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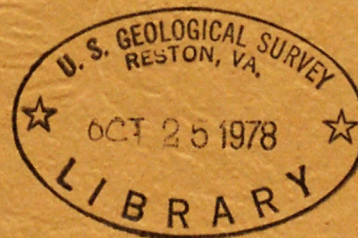
MANAGEMENT OF FLOOD-PLAIN VEGETATION,  
1967 TO 1972

SAN CARLOS INDIAN RESERVATION, ARIZONA

BY

D. M. PARK, R. C. CULLER, AND R. M. TURNER

USGS OPEN-FILE REPORT 78-412





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UNITED STATES  
(DEPARTMENT OF THE INTERIOR)  
GEOLOGICAL SURVEY

[Reports - Open file series]

MANAGEMENT OF FLOOD-PLAIN VEGETATION, 1967 TO 1972,

SAN CARLOS INDIAN RESERVATION, ARIZONA

By D. M. Park, <sup>Richard</sup> R. C. Culler, and R. M. Turner, <sup>1912-</sup> <sup>1940-</sup>

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Prepared in cooperation with  
The Bureau of Indian Affairs

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Tucson, Arizona

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## Preface

This report is one of several reports describing the hydrologic studies and associated activities related to the Gila River Phreatophyte Project. The objectives of this project were to study the hydrologic changes resulting from the removal of phreatophytes and substitution of grasses. Numerous methods have been used for removing the phreatophytes, preventing reinfestation, and establishing the replacement vegetation. Varying degrees of success in controlling the phreatophytes have been achieved and varying effects on the hydrology of the site have been observed. This report describes the management of flood-plain vegetation during the period of the hydrologic study.

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## List of Plants

Scientific name	Common name
<i>Agropyron elongatum</i> Host.	
ex Beauv.	Tall wheat grass
<i>Baccharis glutinosa</i> Pers.	Seepwillow
<i>Cynodon dactylon</i> (L.) Pers.	Bermuda grass
<i>Eragrostis Lehmanniana</i> Nees.	Lehmann lovegrass
<i>Panicum antedotale</i> Retz.	Blue panic grass
<i>Populus fremontii</i> Wats.	Cottonwood
<i>Prosopis juliflora</i> var.	
velutina (Woot.) Sarg.	Mesquite
<i>Sporobolus airoides</i> Torr.	Alkali sacaton
<i>Suaeda depressa</i> Watson	Seepweed
<i>Tamarix chinensis</i> Lour.	Saltcedar

MANAGEMENT OF FLOOD-PLAIN VEGETATION,  
1967 TO 1972, SAN CARLOS  
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By D. M. Park,<sup>1/</sup> R. C. Culler, and R. M. Turner

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Abstract

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During 1967-71, 15,800 acres of flood-plain vegetation were cleared from a 26-mile reach of the Gila River valley and a 9-mile reach of the San Carlos River valley. Both areas are on the San Carlos Apache Indian Reservation, Arizona. The area cleared in the Gila River valley included the Gila River Phreatophyte Project and the clearing was conducted as prescribed by the experimental design of that research program. Establishment of replacement vegetation was attempted on the cleared areas with indifferent success.

The report outlines methods used to remove the vegetation and to discourage its subsequent regrowth. Costs of the clearing operation are given by vegetation type, and descriptions of the procedures used for establishing new vegetation are given.

Clearing and subsequent maintenance of parts of the flood plain were hampered by channel clogging and subsequent flooding of adjacent areas. Part of the area selected for clearing lies within the San Carlos Reservoir. The wide range of water level in the reservoir further aggravated maintenance of an inflow channel. Both draglines and a dredge were used to open a channel to the reservoir. Because the flow of the Gila River is intermittent, vegetation becomes established in the channel at the head of the reservoir during periods of no flow. The report concludes that the presence of the vegetation promotes silt deposition and further clogging. Inflow channel maintenance is a persistent problem that will require well-planned repetitive clearing of vegetation at the head of the reservoir.

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## Introduction

The flood plain is defined as the lowland that borders a river, usually dry but subject to flooding (Hoyt and Langbein, 1955, p. 12). It serves two functions in the hydraulic system of a drainage basin: it conveys surface flows exceeding the conveyance capabilities of the river channel and it conveys subsurface flow either to the river channel or down the valley. Because of the fertile soil and abundant water supply, the flood plain is also an ideal environment for vigorous plant growth. On the flood plains in the Southwestern States the natural vegetation includes plants called phreatophytes that depend for their water supply upon ground water lying within reach of their roots (Meinzer, 1927). This vegetation has a significant impact upon the hydraulic functions of the flood plain: The plants retard the movement of the flood water over the surface, and the consumptive use of phreatophytes is a withdrawal from the subsurface system. These impacts result, respectively, in greater flood damage during the periods of flood flows, and in reduction in the quantity of water moving downstream.

