte growth. The ultimate objectives include satisfying land and water needs, and providing benefits to the people by increasing the productive use of land and of the water.

Estimates of phreatophyte infestation and water consumption in New Mexico showed that 441,000 acres occupied by phreatophytes wasted nearly 900,000 acre-feet of water a year. Nevada's phreatophyte infestation is placed at 2,801,000 acres, and the annual water loss at 1,500,000 acre-feet.

Numerous experiments on test plots have and are now being conducted by the Bureau of Reclamation and by local interests on means of eradication and control of phreatophytes. Results of studies indicate that chemical spray treatment of phreatophytes by one spraying is not effective and that complete kill requires subsequent spraying. Experience with burning indicates that after the infested areas had been burned, many saplings sprung up from the root crowns of the burned plants and grew to heights of 5 to 7 feet in one year. Information to date indicates that eradication by burning and chemical spray applications still require mechanical operations for clearing the infested floodways. The one method of eradicating phreatophytes that appears most effective is mechanical clearing followed by controlled burning and then by spring and fall chemical spray treatments. After the land has been cleared and chemically treated by selective herbicides, seeding to adaptable forage grasses for grazing purposes is essential to prevent regrowth of phreatophytes. Eradication and control is a long-range problem, and work of this nature must continue because of reinfestation.

Suggested species of fast-growing, sod-forming grasses adaptable to many areas for permanent range include the following:

Brome grass (Bromus inermis). Climatic adaptation for mild, cool, or cold arid regions. Develops by creeping rootstocks near the surface and the palatability is very high.

Blue grama (Bouteloua gracilis). Climatic adaptation in arid regions. In northern range, plants form sod more readily than in southern range. Plants are more vigorous and assume a bunch habit. Palatability is high.

Buffalo grass (Buchlos dactyloides). Climatic adaptation in semi-arid regions. Very drought resistant and sod forming. Spreads rapidly by means of creeping runners. Palatability is very high. Usually is not found west of the Pecos River.

Harding grass (Phalaris tuberosa). Climatic adaptation is from hot to cold, but not below zero. Winter grower, making excellent feed for winter or dry range.

Tall fescue (Festuca elatior). Climatic adaptation for any climate. Suitable for extremely wet conditions.

Western wheat grass (Agropyron smithii). Climatic adaptation for cold and arid regions. Produces a quick ground cover, a heavy sod with surface-creeping rootstocks.

Reed canarygrass (Phalaris arundinacea). Climatic adaptation for cool areas. Thrives in medium to extremely wet conditions. Spreads by creeping underground roots near the surface. Palatability is medium.

Alsike clover (Trifolium hybridum). Climatic adaptation from mild to cold. Stands medium to excessive moisture, and has a fibrous root system from a single crown. Palatability is high.

Strawberry clover (Trifolium fragiferum). Climatic adaptation from hot to extremely cold. Stands moist to wet conditions. It is low-growing, spreading by creeping stems that root at the nodes. Palatability is very high. Excellent results have been obtained in areas with sufficient moisture during the germination period.

Burnet (Poterim sanguisorba). Climatic adaptation mild to cold. Stands extreme drought, but prefers moisture. Palatability is very high.

Meadow fescue (Festuca pratensis). Climatic adaptation mild to cold regions. Stands very wet land and some drought. Grows from early spring to late fall and stays green through winter.

Sudangrass (Sorghum vulgare) has also proved a very efficient ground cover for prevention of undesirable plants and erosion. It stands considerable drought, but does best with moderate moisture. Palatability is high.

Other suitable ground cover for use in southwestern states on heavy alkaline soils and on sandy loam or silt are the following species:

Alkali sacaton
Wild millet
Rothrock grama
Black grama
Arizona cottongrass
Cane beardgrass

These should be seeded prior to seasonal rains. If protected from grazing for a few years, the areas will provide a source of seed which will aid in the natural reseeding of the surrounding area and restore production of forage for livestock.

A SUMMARY OF RESULTS OF EXPERIMENTS AND FIELD TRIALS PERTAINING TO THE CONTROL OF SALTCEDAR (TAMARIX PENTANDRA)

By H. Fred Arle 1/

ABSTRACT

Control of saltcedar in waste places and along irrigation canals has been a problem since the species first gained sufficient foothold to be considered a weedy plant. Mechanical measures such as undercutting, burning, or application of herbicides other than the systemic herbicides generally were considered ineffective because of requirement for periodic retreatment. Mechanical measures and systemic herbicides now show promise of becoming practical control measures.

