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ISSUES CONCERNING PHREATOPHYTE CLEARING, REVEGETATION, AND WATER SAVINGS ALONG THE GILA RIVER, ARIZONA

William L. Graf Duncan T. Patten Bonnie Turner

Submitted by the Forum in partial fulfillment of U.S. Army Corps of Engineers Contract DACW09-83-M-2623

April 1984

ISSUES CONCERNING PHREATOPHYTE CLEARING, REVEGETATION, AND WATER SAVINGS ALONG THE GILA RIVER, ARIZONA

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A report submitted in partial fulfillment of U.S. Army Corps of Engineers Contract DACW09-83-M-2623.

April 1984

EXECUTIVE SUMMARY

A detailed analysis of the published results of the U.S. Geological Survey Phreatophyte Project conducted in the area of interest for the Corps of Engineers Camelsback Dam study provides the following results. It appears that the figure of 18.53 inches per year for water savings from phreatophyte clearing along the Gila River in southeast Arizona should not be used for predicting potential water salvage because of large sampling errors, measurement errors, and the inherent variability of the natural processes of evapotranspiration. An extensive literature review shows that no dependable values are available for the Gila River project area. It also appears likely that any savings of water would be completely consumed by required replacement vegetation. Replacement vegetation cannot be profitably grown in the study area irrespective of its water demands. From a cost/benefit perspective, the clearing of phreatophytes, replacement with substitute species, and maintenance do not appear to be justified by the presently available data.

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1.0.0. INTRODUCTION

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1.1.0. Introduction and Purpose of Report

The purpose of this report is to provide a detailed analysis of the published results of the U. S. Geological survey Phreatophyte Project conducted on the Gila River in southeastern Arizona. Special attention in the review is given to the reliability of the calculated water savings resulting from the clearing of the phreatophytes on the Gila River flood plain and channel. A complete review of the literature pertaining to water use by phreatophytes in the American Southwest is complemented by an assessment of the applicability of previous work to the Gila River area. The following report also provides a complete review of possible replacement species that might be used to replace phreatophytes cleared from the Gila River flood plain. Finally the report provides an annotated bibliography of relevant lierature.

1.2.0. Background to the Phreatophyte Problem

The Gila River is typical of many arid region rivers in that it is primarily a conveyance system for precipitation which falls in the headwaters regions. As this moisture makes its way through the stream system in channels and in the subsurface as groundwater, it is partially returned to the atmosphere by evaporation from exposed water surfaces and by transpiration of growing plants. One way to reduce this moisture loss to the atmosphere and to retain the water in the near-surface environment for human use is phreatophyte control. Phreatophytes are plants which grow in and near streams and that have such extensive root systems that they directly tap the groundwater supply. Phreatophyte control of necessity consists of two functions: the removal of the phreatophyte vegetation and replacement of the phreatophytes with species more conservative of the groundwater supply. Continual clearing operations do not appear to be a likely alternative because of the cost and the fact that such maintenance would require the floodplain to remain in a completely unnatural condition.

Phreatophytes cause problems for river managers because they clog channels and floodways and because they occupy lands that might otherwise be agriculturally productive. The dense growth of phreatophytes obstructs the flow of floodwaters in the channels, reducing channel capacity and increasing the likelihood of overbank flows. The trunks and stems of phreatophytes introduce turbulence to channel flow and cause increased sedimentation, further reducing channel capacity. Flood-plain areas occupied by phreatophytes can be cleared and used for crop

production, although continual maintenance is required to prevent reinvasion of the area by the phreatophytes.

Beneficial influence of phreatophytes include channel-bank stability, preservation of greenery in an arid environment, maintenance of the honey-bee industry, and wildlife habitat. The plant structure of phreatophytes anchors unconsolidated bank material and inhibits erosion. The plants also provide a green belt along flood plains that desert dwellers find a pleasing relief to the otherwise brown landscapes. Honey production in some areas uses tamarisk (a common phreatophyte) as a source for the insects, and removal of the tamarisk would eliminate the honey production. Phreatophyte growth along river channels also provides critical wildlife habitat because in many semi-arid regions the dense phreatophytes provide the only available cover. White-winged dove, a common Arizona game bird, is a common resident in phreatophyte areas.

1.3.0. Methods of Measurement

Three general measurement techniques appear frequently in research directed toward determining the evapotranspiration of vegetation: lysimeters, tents, and the analysis of a regional water balance. The following section reviews each of these approaches by describing the technique and reviewing its strengths and weaknesses. The section concludes with a discussion of the problems associated with the interpretation of statistical data generated by the techniques.