Because of their dense, tall canopy, many phreatophyte communities provide an important habitat for mammals and birds, many of which are exclusively dependent upon these forests during the breeding season (Carothers and Johnson, 1975). These communities also provide an esthetically pleasing green belt of luxuriant vegetation in otherwise sparsely vegetated areas. Aside from these important attributes, man often views these communities as having low economic value where they occupy fertile, moist sites which could be used to produce vegetation with greater and more direct economic returns.

Because of the detrimental effects of phreatophytes on the hydraulic functions and economic productivity of the flood plain, phreatophyte control has been proposed and applied. Phreatophyte control consists of removing all or part of the phreatophytes and substituting vegetation with a lower consumptive use, higher economic value, and lesser resistance to surface flow. The proportion of phreatophytes removed depends on the specific objectives for the site.

The Gila and San Carlos River flood plains within the San Carlos Indian Reservation are ideal examples of the phreatophyte problem as described by Robinson (1965) and more recently by Horton and Campbell (1974). The discharge of the Gila and San Carlos Rivers is completely appropriated to satisfy upstream diversions in Duncan and Safford valleys and downstream recreation, hydro-electric power, and irrigation demands of the San Carlos Project. To satisfy the demands, maximum efficiency is required of the Gila and San Carlos River channels and flood plains in conveying surface and subsurface flow through the reservation. The fertile soil and abundant water supply of the flood plains is also important to the San Carlos Apache Tribe for livestock grazing and irrigated farming. In the past 35 to 40 years, the economic productivity of these valleys has been severely reduced by phreatophytes. Saltcedar, mesquite, and cottonwood are the primary phreatophytes found here, with saltcedar far exceeding the other species (figs. 1a and 1b).

The potential for production of forage on these flood plains far exceeds that of the surrounding land in this part of the reservation. However, forage will not grow under the phreatophytes, and fencing is necessary to exclude cattle because of the difficulty of collecting animals which stray into the thickets. Not only is the land unusable for grazing purposes, but the high consumptive use of water by the phreatophytes reduces the quantity of flow to the San Carlos Project. The dense phreatophytes also retard the movement of flood flows, increase siltation, and cause flood damage to irrigated farmlands within the reservation. The recognized benefits of phreatophytes for their wildlife habitat and esthetic values were considered by the San Carlos Apache Tribe to be lower than the benefits to be derived from improved cattle grazing and from irrigated farming.

The planned project entitled "Gila River Channel Improvements between the Camelsback Reservoir Site and Salt River, Arizona" was authorized to the Corps of Engineers by Public Law 85-500, 85th Congress, approved July 3, 1958. The stated purpose of this project was to (1) provide protection against floods in the Safford Valley by means of a cleared floodway in the Gila River and (2) increase the supply of water for irrigation by eradicating phreatophytes which transpire large quantities of water (Design Memorandum No. 1, U.S. Corps of Engineers, 1961). This project plan included a 26-mile (mi) reach of the Gila River flood plain within the San Carlos Indian Reservation.

In May 1962, the Geological Survey initiated the Gila River Phreatophyte Project (Culler and others, 1970), a comprehensive research study to evaluate the change in evapotranspiration and other hydrologic effects that might be produced by the removal of phreatophytes and subsequent substitution of other vegetation. A 15-mi reach of the Gila River flood plain within the San Carlos Indian Reservation, containing 5,500 acres of phreatophytes, was selected for the study site.

A separate program, the Gila River Phreatophyte Control Project, was started in 1967 and was designed to: (1) clear the project area of phreatophytes in accordance with the Corps of Engineers' Gila River Channel Improvement plans; (2) establish replacement grass cover essential to the U.S. Geological Survey study of the hydrologic effects of phreatophyte control; and (3) improve Gila and San Carlos River flood plains utilization by the San Carlos Apache Tribe.

Actual work of removal was accomplished by members of the San Carlos Apache Tribe using equipment of and with supervision provided by the Bureau of Indian Affairs. The work was inspected by the Corps of Engineers as an integral part of the authorized Gila River Channel Improvement Project. The senior author of this report is an employee of the Bureau of Indian Affairs and was directly responsible for the completion of the project. Assistance in the preparation of the report was provided by employees of the Geological Survey.

## Description of the Project Site

### Location and Topography

The project area includes a 26-mi reach of the Gila River flood plain extending from the eastern boundary of the San Carlos Apache Indian Reservation to a point 1 mi downstream from the mouth of the San Carlos River in the San Carlos Reservoir as shown in figure 2. This area is bounded by sloping terraces and alluvial fans and includes 13,700 acres of flood plain ranging in width from 3,500 to 5,000 feet (ft). The river meanders across the flood plain in a channel 100 ft wide and 7 ft deep. This channel has been dry for periods of up to four months and the flood plain has been completely inundated by floods about every three years. High flows of silt-laden water have resulted in the formation of natural levees at the channel's edges. These levees restrict or prevent return of flood water to the channel as the flood subsides. This trapped water is then used by plants. Discharge and channel changes in this reach are described by Burkham (1970, 1972, and 1976). The depth to ground water on the flood plain ranges from 5 to 20 ft. The geology and ground water have been described by Weist (1971) and Hanson (1972).