Attention first was given to investigating methods of controlling saltcedar (Tamarix pentandra) with systemic herbicides in 1948. The initial treatments basically compared effectiveness of varying rates of 2,4-D sodium salt with esters of 2,4-D applied by both ground-operated and aerial equipment. Results from these field demonstrations throughout South Central and Pacific Southwest were inconclusive, but sufficiently promising to warrant further investigations.

Continued investigations with systemic herbicides have revealed several definite trends. Esters of 2,4-D and 2,4,5-T were especially effective when applied to regrowth from plants previously broken down by mechanical means, or upon seedlings. The studies also indicate that several chemical applications are required to eradicate saltcedar and that certain of the 2,4-D formulations consistently are more effective than other preparations. Saltcedar plants show a marked increased resistance to all chemicals as plants grow older which conclusively shows the need for timely and programed maintenance operations following initial clearing of mature growth.

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The work being reported has been conducted by various Federal and State agencies in Arizona, New Mexico, and Southern California to evaluate the effectiveness of chemical and mechanical methods for the control of saltcedar (Tamarix pentandra).

The encroachment of saltcedar onto river flood plain areas and along irrigation systems had been noted with increasing concern over a period of years, but possibility of controlling these plants through the application of herbicides was not investigated until 1948. Since then, many experiments and trials have been conducted to evaluate the efficiency of herbicides.

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During early May of 1948, personnel of the Dow Chemical Company made an aerial application of the isopropyl ester of 2,4-dichlorophenoxy acetic acid to old growth saltcedar on a five-acre plot south of Avondale, Arizona, near the confluence of the Salt and Agua Fria Rivers. This material was applied at an acid equivalent rate of 5 pounds in 15 gallons of diesel fuel per acre as the carrier. The area was retreated during early August 1948 with a sodium salt formulation of 2,4-D. Aircraft applications of 2,4-D were also tested by Bureau of Reclamation and Department of Agriculture personnel on plants growing on bottom lands of the Gila River near Dome, Arizona. Plots of 6.5 acres each were sprayed during May 1948 to compare the effectiveness of 3, 4, and 5 pounds per acre of the sodium salt of 2,4-D with comparable rates of an ester formulation. The esters were applied in a diesel oil carrier while a diesel oil-water emulsion was used for the sodium salt, both applied at 15 gallons per acre.

In each of these initial tests, it was noted that the first symptoms of herbicidal action developed rapidly. Curving and bending at the tips of young stems were evident the day following treatment and several days later defoliation occurred. The mature saltcedar plants were suppressed severely throughout the growing season, especially by applications of 4 and 5 pounds per acre. There also was evidence that the ester formulations were more effective than the sodium salt formulations of 2,4-D. Throughout the summer, continued effect of herbicidal action was indicated by alternate leafing out and dying back of foliage. Observation of the treated plots during the late fall showed that the understory of arrowweed (Pluchea sericea), pickleweed (Allenrolfea occidentalis), and other miscellaneous annuals, and many of the one- and two-year-old saltcedar plants, particularly those growing in open areas and not sheltered from the spray by taller growth, were killed by the higher rates of application. Observation of these plots in April 1949 revealed that the foliage and new canes on the mature saltcedar plants still were showing effects of 2,4-D action as epinasty could be noted on some green growth. However, the preponderance of new twigs and foliage coming from the center and base of the treated plants indicated that respraying would be advisable.

The initial effect of these early applications appeared to be a deterring factor in the normal growth and vigor of saltcedar, and interest in this method of control was further stimulated. The first "large-scale" aerial application of 2,4-D to saltcedar was made on the McMillan Reservoir delta near Carlsbad, New Mexico, by Bureau of Reclamation personnel. The sodium salt of 2,4-D was applied at 1 pound per acre for the initial treatment in September 1948 and 2 pounds acid equivalent per acre of the same material for retreatment in June 1949. In both cases the chemical was applied in 5 gallons of spray per acre consisting of 4 gallons of water and 1 gallon of diesel oil. Excellent control of saltcedar resulted from the two treatments. When the final estimation of results was made during October 1950, almost 1-1/2 years after the second and final spraying, the regrowth varied from as little as 1 percent in some areas to 100 percent in a few small, more or less circular patches. It is conceivable that the areas of high survival were due to poor coverage during the spraying operation. The overall kill was estimated at 85 percent. Even today, this represents the maximum control ever reported from airplane spraying of saltcedar with 2,4-D.

