Riparian Vegetation and Its Water Use During 1995 Along the Mojave River, Southern California

By GREGORY C. LINES[1] and THOMAS W. BILHORN[2]

[1]U.S. Geological Survey.
[2]Consultant to California Department of Fish and Game.

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 96-4241

Prepared in cooperation with the MOJAVE WATER AGENCY and the CALIFORNIA DEPARTMENT OF FISH AND GAME

Sacramento, California
1996

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, Director

For additional information write to:

District Chief
U.S. Geological Survey
Federal Building, Room W-2233
2800 Cottage Way
Sacramento, CA 95825

Copies of this report can be purchased from:

U.S. Geological Survey
Information Services
Box 25286
Federal Center
Denver, CO 80225

CONTENTS

PLATE (in pocket)

FIGURE

TABLES (on plate 1)

CONVERSION FACTORS

Multiply	by	To obtain
acre	0.4047	hectare
acre-foot (acre-ft)	1233	cubic meter
inch (in.)	25.40	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer

Riparian Vegetation and Its Water Use During 1995 Along the Mojave River, Southern California

By Gregory C. Lines *and* Thomas W. Bilhorn

ABSTRACT

The extent and areal density of riparian vegetation, including both phreatophytes and hydrophytes, were mapped along the 100-mile main stem of the Mojave River during 1995. Mapping was aided by vertical false-color infrared and low-level oblique photographs. However, positive identification of plant species and plant physiological stress required field examination.

The consumptive use of ground water and surface water by different areal densities of riparian plant communities along the main stem of the Mojave River was estimated using water-use data from a select group of studies in the southwestern United States. In the Alto subarea of the Mojave basin management area, consumptive water use during 1995 by riparian vegetation was estimated to be about 5,000 acre-feet upstream from the Lower Narrows and about 6,000 acre-feet downstream in the transition zone. In the Centro and Baja subareas, consumptive water use was estimated to be about 3,000 acre-feet and 2,000 acre-feet, respectively, during 1995. Consumptive water use by riparian vegetation in the Afton area, downstream from the Baja subarea, was estimated to be about 600 acre-feet during 1995.

Consumptive water use by riparian vegetation during 1995 is considered representative of "normal" hydrologic conditions along the Mojave River. Barring major changes in the areal extent and density of riparian vegetation, the 1995 consumptive-use estimates should be fairly representative of riparian vegetation water use during most years. Annual consumptive use, however, could vary from the 1995 estimates as much as plus or minus 50 percent because of extreme hydrologic conditions (periods of high water table following extraordinarily large runoff in the Mojave River or periods of extended drought).

INTRODUCTION

Problem

Native riparian vegetation is an important natural resource along the Mojave River and elsewhere throughout the southwestern United States. Much of the riparian zone along the Mojave River has been cleared of native vegetation for agricultural, residential, and other uses. Also, because of ground-water pumping and other factors, some riparian vegetation has died and much of the remaining vegetation is threatened. Assuring an adequate water supply for the remaining native riparian vegetation is an important element in the court's recent decision regarding water rights in the Mojave basin management area (City of Barstow versus City of Adelanto, 1996, case no. 208568, Superior Court of California).

For water-management purposes, the Mojave basin management area has been divided into five subareas (fig. 1) by the Mojave Water Agency. Most of the riparian zone of the Mojave River is in the Alto, Centro, and Baja subareas, although riparian vegetation extends downstream through Afton Canyon. In addition, the Alto subarea has been divided into an unnamed zone upstream from U.S. Geological Survey gaging station 10261500 at the Lower Narrows and a zone downstream from the station designated the "transition zone" (plate 1). Water accounting, including