A 9-mi reach of the San Carlos River flood plain is also included in the project. This reach, approximately 2,000 ft wide, extends from the mouth of the San Carlos River to a point 2 mi downstream from the town of San Carlos. The area is 2,100 acres. The river channel is approximately 4 ft deep and 40 ft wide. The river has been dry for periods of one month and the flood plain is completely inundated by floods at intervals of three years.

The project area flood plain was surveyed in 1966 for prehistoric Indian ruins, under the direction of J. E. Ayres, Assistant Archaeologist, Arizona State Museum, University of Arizona. The area had been surveyed and the important archeological sites excavated in 1959.

### Climate

The climate of the project area is typical of east-central Arizona at an elevation of 2,600 ft above mean sea level and is classified as semi-arid. Annual precipitation averages 14 inches (in.) and has ranged from a minimum of 4 in. to a maximum of 25.8 in. The seasonal distribution of precipitation is produced by widespread weather fronts in winter and short-duration high-intensity convective storms in July, August, and September. Drought is common in April, May, and June as well as October through mid-November. Snow seldom falls on the area but does accumulate on the nearby mountains. In the winter daily temperatures range from an average minimum of about 27°F to an average maximum of about 67°F; in the summer from 68°F to 101°F. Mean monthly temperatures range from 44°F in January to 84°F in July (Sellers and Hill, 1974). Winter nights tend to be cooler in the project area than in the surrounding area because of downslope cold-air drainage. Freezing temperatures do not generally occur during the period March-October. Average daily humidity is highest in July and August.

## Soils

The soils of the project area are developed in a heterogeneous complex of alluvium ranging from clay to cobbles which are constantly relocated by erosion and deposition. All tributaries to the project area are graded to the flood plain, not to the river channels. Flow in these tributaries consists of high peak discharges of short duration produced by the intense summer storms. Large quantities of sediment are thus deposited in alluvial fans on the flood plain. Flood flows in the river redistribute this alluvium on the flood plain, creating a heterogeneous and frequently changing surface on which immature soils have developed locally. Soil-texture profiles at a number of sites in the project area have been described by McQueen and Miller (1972).

## Vegetation

Because flood plains are unstable, plant communities occupying these sites are prone to destruction. The recent experimental clearing program on the Gila River flood plain is but the last of what must have been numerous clearing events. The most recent previous event occurred between 1905 and 1909, when most of the vegetation along the upper Gila River valley was destroyed by major floods (Burkham, 1972). Establishment of the flood-plain vegetation occurred during the following relatively stable period from 1918 to the 1960's (Burkham, 1972). The postflood vegetation during the first half of this period developed into a complex assemblage of plant communities dominated by forests of cottonwood and willow; thickets of seepwillow, arrowweed, and seepweed; and low woodlands of mesquite (Turner, 1974). This same vegetation had probably grown here during the preceding millenia.

Beginning in the 1930's or 1940's, most of the native plants that usually reoccupied and dominated flood plains between major floods were replaced by a new plant introduced into the area by man (Turner, 1974); except for the mesquite woodland, the archtypal plant communities of the flood plain have given way to a uniform vegetation of saltcedar, the introduced plant. At the time of the most recent clearing operation, the lowest, most humid habitats were occupied by saltcedar; mesquite woodlands continue to occupy higher ground (figs. 1a and 1b).

Preclearing vegetation along the San Carlos River was similar to that of the Gila River except that forests of cottonwood and thickets of seepwillow remained along the upper few miles of the San Carlos.

The schedule of clearing operations on the area of the Geological Survey's hydrologic study was prescribed by statistical requirements of the experimental design. The upper subreach, cross-sections 1 to 9 (fig. 2), was cleared in the winter of 1967. The middle subreach, cross-sections 9 to 17, was partially cleared in 1969 and not completed until 1971. The downstream reach, cross-sections 17 to 23, was not used after 1965 because of log jams and inundation. The planned schedule of clearing had to be revised in 1966 and 1968. Care was exercised during the clearing operations to avoid disturbing the hydrologic instrumentation. Channel

excavation and dredging operations were planned to maintain or improve stream-gaging conditions, to reduce the frequency of overbank flow, and to drain areas scheduled for phreatophyte removal.

### Phreatophyte Control

Phreatophyte control as applied on this project has been divided into three phases: (1) clearing to eliminate the existing phreatophytes, (2) maintenance to prevent reoccupation by phreatophytes, and (3) seeding to establish the replacement vegetation.

A review was made of the available literature on phreatophyte removal to determine practical methods that could be applied to the project area. The various techniques for removing phreatophytes, whether chemical or mechanical, are influenced or limited by such factors as size, density, and species of plants; season of removal; soil moisture; and use of adjacent land.