An additional 100 acres of saltcedar were sprayed by airplane during the Fall of 1948 using 1 pound per acre of the sodium salt of 2,4-D. This single application was much less effective than the combination fall and spring treatment, which was mentioned previously.

During this period the results from both single and repeated low-volume aerial applications of 2,4-D on saltcedar on the McMillan Reservoir delta were consistently better than from similar applications at higher rates to saltcedar on the Gila River flood plain near Yuma, Arizona. The much drier climate and the greater depth to groundwater (14 to 20 feet) at Yuma compared to only 6 to 8 feet on the McMillan Reservoir delta were considered possible factors in this difference in results.

It should also be noted that during this same period personnel of the Imperial Irrigation District in California were obtaining highly satisfactory results with 2,4-D applications to saltcedar growth along irrigation canals and irrigation systems. Two applications in one season usually gave almost complete control. Along canal banks the eradication of saltcedar created an unexpected problem: the decaying roots left passageways or tunnels, thus providing an escapeway for irrigation water which necessitated reworking of the canal banks.

Through the cooperative efforts of the Bureau of Reclamation and the Department of Agriculture another experimental tract was established in the Gila River channel near Yuma, Arizona, during July 1949. One plot of 10 acres of dense saltcedar growth was bulldozed to ground level in July 1949. The results of 2,4-D applications to regrowth on this area were to be compared with treating an adjoining undisturbed tract. The regrowth from crowns were 3 to 5 feet in height when sprayed by airplane on April 18, 1950. An amine formulation of 2,4-D was applied at 4 pounds per acre. A year later, rather dense regrowth which was 3 to 6 feet tall remained on the previously bulldozed area and the effects of treatment were also obscure on the old growth plot. The areas were then divided equally and retreated with an amine salt of 2,4-D at 2.5 pounds per acre while the other half was sprayed with an ester formulation of 2,4-D and 2,4,5-T in equal proportions at 2.5 pounds per acre. The plots were retreated during October 1951 and again in May of 1952. Best final results were obtained where sprays were applied to regrowth following bulldozing and the ester formulation of 2,4-D and 2,4,5-T was superior to other formulations tested.

The inconclusive results from aerial applications in Arizona prompted the establishment of an experimental tract in the Gila River flood plain southwest of Phoenix, Arizona, with the Bureau of Reclamation and the Department of Agriculture, Division of Weed Investigations, cooperating.

The study was designed to allow experimental applications of various herbicides with ground-rig equipment. Such an arrangement facilitated the inclusion of a large number of plots and treatments on a limited area.

During March of 1951, an area of approximately 40 acres of dense and tall saltcedar was cleared by bulldozing and burned two months later. Access lanes were established between plots to allow passage of ground spray equipment. A total of 74 plots, each approximately 37 feet wide and 380 feet long (1/3 acre), were established. Plans were formulated whereby applications of 2,4-D at rates of 1.3 and 2.6 pounds per acre would compare the effectiveness of amine 2,4-D with an ester combination of 2,4-D and 2,4,5-T. The effect of these materials on regrowth of various ages was also a consideration. Initial applications were planned for regrowth after it had reached ages of 6, 12, 18, and 24 months. Each series of plots was then retreated during the spring and fall of each year following the original treatment.

Definite trends became apparent as the study progressed. The 50-50 mixture of 2,4-D and 2,4,5-T esters was consistently more effective than the amine salt of 2,4-D. The heavier rate gave better results with both chemicals and kills were highest when regrowth was treated at an early age. In no case did the first application give a high percentage kill of regrowth. The results improved with each treatment, but only those made to 6-month-old regrowth produced satisfactory kills when followed by two or more applications. This can best be seen by reviewing the survival figures of the higher application rates of each chemical when initial treatments were made to 6- and 18-month-old regrowth. In August 1952, the percentage kill of 6-month-old regrowth from two applications made in September 1951 and May 1952 were 81 percent for the ester and 60 percent for the amine formulation. In August 1953, the percentage kill of 18-month-old regrowth upon plots which were treated during September 1952 and May 1953 were 33 percent for the ester and only 11 percent for the amine formulation. Although spraying was continued on this series of plots through 1955, the general trend of results remained the same.

A somewhat similar experiment was conducted in an adjacent area to determine when saltcedar seedlings became resistant to applications of 2,4-D and related chemicals. Applications of amine 2,4-D, the propylene glycol butyl ether esters of 2,4-D, 2,4,5-T, and a 50-50 combination of 2,4-D and 2,4,5-T were made at a rate of 2 pounds per acre when seedlings reached 3, 9, and 15 months of age. There was no significant difference between the various ester formulations; however, the amine salt of 2,4-D was decidedly less effective and did not kill all seedlings even when the treatment was made to 3-month-old seedlings. When treatments were delayed until seedlings were 15 months old and were 3 to 6 feet tall, there was a marked reduction in the effectiveness of all chemicals.