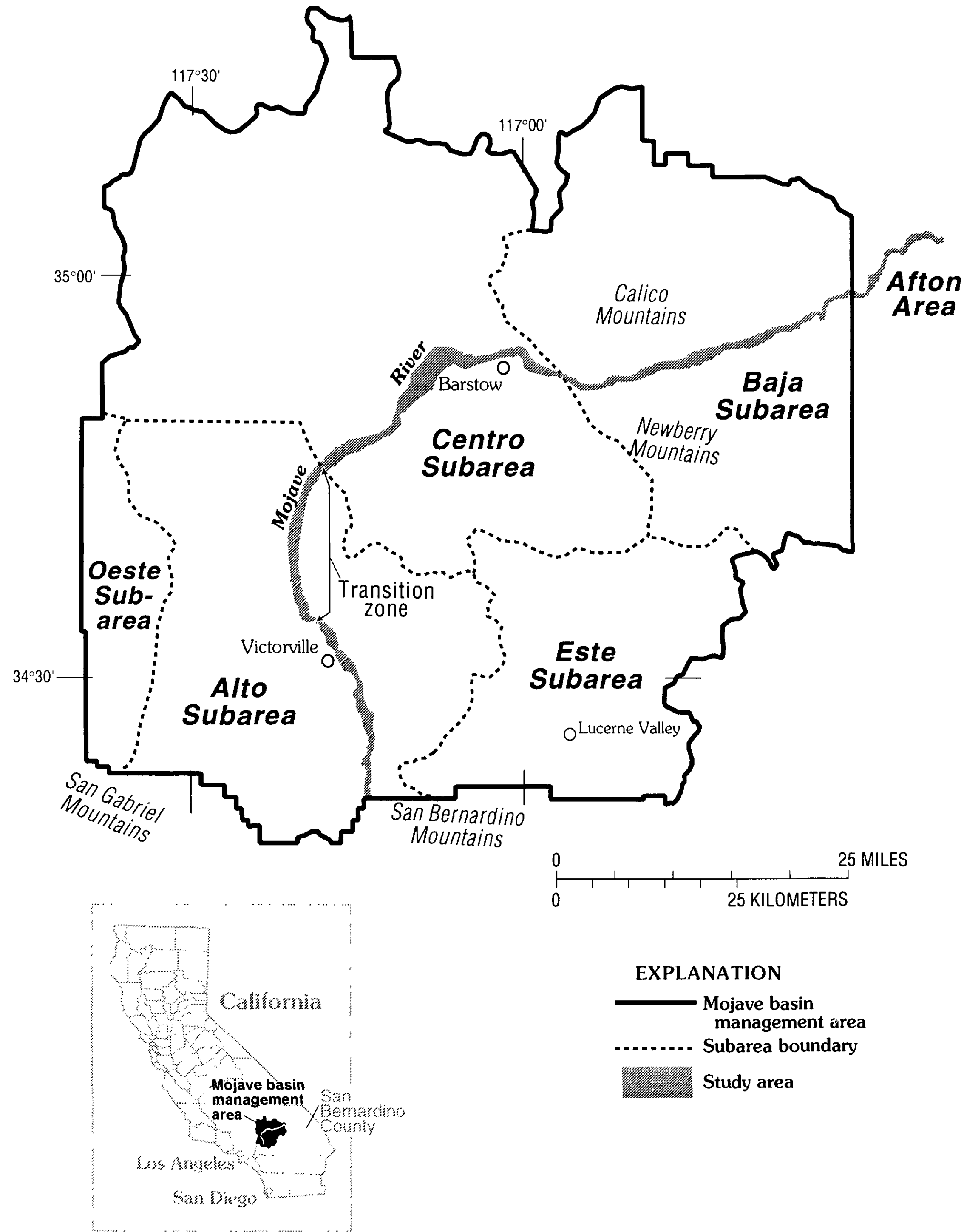

Figure 1. Study area in the Mojave basin management area.

the consumptive use of ground water and surface water by riparian vegetation, is required by the court in order to determine "safe yield," production allowances, the need for replacement water, and other water-management options.

Purpose and Scope

In 1995, the U.S. Geological Survey and the Mojave Water Agency agreed to conduct a study of riparian vegetation along the main stem of the Mojave River from The Forks (confluence of West Fork Mojave River and Deep Creek) to Afton Canyon, a distance of about 100 mi (plate 1). The study area includes the riparian zone of the Alto, Centro, and Baja subareas of the Mojave basin management area. It also includes the riparian zone downstream from the management area to U.S. Geological Survey gaging station 10263000 at Afton Canyon, which is designated the "Afton area" in this report. The ultimate goals of the study are to determine the source(s) of water utilized by riparian vegetation and the hydrologic factors that control its survival and reproduction. Initial elements of the study include an inventory of the extent, diversity, and density of riparian vegetation and estimates of its use of ground water and surface water. The inventory and water-use estimates, which are the subject of this report, will provide some of the information needed for protection of the remaining riparian vegetation and for future water management.

The California Department of Fish and Game also was contemplating an inventory of riparian vegetation along the Mojave River in 1995. Resources of the three agencies were combined, and the mapping of riparian vegetation and the water-use estimates presented in this report are the result of that cooperative effort.

Acknowledgments

The authors express their gratitude to the many landowners in the area who allowed access to their property for mapping of riparian vegetation. For their technical reviews and suggestions that greatly improved this report, the authors also express their gratitude to Thomas B. Egan, Biologist, U.S. Bureau of Land Management, Barstow, California; George C. Heise, Hydraulic Engineer, California Department of Fish and Game, Sacramento, California; and Juliet C. Stromberg, Associate Professor, Center for Environmental Studies, Arizona State University, Tempe, Arizona. Thanks are due Steven K. Predmore, U.S. Geological Survey, San Diego, California, for converting the authors' digitized mapping data to a geographic information system that allowed completion of the vegetation map in this report. Also, this report would not have been possible without the diligent help of Jerrald A. Woodcox (Editor) and Anna C. Borlin (Scientific Illustrator), both also with the U.S. Geological Survey, San Diego.