Chemical-eradication methods are most effective in destroying young plants and, although rather unpredictable (Lowry, 1966), can be applied to mature vegetation on sites which are inaccessible to heavy ground equipment. Effective herbicides are non-selective and the possibility of damage to adjacent crops and of water pollution must be considered before applying chemical-control methods.

Mechanical-eradication methods, such as root plowing, uprooting, and mowing, are limited to soil conditions stable enough to support the equipment. The ability of mesquite and saltcedar to sprout new stems from the root crown necessitates severing the root from the crown. Root plowing, which cuts the root below the crown, is a proven method of eliminating mature phreatophytes. Saltcedar stems also sprout roots and new stems if buried in moist soil. Thus, unless the soil is dry, stems and branches of saltcedar must be removed from the area of phreatophyte removal. Large trees such as cottonwood can be uprooted. The uprooted trees will not burn and thus pose a threat to downstream structures if left on the flood plain. Removal of the entire tree is required. The removal procedure smooths and clears the ground surface, facilitating subsequent maintenance practices. Small phreatophytes can be suppressed but not killed by annual mowing to remove the top growth.

### Clearing

The basic equipment used in clearing live phreatophytes was the crawler tractor with a bulldozer blade mounted on the front and a root plow attached to the rear, as shown in figure 3. Root plowing was the first step in the normal sequence of clearing operations. The objective was to sever the root just below the root crown. This function was performed by drawing a blade horizontally through the soil at the desired depth to cut the root (fig. 4). Problem-free root plowing was seldom encountered. Among the factors complicating this practice were:

1. Cut stems and root crowns hanging to the root-plow frame (fig. 4).
2. Varying blade depth caused by rough ground surface. The operators were inclined to set the blade too deep to compensate for this condition.
3. Maintaining a minimum of 12 in. overlap in each swath to reduce the possibility of plants slipping around the end of the root-plow blade.
4. A dull cutting edge on the root-plow blade required excessive horsepower because roots, especially mesquite roots, would bend around the blade and drag through the soil. The blade was forced to the ground surface if many roots accumulated in this manner.
5. Protective covers were provided for vital parts of the tractor but considerable damage was still incurred by limbs penetrating or otherwise interfering with fuel, oil, hydraulic, or water lines; electrical wiring; radiators; mechanical linkage; and grease fittings. Operation of the tractors in reverse was frequently necessary and damage was sustained because the protective covers were designed for forward movement.
6. In some areas of recent silt deposition, the saltcedar root crowns were deeper than the root plow was capable of cutting.

The hot season is the most effective period to remove phreatophytes by mechanical methods. Wilting is rapid, nearly eliminating regrowth from buried limbs and root crowns. Seeds that fall on or are buried in dry soil by the root plow are less apt to germinate. Brush raking is also facilitated because dry soil is not gathered with the stems nor does it stick to plant roots or form clods.

Following root plowing, plant debris was gathered by a brush rake attached to the front of a crawler tractor as shown in figure 5. The rake teeth were set to penetrate the soil only a short distance in order to gather surface debris and limbs and roots buried at shallow depths. Areas of dense phreatophytes were raked twice, in opposite directions, to gather all roots and stems as completely as practicable and thus reduce regrowth. Efficient operation of a root plow was impossible in extremely dense thickets of phreatophytes because of the accumulation of large quantities of woody material in front of and under the tractor. This material was first removed from the area by brushing using a bulldozer blade held just above the ground. The cut stems were then piled and burned. The cleared area could then be efficiently root plowed to eliminate the root crowns. Raking and burning of the remaining root crowns and stems completed the clearing operation.

Large areas of swampy ground, inaccessible to mechanical clearing equipment, were created by the high river flows and reservoir levels of 1965 and 1968-69. Phreatophytes completely submerged for prolonged periods were killed but were replaced by saltcedar seedlings as the water receded. These seedlings were treated by aerial application of herbicides to kill or inhibit the plants until the ground dried sufficiently to support clearing equipment.

Removing dead brush from previously inundated areas presented different problems. Various grass species germinated following inundation. Methods were adopted that minimized soil disturbance and protected the grass seedlings. A "drag" made of two lengths of eighty-pounds-per-link anchor chain, one trailing the other by several feet, was used to break off or uproot plants killed by inundation (fig. 6). Two passes in opposite directions were made with the drag. The fallen plants were then piled and burned.

Cottonwood trees were confined to the San Carlos River flood plain, an area of relatively shallow water table. The trees were shallow rooted and individual trees with a trunk diameter of less than 10 in. could be pushed over with no preliminary steps. When removing cottonwoods the bulldozer blade contacted the tree trunk about 5 ft above the ground. The machine then moved forward until the trunk was nearly horizontal. On the next approach, the dozer blade was lowered to the ground level where it contacted the upturned roots. The entire tree was then pushed forward, pulling any attached roots from the ground.