1.3.1. Lysimeter Techniques

The oldest and most common approach to assessing the evapotranspiration of vegetation is the use of lysimeters, or tanks that are large enough to contain a column of soil with its associated plant community. These tanks may range in size from the dimensions of a common flower pot to cannisters several feet in diameter and twenty feet deep. The tanks are recessed into the ground surface so that the soil surface in the tank is in a similar position to a natural surface. The amounts of water added to the tanks to nourish the plants are monitored over a period of several months, usually by weighing the tanks, the soil and plants, and the water they contain. By recording the weight changes and comparing the weight with the amount of water added, the water lost to evapotranspiration may be determined.

The advantages of lysimeters include the direct measurement of water, ease of control of the plant community involved, and comparability of the results. Lysimeters provide the only method by which water is directly measured in the evapotranspiration process from the time it is introduced to the surface environmental system to the time it leaves as a vapor. The physical processes involved are measured with a high degree of accuracy, so the direct measurements produce an accurate reflection of those processes. The plant community to be

analyzed can be closely controlled because only a very limited surface area is involved. Plant size and community composition can be closely regulated and mixtures of species are included only if desired. More often, individual plants are the subject of the research. Finally, because lysimeters have been in use for over half a century (though not always referred to by that name) there is the possibility of comparing data from divergent test sites.

The disadvantages of lysimeters include the lack of accurate simulation of water movement in real environments, inability to simulate the scale of processes in the real world, and problems in comparing the results of some studies to others. Although the measurements in lysimeters accurately record the use of water by plants, the recorded data reflects a highly artificial environment in which there is no lateral movement of the water through the soil layer, a process that is known to occur in the real world and that may drastically affect the actual rates of evapotranspiration. Many lysimeter studies fail to investigate the role of depth to water table, though this measure significantly affects evapotranspiration rates. Lysimeters are also very small scale systems in relation to the systems of flood plain vegetation communities. Evapotranspiration from a tank that is two to 25 feet in diameter may be a poor estimate of the evaporation from a complex plant community of a flood plain a mile across and 100 miles long. Finally, although there are more data from lysimeter studies than from any other source for evapotranspiration, comparison of studies must be done with care because of the variation from one study to another in terms of size of tank, the complexity, maturity, and density of the plants in the tanks, and methods of measurement.

1.3.2. Tent Techniques

The measurement of evapotranspiration from lysimeters is as much of a laboratory experiment as it is a field technique, but the use of a plastic tent to cover a plant in its natural field environment in part solves the problem. The plant to be studied is completely encased in plastic and air is supplied to the interior of the case by a pump. Measurements of the humidity of the input air are compared to measurements of the humidity of air escaping through output openings, with the differences assumed to be derived from withdrawal or storage in the ground water reservoir. Experiments are usually conducted over a span of hours or at most a few days.

The advantages of the tent method are its field application and the fact that it measures evapotranspiration. By making measurements in the field, it is possible to assess processes operating in a relatively undisturbed setting. The lateral movement of soil moisture is accounted for, and the plants under study occur in their natural association. The only measurements that are made are those directly related to water vapor, so that the only physical changes that affect the measurements are

evaporation, transpiration, and condensation. The result is probably a relatively high degree of accuracy for evapotranspiration measures.

The disadvantages of the tent method include scale of analysis, length of measurements, environmental alterations resulting from use of the tent. The scale of analysis is severely limited with the experimental tent usually encompassing only one major plant individual. The extrapolation of the measurements made on one individual to a complex ecological community is probably not valid, especially given the present limited number of measurements by this method. The time length of the tent-derived measurements is especially critical because evapotranspiration is highly variable on a daily and seasonal basis, so that the extrapolation of tent-derived data to year-long time periods is not possible for most studies. Finally, the use of a plastic tent to surround the subject plants results in alteration of natural environmental conditions because temperatures are elevated inside the tent and wind is eliminated. These changes may be significant because both temperature and wind strongly affect evapotranspiration rates.

1.3.3. Water Balance Approach

The water balance approach to the assessment of evapotranspiration consists of the analysis of an entire drainage basin or of a single reach of a large river. The objective of a water balance study is to account for all the inputs and outputs of water from the large-scale surface and subsurface system, including precipitation, surface water, ground water, condensation. In such an analysis, evapotranspiration is determined as the water recognized as input but otherwise unaccounted for in the output of the system. Water balance studies rely on instrumented acquisition of data (well level recordings, use of stream gages and precipitation gages) over a long period, usually of at least a year or more.