INVENTORY OF RIPARIAN VEGETATION

Mapping Techniques

Riparian vegetation grows in the Mojave River channel, on the flood plain, and on adjacent elevated slopes and terraces in what has been designated the riparian zone (plate 1). The riparian vegetation may utilize some soil moisture resulting from infiltration of precipitation; but, for the most part, the vegetation depends on ground water or surface water for survival. The riparian vegetation includes both phreatophytes and hydrophytes. "A phreatophyte is a plant that habitually obtains its water supply from the zone of saturation, either directly or through the capillary fringe" (Meinzer, 1923). Hydrophytes, on the other hand, usually are dependent on surface water for their survival (Meinzer, 1927). Along the Mojave River, hydrophytes typically grow along the edges of the river where there is perennial flow.

The extent and areal density (percent canopy cover) of active water-consuming vegetation in the Mojave River riparian zone were determined with the aid of vertical aerial photography. Aerial photographic coverage of the 100-mile stream reach was accomplished by three flights on July 6, 9, and 12, 1995. Kodak Aerochrome Infrared 2443 film was used, and visible light was filtered out below 520 nanometers. To determine the reproducibility of the false-color infrared signature of water-consuming plants, a part of the Baja subarea near Camp Cady (plate 1) was photographed a second time (July 14, 1996) at the same time of day, under similar weather conditions, and with the same equipment as used on previous flights. The comparison of photographs from the two flights over Camp Cady indicated no distinguishable differences in the location and extent of the orange-to-red false-color signature of water-consuming plants, and the early July photographs are considered representative of summer Mojave Desert conditions. The orange-red color was the basis for identifying phreatophytic plants on the photographs unless information on water-table depths, discussed later, led to the conclusion that plants probably were consuming soil moisture and not ground water.

Field examination was necessary in many areas to distinguish between healthy and stressed trees. Although not measured in a precise manner, trees were considered physiologically stressed if they had less than about 50 percent of the leaves found on healthy trees.

Identification of individual species was aided by low-level (altitude 700 ft) oblique aerial photographs that were taken July 12, 1995, using Kodak Ektar color film. Because of intermixed plant associations, field examination was necessary to positively identify plants to a species level. The entire mapped area was traversed by 4-wheel drive vehicles, by all-terrain vehicles, or by foot.

The latitude and longitude of about 240 locations were determined in the field with a Rockwell GPS (global positioning system) receiver using the Precise Positioning Service, which is available to U.S. Government agencies. The GPS locations were used for photograph scaling, azimuth, and tilt corrections.

False-color infrared photographs were digitally scanned to make color enlargements (scale about 1 in. = 500 ft) that were used for field mapping. At this scale, individual plants at least 5 ft in diameter usually were discernible. Drawings of mapped units were completed using the Autodesk AutoCad program. Angular distortion in the drawings was corrected using the Softdesk CadOverlay rubber-sheeting algorithm. The computer-based drafting allowed on-screen enlargement to a scale of about 1 in. equals 150 ft, which allowed the GPS locations and map units to be identified on the drawings to within 5 to 10 ft. To check overall accuracy, AutoCad drawings were plotted at a scale of 1:24,000 and compared with U.S. Geological Survey topographic maps of the same scale. Differences in the location of features that were identifiable on both the drawings and the maps were consistently less than 30 ft.

The AutoCad drawings were converted to a geographic information system (GIS) using Arc/Info. The areas of mapped plant communities, which are used later in this report to estimate water consumption, were computed using the GIS program. Considering all sources of possible error, the areas of mapped plant communities probably are accurate to within plus or minus 1 percent. Areas of riparian plant communities (in acres) are rounded to two significant figures in this report.

Plant Communities

It has long been recognized that distinctive associations or communities of native riparian plants grow in distinctive hydrologic environments or niches in the riparian zone along the Mojave River (Meinzer, 1927; Thompson, 1929). These riparian plant communities, for the most part, are the basis for selecting the mapped units that are shown on the vegetation map and summarized in tables 1–5 (plate 1). The riparian zone includes areas where riparian plants were growing in 1995. The riparian zone also includes barren and disturbed areas that were devoid of riparian plants, but where the return of the water table or land use to predevelopment conditions could induce future growth of riparian plants. The riparian zone generally includes the Mojave River channel and flood plain, some adjacent terraces, and the bases of some alluvial fans. Information in this report on water-table depth is based mostly on water-level measurements in wells made during 1991–95 for an earlier hydrologic study along the Mojave River (Lines, 1996).