Larger trees or small trees growing in groups had to be loosened from the ground before they could be pushed over. A trench was dug by the bulldozer 3 to 4 ft deep on one side of the tree. The bulldozer then approached the tree from the side opposite the trench, pushing over and uprooting the tree. The hole was then refilled. Because the uprooted large cottonwoods could be carried downstream by flood waters to damage bridges or other structures, these trees were dragged from the flood plain and stacked in piles on high ground. If an understory of brush remained, it was root plowed, piled, and burned.

In 1964, prior to the beginning of the Phreatophyte Control Project, an area of 360 acres in the Gila River flood plain near the highway bridge was cleared by the Bureau of Indian Affairs for an irrigation project as shown in figure 7. Removal of phreatophytes for the control project was started in January 1967 on three areas: the Gila River flood plain upstream from the railroad bridge; the reach between the highway bridge and the eastern reservation boundary; and the area below the mouth of Salt Creek (table 1 and fig. 7). High water levels in the San Carlos Reservoir limited clearing operations during 1968 to (1) the upstream reach of the San Carlos River flood plain, (2) a small area near the highway bridge on the Gila River, and (3) the higher elevations on the right side of the Gila River flood plain below the mouth of Salt Creek (fig. 7). The slow recession of water levels in the reservoir during 1969 restricted clearing to the area just downstream from the railroad bridge on the Gila River. Clearing was completed on the San Carlos River flood plain in 1970 and on the Gila River flood plain in 1971 (fig. 7 and table 1).

Table 1.--Areas of phreatophyte removal (acres).

	1967	1968	1969	1970	1971	1972	Total
Mechanical clearing	4,038	2,461	1,293	1,140	2,267	--	11,199
Chemical clearing	--	992	--	3,010	--	--	4,002
<sup>1/</sup> Mechanical maintenance	--	3,298	7,702	4,170	3,070	3,200	21,440
<sup>1/</sup> Chemical maintenance	--	3,074	694	330	829	4,300	9,227
Seeding	--	837	3,549	1,325	--	--	5,711

<sup>1/</sup>Repetitive maintenance was required on much of the project area.

## Maintenance

The objective of the various maintenance practices used on this project was to prevent the re-establishment of phreatophytes. Saltcedar's ability to reproduce by sprouting, either from buried stems and roots or from seed, complicated the maintenance operations. It was impossible to gather and burn all buried stems and roots during the clearing operation. Sprouting occurred and many areas had to be recleared. Grass seeding was therefore postponed for at least one year after clearing because most of the reclearing practices disturbed the soil and any established grass.

Saltcedar is a prolific producer of seed. Tomanek and Ziegler (no date) reported a production rate of 500,000 seeds per mature plant per season, and Warren and Turner (1975) reported 100 seeds/in.<sup>2</sup>/year were deposited on the soil surface at the Gila River Phreatophyte Project. Moist ground is required for the germination of saltcedar and other phreatophyte seed, and the local rainfall generally will not provide the necessary soil moisture. However, when inundated by the Gila River or its tributaries the flood-plain areas are ideal environments for the germination of seed. With saltcedar largely eliminated, species that were insignificant in the plant community before clearing have become dominant on some areas. As an example, by 1972 seepwillow dominated two rather extensive areas and became sparsely established on the entire cleared area.

Maintenance is accomplished in several ways depending on plant type and density, soil type and moisture content, use of adjacent land, and season. The methods and equipment used under some conditions were similar to those used in clearing operations. Root plowing is the most efficient method of removing regrowth saltcedar that has been growing in a favorable environment for a year or more. Dense seedlings are effectively removed by the brush rake equipped with serrated points (fig. 8). These points extend between the rake teeth, giving complete lateral coverage across the width of the rake, and roots are sheared just below the ground surface. Under optimum conditions, the soil moves between the rake teeth along with the severed plants. The tandem disk plow was effective in controlling seedlings and small regrowth plants under ideal conditions. The plant stems and upper 4 to 6 in. of root were uprooted and deposited on the soil surface. The tandem disk plow, root plow, and brush rake destroy any replacement plants that may have become established.

The top growth of young phreatophytes can be removed by mowing. A farm-size tractor of wheel or crawler type, with a power takeoff, was used to tow and to provide power for the heavy-duty rotary mower. This practice removes only the plant's top; the roots and some stems near the ground surface are not affected and continue to grow. Stems up to one inch in diameter can be severed with the rotary mower. This treatment must be repeated at least yearly to keep top growth reduced to a size that can be controlled by mowing. Mowing destroys the source of seed but does not eliminate the plant nor disturb the soil surface, thus desirable grasses are preserved.