The advantages of the water balance approach include a general system-wide approach and an analysis of the complex aspect of the system rather than of just one component. By analyzing the hydrologic cycle in a particular region, a better understanding of the causes and effects of the budget components on each other and in response to climatic influences is possible than by other methods. By measuring the system in its entirety, the water balance approach assesses the inputs and outputs from the whole system, which in water salvage evaluations is the objective, rather than individual plants. No exptrapolations are therefore required.

Disadvantages of the water balance method include measurement problems and the relatively small quantities of water involved in the evapotranspiration compared to the quantities involved in other parts of the water budget. The success of a water balance assessment rests in large part on being able to

measure accurately the inputs and outputs from the system, but unlike lysimeter studies where the system is carefully circumscribed by the wall of a tank, measurements must be made in. difficult field situations. Water level recorders in wells may be very accurate, but the well itself may not provide a reliable sample site because of high spatial variability of the ground water reservoir. Precipitation gages may also provide biased estimates of precipitation over the study area, especially in arid environments where spatial variability is extreme. Stream gages may provide unreliable information due to channel shifts and vertical changes in the bed elevation. Also, in order to determine the evapotranspiration, all other aspects of the water budget must be accurately known because they make up 98-99% of all the water in the budget: evapotranspiration is what remains. Therefore a small error in other parts of the budget has a large impact on evapotranspiration estimates. A 1% error in the rest of the budget amounts to a 100% error in the evapotranspiration estimate.

1.3.4. Additional Methods

Moisture depletion and energy budget equations are two additional methods available for estimation of evapotranspiration that are most commonly used for plants other than phreatophytes. A study of water use by crops in the arid southwest used a neutron probe in fields to determine the water reductions in the soil by plant use (Erie, French, and Harris, 1982). Over time, the researchers were able to determine the seasonal water consumption of a variety of crops in a variety of soil types.

Energy budget equations have been used by Gay (1979) to determine water consumption of plants. These studies are usually short term (a few days) and often give potentially high water use rates. They may be the most accurate for the time period of measurement, but there are no energy budget data for long periods that might be compared with lysimeter or moisture depletion data.

In summary, no one method of estimation for evapotranspiration appears to be completely satisfactory. The optimum situation would be to use at least two of the methods in conjunction with each other and hope for some congruence of the estimates upon a common value. Fortunately, the Gila River Valley has a history of a variety of approaches, so it is possible to use the results of several studies using different approaches in making an estimate of evapotranspiration and possible water salvage.

1.3.5. Error problem

There are two sources of errors in data sets generated by any of the above techniques: measurement error and sampling error. Measurement error occurs when the instruments being used or the techniques being applied give data values that are not accurate reflections of reality. For example, when the stream

inflow is measured in a water balance study, the depth of flow is measured in the field and then used in an equation to estimate stream discharge. If the measurement is improperly made or if some of the assumptions of the equation are not met (channel shifting or non-uniform flow for example) the resulting data value for inflow will not accurately reflect real conditions and will represent a measurement error.

Sampling error occurs when a sample is not large enough to gain an accurate assessment of the total population or when the sample is not randomly selected. Lysimeter studies assess only very limited representatives of a very large population, for example, so that measurements made with one plant may not be representative for an entire population of plants. All statistical analyses assume that the original sample is randomly selected, but in practice this is rarely true. In water balance studies, for example, field research is of necessity conducted during a relatively brief multi-year span. The measurement period may or may not take place during a time period that is representative of the long-term climatic and hydrologic conditions of the area in question. A water balance study conducted in an arid or semi-arid area during a moist decade, for example, will not be useful for long-term prediction because the sample was not randomly drawn and is not likely to be indicative of future conditions.

Users of evapotranspiration data usually do not have any means to assess measurement and sampling error, but the probable existence of such errors should be acknowledged and precision should not be expected of the figures given in this or any other report.