Woodlands in the flood plain of the Alto and Centro subareas are composed mainly of intermixed cottonwoods *(Populus fremontii)* and willows *(Salix gooddingii, S. exigua, S. laevigata,* and *S. lasiolepis).* The cottonwood-willow woodlands also contain minor numbers of velvet ash *(Fraxinus velutina)*, white alder *(Alnus rhombifolia)*, baccharis *(Baccharis emoryi* and *B. glutinosa)*, and saltcedar *(Tamarix ramosissima).* The water table in healthy cottonwood-willow woodlands is typically less than 10 ft below land surface. The total area of cottonwood-willow woodland was about 2,600 acres during 1995—including about 420 acres of stressed woodland in the transition zone of the Alto subarea (tables 1–5).

Stands of willow and baccharis commonly grow in the Alto subarea in the absence of cottonwoods. The willows and baccharis typically grow in narrow bands along the river's edge in a slightly "wetter" niche than that of the cottonwood-willow woodland. The water table generally is a few inches below land surface. Because the willow-baccharis community commonly is no more than a few feet wide, it has been combined with the cottonwood-willow community in most areas on the map (plate 1). The total area of the willow-baccharis community that was mapped separately is about 120 acres (tables 1–5).

Single-species cottonwood woodlands are common on terraces and slopes that are slightly elevated above the flood plain. The water table is typically 10 to 15 ft below land surface. Monotypic cottonwood stands commonly are less dense and are composed of more mature trees than those found in the cottonwood-willow woodlands. The total area of the cottonwood woodland was about 620 acres during 1995—including about 130 acres of stressed woodland mainly in the transition zone of the Alto subarea (tables 1–5).

Honey and screwbean mesquite *(Prosopis glandulosa* and *P. pubescens)* grow in higher and drier areas than do cottonwood and willow trees, typically near the boundaries of the riparian zone. Widely spaced mesquite plants (areal density less than 1 percent) are common along the boundary of the riparian zone in the Centro and Baja subareas, although their areas typically are too small to be shown on the map (plate 1). Water-table depths in mesquite areas commonly are 10 to 30 ft below land surface, but the mesquite shows signs of stress if the water-table depth exceeds about 15 ft. The total area of mesquite in which areal densities exceeded 1 percent during 1995 was about 1,100 acres, mainly in the Centro and Baja subareas (tables 1–5). Most of the mesquite in the Mojave River riparian zone showed signs of water stress.

Saltcedar *(Tamarix ramosissima)*, a naturalized plant introduced to the United States during the 1800's (Robinson, 1958), is the most widespread riparian plant along the Mojave River. It is not certain when saltcedar was introduced to the Mojave River basin. Saltcedar grows in a wide range of hydrologic environments. The depth of the water table may range from a few inches in some areas to as much as 50 ft below land surface in others. Saltcedar usually forms dense thickets, except where the water-table depth exceeds about 20 ft or where it has to compete for sunlight with taller cottonwoods and willows. The river channel is periodically cleared of vegetation by the scouring of the riverbed during floods. Because of its rapid growth, saltcedar commonly is the dominant plant growing in the ephemeral river channel in the Centro and Baja subareas and in the Afton area. The total area where saltcedar was mapped as the dominant species during 1995 was about 5,200 acres (tables 1–5). In addition, saltcedar grew in subordinate numbers in all the native plant communities along the main stem of the Mojave River. Stressed saltcedar mapped in the Afton area during 1995 is the result of burning and other eradication efforts by the U.S. Bureau of Land Management that began in 1992 (Egan and others, 1993).

Hydrophytes are the most discernible water-consuming plant community. They almost always grow where there is perennial flowing or standing surface water. Common hydrophytes include cattails *(Typha latifolia)*, tule *(Scirpus acutus)*, and bulrush *(Scirpus olneyi)*. Hydrophytes are present mainly in the Alto subarea and at Afton Canyon. The total area of open water and hydrophytes was about 410 acres during 1995 (tables 1–5), of which about 90 percent was open water.

Desert willow *(Chilopsis linearis)* commonly grows on slightly elevated terraces and sand bars along the driest ephemeral reaches of the Mojave River in the Baja subarea and in the Afton area. The areal density of desert willow generally is less than 5 percent, and it seldom exceeds about 20 percent. Where desert willow was mapped as the dominant species during 1995 (about 2,700 acres), it is probably a xerophyte, dependent on soil moisture rather than ground water or surface water. Some desert willow undoubtedly benefits from the buildup of soil moisture during floods, but it probably is dependent mostly on infiltration of precipitation. Depth to the regional water table in these areas is unknown, but it may be greater than 50 ft because saltcedar is absent or very sparse along these driest reaches of the river. Although desert willow is not considered a phreatophyte in these areas, it is included on the map to document its extent for future researchers. Desert willow also occasionally grows in subordinate numbers with mesquite or saltcedar; in these areas, it may be a facultative phreatophyte and use some ground water. Because desert willow is probably a xerophyte where it is the dominant mapped species, it's water use is not included in the consumptive-use estimates for riparian vegetation that are discussed later in this report.