The use of herbicides to control phreatophyte regrowth is the most economical and most effective of all practices used. Three or four applications made in two or three consecutive years have eliminated the highest percentage of plants, as compared with other practices used within the same time period. The herbicide treatment was made by applying the spray mixture to the foliage of the plant by either a ground spray rig or by aircraft. Young plants are more susceptible to herbicide treatment than mature plants. Plants growing on flat, poorly-drained soils were more completely controlled with herbicide than were plants on well-drained, sloping bench land. Best results were obtained with the herbicide 2, 4, 5 TP (Silvex) applied at the rate of 2 pounds of active ingredient per acre in a carrier of diesel oil and water. Precautions to avoid contamination of adjacent land, water, and plants were necessary.

### Seeding

The competition provided by replacement plants against re-establishment of the phreatophytes is a facet of management that has equal or greater potential than mechanical or chemical-control measures. A dense sod of Bermuda grass will effectively compete with saltcedar seed and either prevent seeds from reaching the ground or crowd out small seedlings. Perennial forage plants were nonexistent or very sparse in all the phreatophyte areas cleared, however. Planting of forage plants was necessary to provide: (1) cover to protect the land from erosion, (2) competition for re-established phreatophytes, and (3) feed for livestock and wildlife. Soil-moisture and temperature conditions were often unfavorable for the establishment of forage plants. July and August were the most advantageous months for planting seeds on project lands because moisture and temperature were commonly suitable for germination and establishment of the adapted grass species. The topography of the land was suitable for seeding either broadcast or by drill.

A mixture of forage plant species was more desirable than a single species because of the variation in soil type and moisture-retention qualities along with the limiting factors of climate. The variables were too intermixed to make it practical or economical to plant or manage a single species. Of the forage plant species adapted to this area, the following were used: blue panic grass, Lehmann lovegrass, Bermuda grass, alkali sacaton, and tall wheatgrass.

Because complete removal of saltcedar in one season is difficult, various methods of removal were practiced for more than one season before a seed bed was prepared. These practices tended to leave the ground surface quite smooth. Prior to or just after broadcasting grass seed by aircraft (the seeding method predominantly used) the crust of the land surface was broken by an anchor chain drawn between two tractors or by a series of short-rails drawn by one tractor with the rail ends overlapped and their long axes 90 degrees to the direction of travel. Both methods left approximately one inch of the surface soil loose with various microdepressions and corresponding ridges.

Seed was broadcast only by airplane (fig. 9) when the mixture included seeds of widely varying size. Recommended seed-application rates derived from previous work were used in arriving at the proper seed rate and mixture proportions (table 2). Qualitative measurement of seed-broadcast rate was obtained by placing two one-foot-square greased boards in the seeded area immediately prior to scattering the seeds (fig. 10). Examination of these boards after planting showed that seeds of each species sown were well represented.

A range-land drill was used to plant large seeds of single species. Tall wheatgrass was planted in two limited areas having predominantly high saline-alkali soil. Seed was planted at the rate of 8 pounds of seed per acre. Since this is a cool-season plant, it was planted in January in a year when there was ample soil moisture for germination. However, in the absence of irrigation, few plants survived beyond the seedling stage.

Adequate precipitation for germination and seedling establishment is the most critical factor in producing a satisfactory stand of grass. Following a rainy season in this area, the growing season is so dry and hot that plants have to be developed well beyond the seedling stage to survive until the advent of cool fall or winter weather. Grazing before the plants become well established proved as detrimental as insufficient moisture at critical periods.

Figure 11 shows the location and approximate extent of seeding during each year, and table 1 lists the total acreage seeded each year. Seeding in 1968 was confined to the Gila River flood plain. More specifically, this operation was performed on areas cleared during 1964 and 1966 lying near the highway bridge. Seedling was usually done in July, just before the summer rains. There were two exceptions: a 90-acre parcel on the Gila River flood plain seeded in March 1969; a 200-acre parcel above the highway bridge on the San Carlos flood plain seeded in May 1969. These areas were planted with a rangeland drill. A total of 3,549 acres was seeded by aircraft in 1969. In 1970, a total of 1,325 acres was seeded by aircraft; most of this area had been unsuccessfully seeded in 1969. Bermuda grass, the only grass to be well established as of 1972, was confined to reservoir sediment on the downstream reaches of the flood plains of both the Gila and San Carlos Rivers as shown in figure 11.

#### Unit Cost

The cost (1971) per acre of clearing and maintenance are shown in table 3. Factors included in the cost computation are:

1. Equipment depreciation, repair parts, fuel, lubricants.
2. Repair and service labor.
3. Production rate per acre for equipment.
4. Production time per work shift.
5. Operator labor.

Table 2.--Grass seeds applied, and application rates.

Seed Mixtures	Pounds/Acre	Seeds Per Square Foot
Blue panic grass	4	734
Lehmann lovegrass	1	149
Bermuda grass	1	41

Table 3.-- Cost (1971) of clearing and maintenance per acre.