1.4.0. Water Salvage and Replacement Species

1.4.1. Water Salvage and Water Use

Two general types of plants are the subject of the following chapters. Phreatophytes, plants with deep tap-root systems to access the groundwater table directly are the major concern of chapters 2 and 3. Data in those chapters specifically addresses the problems of assessing the amount of water used by phreatophytes. This water would presumably be salvaged if the phreatophytes were to be removed, though some of the salvaged water would be required to sustain replacement species discussed in chapter 4. Generally, replacement species are not phreatophytes, and instead of tapping the groundwater supply they survive on soil moisture from the unsaturated zone. Chapter 4 is primarily concerned with replacement species and includes water use rates that indicate water required to sustain the coverage of the species discussed.

1.4.2. Criteria for Replacement Species

A successful selection of replacement species depends on the

satisfaction of six basic criteria as outlined below:

1) The species must be capable of establishment in the environment where phreatophytes have been removed. Shrubs such as creosote bush cannot be established in some areas while other exotic phreatophytes might survive but would not provide any water salvage.

2) The species used as a replacement species must use less water than the phreatophytes to be removed, otherwise no water savings will be realized.

3) The replacement species must be able to withstand periodic inundation by flooding because the flood plain of the Gila River is subject to occasional over-bank flows.

4) The replacement species must provide wildlife habitat because the phreatophytes to be removed provide excellent habitat especially for white-winged dove. If the replacement species fails to form wildlife habitat the change in vegetation will entail an additional cost.

5) The replacement species must be compatible with the general climatic and soil conditions present in the Gila River area. If these obvious criteria are overlooked, seeding and maintenance will not be likely to produce useful plant cover, a problem encountered in the U. S. Geological Survey Phreatophyte Project.

6) The replacement species must be able to compete effectively with tamarisk because once cleared tamarisk is likely to be an agressive competitor with the replacement species for available space and water.

1.5.0. References

Culler, R. C., Hanson, R. C., Murick, R. M., Turner, R. M., and Kipple, F. P., 1982. Evapotranspiration before and after clearing phreatophytes, Gila River flood plain, Graham County, Arizona, U. S. Geological Survey Professional Paper 665-P.

2.0.0. REVIEW OF U. S. GEOLOGICAL SURVEY PHREATOPHYTE PROJECT

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2.1.0. Introduction and Purpose of This Section

The purpose of this chapter is to provide an evaluation of the U. S. Geological Survey Professional Paper 655-P, "Evapotranspiration Before and After Clearing Phreatophytes, Gila River Flood Plain, Graham County, Arizona," by R. C. Culler, R. L. Hanson, R. M. Myrick, R. M. Turner, and F. P. Kipple (Culler and others, 1982). Associated professional papers in the 655 series are included in the evaluation where pertinent, though many of the papers deal with subjects only distantly related to the problem of water savings by phreatophyte removal. The present report is designed to provide U. S. Army Corps of Engineers, Los Angeles District Office, with technical assistance in determining the likely water salvage that might result from phreatophyte clearing along 94 miles of the Gila River in Graham and Pinal Counties. Reasonable estimations of water salvage are needed in the analysis of the proposed channel clearing project.

The following chapter provides brief descriptions of the background to the U.S. Geological Survey work, its study area, the method of analysis used, the results, comparisons with other areas, the stated project conclusions, and a summary of a related Corps of Engineers memorandum for the record. This section concludes with an evaluation and recommendation.

2.2.0. Review of the U.S. Geological Survey Final Report

<u>2.2.1.</u> Introduction to the U. S. Geological Survey Project

The U. S. Geological Survey project had four major objectives: to develop methods for study of flood plains, to determine the change in evapotranspiration rates by phreatophyte control, to develop methods for extrapolating the results to other areas, and to evaluate the reliability of the results. The phreatophyte control efforts were proposed by the Corps of Engineers and approved in 1958 by the U.S. Congress as Public Law 85-500, part of the section "Gila River Channel Improvements Between Camelsback Reservoir Site and Salt River, Arizona." The Geological Survey reached agreement with the San Carlos Indian Tribe in 1962 to use tribal lands near the San Carlos Reservoir. The project began in March, 1963 and ended in September, 1971; phreatophyte clearing began in December 1964. During the project there were 530 measurement periods of two to three weeks each, but insufficient data reduced this number to 414, and reliability analyses further reduced the total number of test periods to 321.

2.2.2. Study Area

The Geological Survey study area consisted of a 15-mile reach of the Gila River on the San Carlos Indian Reservation from the U. S. Highway 70 bridge near Bylas to Hackberry Draw, a tributary that enters the pool area of San Carlos Reservoir about 11 miles upstream from Coolidge Dam. The flood plain of the river in the study reach was 3,500 to 5,500 feet wide and its total area was about 5,500 acres. A brief review of the general environmental conditions of the area follows so that the study results may be viewed in context.