Arundo or giant reed *(Arundo donax)*, another introduced nonnative species, is scattered throughout the Alto and Centro subareas. During 1995, it was not growing in sufficient quantities to be mapped as a separate community, but single plants were common in open areas within the cottonwood-willow woodlands. Because arundo has been a very aggressive invader in other riparian zones in southern California, its presence along the Mojave River is documented here mainly to aid future researchers. Whether arundo will proliferate along the Mojave is uncertain. However, it seems to prefer the wetter and more humid environment of coastal streams, such as the Santa Ana River.

During 1995, there were about 10,000 acres of riparian vegetation and about 2,700 acres of desert willow (areal densities greater than 1 percent) along the main stem of the Mojave River. A total of about 12,000 acres of the riparian zone had been disturbed and was being used for agricultural, residential, and other uses—including about 5,400 acres in the Alto subarea, 6,300 acres in the Centro subarea, and 420 acres in the Baja subarea. In addition, a total of about 13,000 acres of the riparian zone was barren (less than 1 percent areal density of riparian vegetation or desert willow). The barren land typically was in the channel of the Mojave River where floods had removed vege-tation or where the water table was too deep to support phreatophytes. During 1995, there were about 2,700 acres of barren land in the riparian zone of the Alto subarea, 7,200 acres in the Centro subarea, 2,400 acres in the Baja subarea, and about 330 acres in the Afton area.

ESTIMATES OF WATER USE

Transfer of Previous Estimates

Water use by the riparian vegetation along the Mojave River can be estimated by using the results of a select group of studies conducted elsewhere in the southwestern United States. Estimates of water use from other studies were considered for use if they were obtained using water-budget, streamflow-depletion, or micrometerological techniques and if they were representative of fairly large areas (several acres) of the flood-plain environment. Tank-lysimeter studies, in which water use is determined in small artificial environments, were not used. Also, physiological studies using stem-flow gauges were not considered for use because converting the flow of sap in a few plant stems to an estimate of water use for a complete forest is not practicable.

Other criteria used for acceptance of water-use estimates were the documentation of areal densities of the plant species studied and a climate similar to that of the Mojave Desert. Many factors define an area's climate, but free-water surface evaporation is an excellent indicator of the climatic variables that also partly control transpiration of plants, such as solar radiation and wind. Thus, results of other studies were considered transferable if annual free-water surface evaporation was within about 10 percent of that along the main stem of the Mojave River, which ranges from about 60 to 85 in. (National Oceanic and Atmospheric Administration, 1982).

As pointed out earlier, distinct communities of riparian vegetation grow in distinct hydrologic niches along the Mojave River (Meinzer, 1927). Literature review indicates that these same communities commonly grow in the same hydrologic niches throughout the southwestern United States (Bowie and Kam, 1968; Weeks and others, 1987; Ball and others, 1994; U. S. Bureau of Reclamation, 1995, and Lines, 1996). The depth of the water table probably is the most important hydrologic factor that controls the composition and density of riparian plant communities. In the authors' opinion, this makes the transfer of water-use data for the same plant communities and areal densities in the southwestern United States a valid approach if the criteria above are met.

On the basis of micrometerological data collected along the Pecos River flood plain, in southeast New Mexico, Weeks and others (1987) estimated that annual water use by healthy saltcedar with areal densities ranging from about 50 to 80 percent averaged about 3 ft (or 3 acre-ft per acre). Ball and others (1994) and the U.S. Bureau of Reclamation (1995) in a study along the lower Colorado River near Blythe, California, estimated that saltcedar annually used 2.3 to 2.5 ft of water. These estimates were based on micrometerological data collected at healthy saltcedar thickets. Examination of aerial photographs of the saltcedar study sites supplied by the U.S. Bureau of Reclamation indicated that areal densities ranged from about 80 to 95 percent. Similarly, it was estimated that healthy mesquite along the lower Colorado River annually used about 1.4 ft of water. Areal densities of the mesquite study sites, estimated from aerial photographs, ranged from about 50 to 80 percent.

Water-use estimates from both areas are considered transferable to the Mojave River basin because annual free-water surface evaporation ranges from about 75 to 85 in. in the Pecos River study area and from about 80 to 90 in. in the study area along the lower Colorado River (National Oceanic and Atmospheric Administration, 1982). In the Centro and Baja subareas and in the Afton area, where saltcedar and mesquite are prevalent, annual free-water surface evaporation ranges from about 75 to 85 in. Using the water-use data from the Pecos River and Colorado River studies, it was estimated that annual water use of saltcedar with an areal density of 71 to 100 percent was 2.8 ft along the Mojave River during 1995 (table 6). Likewise, it was estimated that healthy mesquite with an areal density of 71 to 100 percent used 1.4 ft (table 6).