VEGETATION TYPE, PLANT HEIGHT, AND PERCENT COVERAGE	COST (DOLLARS)	
	ROOT PLOWING	RAKE AND PILE
	Range	Range
Mesquite, greater than 7 ft., less than 75 percent	17 to 59	23 to 61
Saltcedar, less than 6.5 ft., less than 75 percent	16	24
Saltcedar, 6.5 - 13 ft., less than 75 percent	31	82
Saltcedar, 6.5 - 13 ft., greater than 75 percent	26 to 62	42 to 71
Saltcedar, greater than 13 ft., less than 75 percent	38	63
Saltcedar, greater than 13 ft., greater than 75 percent	60 to 77	40 to 70
Saltcedar, greater than 13 ft., greater than 75 percent (wet area)	58 to 98	37 to 113
Cottonwood	62 to 150	86 to 163

MAINTENANCE	COST (DOLLARS)
	Range
Spraying, Ground and Air	3 to 9
Discing, Tandum Disc	5 to 8
Mowing	5 to 10
Root plowing (Spots)	6 to 17

### Channel Clogging and Excavation Within the San Carlos Reservoir

The project area within the San Carlos Reservoir presented unique problems in clearing and maintenance. Coolidge Dam was completed in 1928. The maximum elevation above mean sea level reached by the reservoir pool was 2,502 ft, 9 ft below spillway level, in March 1942. During the period from 1944 to 1966 the pool was confined to the area below the mouth of the San Carlos River, except for a few periods of several months. The reservoir boundary and normal pool are shown in figure 2.

Sediment deposited in the reservoir during the period of maximum storage, 1941-42, and the superimposed delta at the mouth of the San Carlos River, appreciably decreased the slope of the Gila River channel and of the flood plain above the delta as shown in figures 12 and 13. A reduction in channel width was apparent but the channel location had not been radically changed since 1935. Dense and tall saltcedar lined the river bank and covered the flood plain. This growth gradually encroached on the channel and, together with reduced slopes, caused a decrease in the channel conveyance of flood flows. As a result of the increased frequency of overbank flow of sediment-laden flood water, natural levees were deposited where the velocity of the water was reduced on entering the saltcedar thicket. During a period of about 20 years this deposition raised the channel and its levees above the other parts of the flood plain as shown in figure 14. Because of the gradual decrease in slope, the channel was eventually filled with sediment. Debris, mainly logs carried by summer storm flows, was stopped by the shallow depths in the channel and, due to the screening action of the saltcedar on the banks, was deposited in the channel as shown in figure 15. Additional sediment was then deposited in the resulting log jam.

This channel plugging was first observed in the winter 1962-63 at a point 1.5 mi above the mouth of the San Carlos River. After January 1963, the upstream progress of the log jam was documented by observation and photography as shown in figure 16 and as reported by Kipple (1977). During the summer flows of 1963 and 1964 the channel plug moved upstream 1.5 and 2.5 mi, respectively. By 1965 the rapid upstream progress of plugging made it impossible to measure the discharge of the Gila River at the downstream end of the Geological Survey hydrologic study. The diversion of even low and medium flows from the Gila River channel to numerous rivulets and ponds was also decreasing the inflow to the San Carlos Reservoir. The soggy soil on extensive areas of the flood plain also complicated phreatophyte-control operations. A channel excavation and maintenance program was indicated. In the interest of economy the channel dimensions were designed to provide conveyance for low and medium flow. A depth of 4 ft and a width of 20 ft were selected. If maintained at valley slope this channel could be expected to deepen and widen by erosion. The San Carlos Project provided the men and equipment for this program.

The most significant slope reduction of the Gila River flood plain from sediment deposition in the reservoir occurred in the reach extending from 1 to 2.5 mi upstream from the mouth of the San Carlos River. The exceptional deposition here was the result of the narrow flood plain and the obstruction to flow produced by the approaches to the former railroad bridge (figs. 13 and 14). Creation of a new channel through this reach was essential to the establishment and maintenance of a channel across the flood plain upstream from this point. In September 1965 a 2-cubic-yard (cu yd) dragline excavated 4,000 ft of channel through the railroad fill along the left side of the flood plain (fig. 17). The unconsolidated wet sediment in the center of the flood plain was incapable of supporting the heavy dragline and timber matting was required at some locations along the selected alignment.

Another 0.75-cu-yd dragline (fig. 17) started work in September 1965 in the vicinity of section 23 (fig. 18) and excavated 7,000 ft of channel along the right edge of the flood plain. The work of both draglines was halted by the high flows in the Gila River during the winter of 1965-66. The San Carlos Reservoir was filled to an elevation of 2,477 ft above mean sea level, and the excavated reaches of channel were inundated. The high flows also changed the channel alignment near section 1 and between sections 7 and 9 (fig. 18). A total of 4,000 ft of excavation was required to return the channel to the previous alignment in these reaches.

The reservoir receded sufficiently by the summer of 1967 to expose the channel excavated near section 23. On August 13, 1967, a flood filled this channel with debris as shown in figures 19 and 20. A dragline was operated a total of 21 days during the fall of 1967 to clear that debris from 3,000 ft of channel.