During the period between 1951 and 1956, an extensive acreage of saltcedar in New Mexico was treated by aerial application of 2,4-D through the combined efforts of the Bureau of Reclamation and the State Engineer of New Mexico. Most of this acreage was treated with an amine salt of 2,4-D and usually at a rate of 2 pounds per acre applied in an oil-water emulsion. Although these applications invariably produced an almost complete kill of foliage and a partial kill of the upper twigs and stem extremities, eradication of adult saltcedar plants was always very low. One 250-acre tract was treated five times during a period of three growing seasons and showed less than a 50 percent reduction in population a year after the final treatment.

The work in New Mexico was indicative that the chemical formulations and rates employed were merely control measures which were effective only during the period of repeated treatment. When spraying was discontinued, saltcedar growth could be expected to reach its original stand and density within one or two years.

A further discouraging fact in the aerial application of 2,4-D is the ever present possibility of spray drift onto nearby agricultural fields which could conceivably result in injury and yield reductions of 2,4-D susceptible crops, especially cotton.

Several aerial applications of 2,4-D and related materials have been attempted while saltcedar was dormant. Results thus far have been inconclusive; however, it is apparent that ester formulations of 2,4-D are much more effective than the amines. Also, there is evidence that better control is obtained when oil rather than water is used as the carrier.

Applications of 2,4-D and 2,4,5-T have also been made as basal or stump treatment with ground spraying equipment. Both methods have been decidedly more effective than treatments made by airplane. However, these methods are much more costly and very frequently impractical or even impossible in dense saltcedar thickets.

Mechanical control of saltcedar has also been attempted on a rather large scale in the Rio Grande Valley of New Mexico. This work is being carried on cooperatively by the State Engineer, New Mexico, and the Bureau of Reclamation. Clearing of several thousand acres of flood channel and flood plain has been accomplished by using large tractors, dozers and Towner discs. To date these practices have afforded only temporary control with one or two operations per year necessary to maintain the areas relatively free of interfering growth.

Mechanical control has also been practiced in New Mexico by the Fish and Wildlife Service. Several thousand acres of river-bottom vegetation which included saltcedar, willow, and cottonwood have been cleared from the Bosque del Apache National Wildlife Refuge. The saltcedar population varied from seedling to trees up to 5 inches in diameter. The larger growth was cleared through the use of bulldozers and a tandem-type brushcutter pulled by a large tractor. On light growth of saltcedar, where plants did not exceed one inch in diameter, large 5-bottom, 30-inch disc plows were used. After clearing was completed much of this land was leveled and put into cultivation.

Although the considerable number of experiments and trials have not resulted in an entirely economical and practical method of killing saltcedar, valuable information on its control has been developed. This information may be summarized as follows:

1. Saltcedar is more difficult to kill on flood plains than along irrigation channels and streams.

2. Single spray operations have never given satisfactory total plant kill of adult saltcedar and only rarely have two repeated treatments eliminated 80 percent or more of the plants.

3. Periodic spraying of infested areas with 2,4-D and 2,4,5-T will defoliate saltcedar and in this manner reduce transpiration losses.

4. Applications of 2,4-D and related materials appear more effective on young regrowth following mechanical destruction than on adult saltcedars.

5. Application rates of less than 2 pounds per acre have generally given poor results.

6. Low-volatile esters of 2,4-D or combinations of 2,4-D and 2,4,5-T have been consistently more effective than amine or sodium salts of 2,4-D.

7. Dormant applications of 2,4-D and 2,4,5-T esters have shown promise in the control of saltcedar.

8. Mechanical means, although expensive, are useful in the eradication of saltcedar, especially in areas near cotton or other crops susceptible to 2,4-D.

9. Mechanical control must be exercised at least yearly to eliminate regrowth from root sprouts and seedlings.

10. Saltcedar is more difficult to kill with 2,4-D and related materials than most willows, cottonwoods, and other woody phreatophytes.

11. Mechanical clearing followed by spraying of young regrowth with 2,4-D or a mixture of 2,4-D and 2,4,5-T at 2.5 pounds or more per

acre repeated as necessary once or twice a year appears to be the most effective and practical method now known for controlling saltcedar.

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