Bowie and Kam (1968) studied a cottonwood-willow woodland along Cottonwood Wash in western Arizona. The woodland also contained baccharis and velvet ash and was very similar to cottonwood-willow woodlands in the Alto subarea. The woodland had an areal density of about 27 percent, and annual water use was estimated to be 1.7 ft. The woodland's water use was determined from the increase in base flow (natural ground-water discharge) of Cottonwood Wash following the eradication of 22 acres of trees. Annual free-water surface evaporation at the study site is about 60 in. The transfer of this water-use estimate to the Mojave River basin, particularly to the cottonwood-willow woodlands in the Alto subarea where annual free-water surface evaporation ranges from about 60 to 75 in., is considered acceptable. Thus, annual water use by cottonwood-willow woodland with an areal density of 11 to 40 percent was estimated to be 1.7 ft along the Mojave River during 1995 (table 6).

Hydrophytes, water-loving plants that typically grow in flowing or standing water along the Mojave River, almost always have an "unlimited" supply of water. Because this mapped unit is about 90 percent open water, annual water use is assumed to be equal to the annual free-water surface evaporation, which averages about 5.6 ft in the Alto subarea and about 6.7 ft in the Centro and Baja subareas and in the Afton area (National Oceanic and Atmospheric Administration, 1982). Data from a tank-lysimeter study in Idaho indicated that tules transpired about 50 percent more water than was evaporated from open water (Stearns and Bryan, 1925). Whether this is true for hydrophytes along the Mojave River is uncertain. In any case, the error in assuming a water use equal to free-water surface evaporation is small because the plants compose only about 10 percent of the area of this mapped unit.

Estimated average annual water use for each of the mapped areal densities of healthy riparian vegetation along the Mojave River is given in table 6. The estimates for different densities of phreatophytes are based on the above studies and work by Hughes (1972) and van Hylckama (1974), both of whom found that a density reduction from 100 to 50 percent reduced water use by saltcedar only about 10 percent. Therefore, in estimating the water use for each mapped plant community in the present study, it was assumed that there is a 10-percent reduction in water use between the mapped density ranges of 71 to 100 percent and 41 to 70 percent.

Water use was assumed to decrease linearly for the mapped density ranges of 1 to 10 and 11 to 40 percent. Thus, water use for the 11 to 40 percent density range was assumed to be equal to 46 percent of the water use for the 41 to 70 percent density range. And water use for the 1 to 10 percent density range was assumed to be equal to 22 percent of the water use for the 11 to 40 percent density range. The values of 46 and 22 percent are calculated using the median value of each density range. For example, 25.5 (median of 11 to 40) divided by 55.5 (median of 41 to 70) and multiplied by 100 equals 46 percent. Likewise, 5.5 (median of 1 to 10) divided by 25.5 (median of 11 to 40) multiplied by 100 equals 22 percent. The percentages of water use used in this study for different areal densities of riparian vegetation agree closely to percentages proposed by Brock (1994, fig. 4a) for saltcedar.

During 1995, a total of about 1,600 acres of stressed riparian vegetation was identified in the Mojave River riparian zone. Stress can be caused by water shortage, fire, disease, and many other factors. The lack of plant foliage is indicative of stress, and where plants had less than about 50 percent of the leaves of healthy plants they were considered stressed. Although not documented in a systematic way, plants mapped as being stressed probably had, on the average, about 25 percent of the leaves of healthy plants. Thus, water use by stressed vegetation was assumed to be 25 percent of the estimated water use by healthy vegetation given in table 6.

In addition to the nonlinearity of water use in dense stands of healthy vegetation, there are many poorly understood physiological factors that control the transpiration of water by plants. For example, Weeks and others (1987) found that healthy old-growth saltcedar thickets consumed less water than did younger thickets. As pointed out earlier, saltcedar and other plants grow in subordinate numbers in all the plant communities mapped along the Mojave River. In the absence of a complete accounting of each plant, the consumptive-use estimates are necessarily based on the dominant species in each mapped area. Therefore, when the estimates given in table 6 (some of which are shown to two significant figures) are multiplied by a mapped area for a particular plant community and density, the resulting consumptive use (in acre-feet) should be considered accurate to only one significant figure.

Verification of Water-Use Estimates

On the basis of seasonal depletion of base flow (natural ground-water discharge) of the Mojave River at Afton Canyon, Lines (1996) estimated that annual transpiration of phreatophytes and evaporation from the river averaged about 600 acre-ft along a 2-mile reach upstream from gaging station 10263000 (prior to the U.S. Bureau of Land Management's program of saltcedar eradication in the Canyon that started in 1992). By multiplying the water-use estimates in table 6 by the corresponding 1995 mapped acreages in this reach (stressed saltcedar assumed to be healthy), it is estimated that 600 acre-ft of ground and surface water was consumed annually prior to the eradication program. Thus, estimates of water use by healthy mesquite, saltcedar, and hydrophytes (including open water evaporation) seem to be verified.