The high flows of 1968 filled the reservoir to an elevation of 2,490 ft above mean sea level, extending the head of the pool to section 13 (fig. 18). In April 1968 it was decided that a dredge should be obtained which could excavate and maintain the channel during the recession of the reservoir. A cleared channel extending into the reservoir pool was essential in order to prevent plugging by debris. Because sediment was deposited in the channel at the head of the reservoir, channel filling was concentrated near the location of the head of the pool during periods of high sediment-laden flow. Dredging operations were confined to excavating or clearing of the channel at these locations of concentrated deposition. Soundings indicated that the channel had been completely filled at section 17 and was partially filled at locations between sections 17 and 23.

Blasting, using 20 cases of dynamite, was used to open 750 ft of channel near section 17 in the fall of 1968. A dredge was obtained and dredging operations were started in January 1969 as illustrated in figure 21. The dredge was operated to create a channel approximately 6 ft deep and 50 ft wide. A new channel one-half mile long was excavated by dredge between sections 17 and 19. In April and May 1969, the dredge cleared six reaches of channel 600 ft long, as needed, between sections 19 and 23.

Dredging operations were continued in June 1969 to excavate new channels or to clean old ones as the reservoir receded. One mile of new channel near section 23 was excavated as an extension of the channel constructed by dragline in 1965. In February and March 1970 the dredge cleaned 1 mi of channel in the vicinity of the abandoned railroad bridge. A channel 1.75-mi long near the mouth of the San Carlos River was excavated in April and May 1970. Dredging was continued on three-quarters of a mile of channel near Coolidge Dam in June and July 1971. Blasting was required on 1,200 ft of channel below the abandoned railroad bridge, where rock and saltcedar roots had prevented clearing by dredging.

### Summary and Conclusions

Brush removal and the establishment of replacement vegetation on a flood plain pose numerous problems not generally encountered on upland sites—unstable ground, inundation, and extensive areas of loose sand are but a few. Factors favorable under one set of conditions may be detrimental in another. For example, moisture, essential to seedling establishment, renders the soil unstable when carrying the weight of brush-removal equipment. To avoid encroachment of undesirable plants, vegetation should be planted to emerge the first growing season after brush removal. However, saltcedar and seepwillow reoccupy the land very rapidly: seeds from these plants germinate in the spring and summer while adapted grass species germinate only during the warm summer. Flooding kills most plants that are submerged for an extended period, and as the flood waters recede an area of soft unstable land remains that is inaccessible to equipment, yet ideal for the germination of seeds. Root plowing kills desirable and undesirable plants alike by cutting their roots a few inches below the ground surface. The same procedure may bury a plant stem in moist soil where it can sprout. Although mowing does not disturb the soil, the cutting of plant stems stimulates growth from plant parts below the cut and regrowth may be prompt and vigorous. Herbicides provide an effective, economical means of removing saltcedar and mesquite but the risk to the environment must be considered.

Results from phreatophyte control have been mixed. By removing the brush, livestock grazing can be more easily controlled. In areas where moisture has been adequate, forage plants have increased following removal of woody plants. However, in these same cleared areas typical flood-plain plants, principally saltcedar, Suaeda, seepwillow, and mesquite, have also become re-established. Suaeda is re-established in fine-textured, highly saline-alkali soil previously occupied by mesquite. Seepwillow, one of the predominant phreatophytes prior to introduction of saltcedar, has invaded areas of poorly drained lacustrine silt to a limited extent and is more abundant now than before clearing. Seepwillow is highly resistant to the herbicides to which saltcedar is sensitive.

Bermuda grass, almost absent among the saltcedar thickets, has re-established itself, especially on inundated areas. If the tall phreatophytes are held in check by either herbicide or mowing, Bermuda grass does very well as a ground cover and a forage plant, yielding enough forage for approximately 3 animal units per acre per year. Bermuda grass withstands early grazing better than the other introduced grass seeded. Grazing must be controlled for management of planted grasses.

In the absence of brush the river channel moves with each flood, endangering man-made structures on or near the stream banks. Shifts in the location of the channel will increase, and widening of the channel can be expected as a result of removing the confining brush. Each new abandoned channel becomes occupied by saltcedar, if viable seed is present when the channel shifts. The moving channel may also remove dense stands of brush and, if the plants do not become re-established, may produce a more open flood plain.

The extreme range of variability of the San Carlos Reservoir aggravates the problem of maintaining an inflow channel. The reservoir dimensions varied by 108 ft in depth, 15 mi in length, and 12,000 acres in surface area during 1965-71. The inflow of the Gila River ranged from 0 to 40,000 cubic feet per second during this period. The exposure of a large part of the reservoir bottom results in partial consolidation of sediments and the establishment of phreatophytes. The lack of sustained inflow permits the vegetation to encroach on the channel; this encroachment in turn promotes deposition in the channel. Under these conditions the problem cannot be solved by any feasible construction program. Well-planned repetitive clearing appears to be the only solution.

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