Unfortunately, no hydrologic data are available in the Mojave River basin to verify the water-use estimates for cottonwoods, willows, and baccharis. Seasonal depletion in base flow of the Mojave River also occurs at the Lower Narrows downstream from cottonwood-willow woodlands; but, as Lines (1996, p. 39–40) points out, the seasonal streamflow depletion observed at gaging station 10261500 is due to both ground-water pumping and evapotranspiration.

CONSUMPTIVE USE BY RIPARIAN VEGETATION

Estimated consumptive water use during 1995 by riparian vegetation along the Mojave River is given in table 7. In the Alto subarea, consumptive use of water by riparian vegetation was estimated to be about 5,000 acre-ft upstream from the Lower Narrows and about 6,000 acre-ft downstream in the transition zone. In the Centro and Baja subareas, consumptive use was estimated to be about 3,000 and 2,000 acre-ft, respectively. Consumptive use in the Afton area, downstream from the Mojave basin management area, was about 600 acre-ft. Consumptive use was computed on the basis of water-use estimates for various plant species and areal densities (table 6) and the riparian vegetation inventories (tables 1–5). Almost all precipitation along the Mojave River (annual average of 4 to 6 in.) is believed to be evaporated fairly quickly from the soil or consumed by grasses, herbs, and shrubs (xerophytes). Thus, the consumptive-use estimates in table 7 are believed to represent the consumptive use of ground water and surface water.

Total consumptive water use by the 10,000 acres of riparian vegetation along the main stem of the Mojave River during 1995 is estimated to be about 17,000 acre-ft by this study. The California Department of Public Works (1934) estimated that in 1929 approximately 7,800 acres of phreatophytes consumed 40,000 acre-ft of water. The U.S. Bureau of Reclamation (1952) estimated that annual evapotranspiration from about 11,000 acres of phreatophytes and open water consumed about 35,000 acre-ft. The smaller consumptive-use estimate of this study can be attributed to more accurate mapping of riparian vegetation, allowance for different plant communities, allowance for differences in areal density, allowance for stressed vegetation, and the incorporation of water-use data from a select group of studies of riparian plant communities similar to those along the Mojave River.

Barring major changes in the riparian vegetation along the Mojave River, the estimated consumptive use for 1995 should represent fairly accurately consumptive use during most years. It is difficult to define "normal" hydrologic conditions; however, conditions during 1995 along the Mojave River, as a whole, certainly were not extreme. For example, on the basis of records at U.S. Geological Survey gaging stations, runoff in the Mojave River during the 1995 water year (October 1, 1994, to September 30, 1995) was above long-term averages in the Alto subarea; however, runoff was slightly below average in the Centro and Baja subareas and in the Afton area (Agajanian and others, 1996).

During 21 of the 31 years when annual evapotranspiration could be estimated at Afton Canyon prior to the saltcedar eradication program, it was within 20 percent of the long-term average of 600 acre-ft (Lines, 1996, fig. 34). However, annual evapotranspiration at Afton Canyon ranged from about 300 to 900 acre-ft (plus or minus 50 percent of the long-term average) during these same 31 years. Many factors affect the transpiration of plants, but at Afton Canyon there was close correlation between annual evapotranspiration and annual base flow of the Mojave River (an indicator of water-table depth). Thus, following periods of extraordinarily large runoff in the river when the water table beneath the flood plain is high, such as 1993 (Lines, 1996), annual consumptive use by riparian vegetation along the Mojave River may be as much as 50 percent higher than consumptive use during 1995. But after several years of drought, much of the riparian vegetation will be stressed, and annual consumptive use may be as low as 50 percent of that estimated for 1995.

Just as the intentional eradication of saltcedar at Afton Canyon may change consumptive use of ground water and surface water (depending on the species and densities of replacement vegetation), other changes in the distribution and health of riparian vegetation along the Mojave River should be evaluated when estimating future consumptive use. If the vegetation does change markedly, future consumptive use can be estimated using updated vegetation inventories. For comparison with the 1995 conditions, it is recommended that future inventories be completed using procedures summarized in the "Mapping Techniques" section of this report.

SUMMARY

Much of the riparian zone along the Mojave River has been cleared of native vegetation for agricultural, residential, and other uses. In addition, some of the vegetation has died and more is threatened as a result of ground-water pumping and other factors. About 10,000 acres of riparian vegetation, with areal densities greater than 1 percent, remained along the main stem of the Mojave River in 1995. Of that total, about 1,600 acres showed signs of stress. The predominant riparian plant communities in the Alto subarea were cottonwood and cottonwood-willow woodlands. The predominant riparian plant community in the Centro and Baja subareas and in the Afton area was saltcedar; most mesquite remaining in these three areas showed signs of stress. In addition to the phreatophytes and hydrophytes that were mapped as riparian vegetation, desert willow (probably a xerophyte in most areas) was the dominant plant in about 2,700 acres of the riparian zone of the Baja subarea and Afton area.

During 1995 in the Alto subarea, consumptive use of ground water and surface water by the riparian vegetation was estimated to be about 5,000 acre-ft upstream from the Lower Narrows and about 6,000 acre-ft downstream in the transition zone. Consumptive use in the Centro and Baja subareas was estimated to be about 3,000 and 2,000 acre-ft, respectively, during 1995. In the Afton area, downstream from the Mojave basin management area, consumptive use was estimated to be about 600 acre-ft during 1995.

If no major changes occur in the riparian vegetation, the estimated 1995 consumptive use along the main stem of the Mojave River (total of about 17,000 acre-ft) should represent fairly accurately consumptive use during most years. However, on the basis of the range of annual consumptive use at Afton Canyon, annual consumptive use along the river could be as much as 50 percent higher than the 1995 estimate following periods of extraordinarily large runoff. But after several years of drought, annual consumptive use of riparian vegetation could be as low as 50 percent of the 1995 estimate.

REFERENCES CITED

Agajanian, J.A., Rockwell, G.L., and Hayes, P.D., 1996, Water resources data—California, water year 1995. Volume 1. Southern Great Basin from Mexican border to Mono Lake basin, and Pacific slope basins from Tijuana River to Santa Maria River: U.S. Geological Survey Water-Data Report CA-95-1, 384 p.

Ball, J.T., Picone, J.B., and Ross, P.D., 1994, Evapotranspiration by riparian vegetation along the Lower Colorado River: Desert Research Institute, Reno, Nevada, 188 p.

Bowie, J.E., and Kam, William, 1968, Use of water by riparian vegetation, Cottonwood Wash, Arizona: U.S. Geological Survey Water-Supply Paper 1858, 62 p.

Brock, J.H., 1994, *Tamarix* spp. (salt cedar), an invasive exotic woody plant *in* arid and semi-arid riparian habitats of western USA, in de Waal, L.C., Child, L.E., Wade, P.M., and Brock, J.R., eds., Ecology and management of invasive riverside plants: New York, John Wiley and Sons, chap. 4, p. 27–35.

California Department of Public Works, Division of Water Resources, 1934, Mojave River investigation: Bulletin 47, 249 p.

Egan, T.B., Chavez, R.A. and West, B.R., 1993, Afton Canyon saltcedar removal, first year status report: Proceedings of the Symposium on vegetation management of hot desert rangeland ecosystems, Phoenix, AZ, p. 155–175.

Hughes, W.C., 1972, Simulation of saltcedar evapotranspiration: American Society of Civil Engineers Journal, v. 98, no.1R4, p. 533–542.

Lines, G.C., 1996, Ground-water and surface-water relations along the Mojave River, southern California: U.S. Geological Survey Water-Resources Investigations Report 95-4198, 43 p.

Meinzer, O.E., 1923, Outline of ground-water hydrology with definitions: U.S. Geological Survey Water-Supply Paper 494, 71 p.

———1927, Plants as indicators of ground water: U.S. Geological Survey Water-Supply Paper 577, 95 p.

National Oceanic and Atmospheric Administration, 1982, Evaporation atlas for the contiguous 48 United States: NOAA Technical Report NWS 33, 26 p., 4 pl.

Robinson, T.W., 1958, Phreatophytes: U.S. Geological Survey Water-Supply Paper 1423, 84 p.

Stearns, H.T., and Bryan, L.L., 1925, Preliminary report on the geology and water resources of the Mud Lake Basin, Idaho: U.S. Geological Survey Water-Supply Paper 560, p. 87–132.

Thompson, D.G., 1929, The Mohave Desert region, California—A geographic, geologic, and hydrologic reconnaissance: U.S. Geological Survey Water-Supply Paper 578, 759 p.

U.S. Bureau of Reclamation, 1952, Report on Victor Project, California: Boulder City, Nevada, 42 p.

———1995, Vegetation management study, lower Colorado River, phase II: Boulder City, Nevada, 72 p.

van Hylckama, T.E.A., 1974, Water use by saltcedar as measured by the water budget method: U.S. Geological Survey Professional Paper 491-E, 30 p.

Weeks, E.P., Weaver, H.L., Campbell, G.S., and Tanner, B.D., 1987, Water use by saltcedar and by replacement vegetation in the Pecos River flood plain between Acme and Artesia, New Mexico: U.S. Geological Survey Professional Paper 491-G, 33 p.

☆U.S GOVERNMENT PRINTING OFFICE: 1996-583-568