The Gila River channel in the U. S. Geological Survey study area is about 110 feet wide and 7 feet deep with a gradient of about 0.0016. It flows on an alluvial bed of sand, silt, and some gravel bars. The general Gila River Valley is a fault basin at least 1,000 feet deep and filled with silt and sand alluvium. The region has a semi-arid climate, with 14 inches of mean annual precipitation and mean monthly temperatures of 65 degrees F (extremes of 10 to 114 degrees F). The vegetation on the flood plain was mostly tamarisk and mesquite with minor amounts of cottonwood, seepwillow, seepweed, and arrowweed.

The drainage area above the Geological Survey gage at Calva, near the upstream end of the study reach, is 11,470 square miles. Based on the gaging period 1929-1972, the mean annual discharge was 181,000 acre feet, ranging from a low of 20,870 acre feet in 1956 to 804,000 acre feet in 1941. Instantaneous peaks ranged from 0 to over 100,000 cubic feet per second. Beneath the flood plain groundwater occurred at a depth of 5 to 20 feet, but in wells just 4 miles from the river, water was not encountered until a depth of 360 feet.

2.2.3. Method of Analysis

The Geological Survey research evaluated the evapotranspiration losses by application of a water balance method. In the approach an attempt is made to measure and account for all water entering and leaving the study reach. Surface flows, precipitation, soil moisture, and groundwater movements were measured and losses from the system not accounted for by these measures were ascribed to evapotranspiration. Several stream gages, precipitation gages, soil moisture recording sites, and groundwater observation wells provided quantitative data. Measurements were taken before the phreatophytes were cleared, and then again after clearing.

2.2.4. Results

Analysis of the 321 test periods with high-quality data showed that the largest amounts of water moved through the study area as surface flow, while soil moisture accounted for the second largest component of the water balance. Groundwater flows

were much less important, and local precipitation was least important.

Direct measurements of all the components of the water balance except for evapotranspiration followed by solution of the balance for evapotranspiration showed that before clearing this loss accounted for 32.32 inches per year. (The figure of 32.32 inches per year means that over a given unit surface area such as an acre or a square mile the amount of water lost would amount to a covering of the area to a depth of 32.32 inches. This unit of measure is used throughout the remainder of this report.) After clearing the loss was reduced to 13.79 inches per year, for a water savings of 18.53 inches per year. Analysis of variability between computed and observed values showed that the possible error in these annual values was $\pm 15\%$ for the pre-clearing value, $\pm 25\%$ for the post-clearing value, and $\pm 30\%$ for the water savings value.

2.2.5. Comparisons With Other Areas

The Geological Survey project included tests of various predictive functions for evapotranspiration by comparing the output of several methods with the measured results. Functions based on radiation, pan evaporation, and multiple components produced broadly similar predictions, but the Blaney-Criddle Method was most accurate. Users of the Geological Survey report should note an error in one of the equations used in the method as reported in Professional Paper 655-P. In equation (14), page 29, first column, an "end parenthesis" symbol should appear between the second value of 100 and the exponent x.

In comparing the results for the San Carlos area with other similar study areas, the Geological Survey researchers found that the Blaney-Criddle method can be used effectively for such species as cottonwood and willow, that the results in the San Carlos area were broadly similar to those found in other reaches of the Safford Valley, and that predictive functions are not effective when temperatures are below 32 degrees F or above 115 degrees F.

2.2.6. Conclusions of the Report

The Geological Survey workers concluded that removal of phreatophytes from the Gila River flood plain resulted in an average annual reduction in evapotranspiration of 18.53 inches and that the Blaney-Criddle method was an accurate means of predicting evapotranspiration in areas without extensive instrumentation. They noted that the reduction of evapotranspiration loss by phreatophyte clearing was only temporary because some replacement species must be introduced and established on cleared areas. The replacements would transpire some water during their own growth, thus reducing anticipated water savings. If no replacements are provided, the phreatophytes will return to the cleared areas. The authors point out that possible replacements such as alfalfa, blue panic grass, and Bermuda grass require more water for growth under irrigation than is required by the phreatophytes that they replace. The report indicates that if grasses are established in a healthy situation, no water salvage is likely.

2.3.0. Review of Unpublished Reports

Two reports written by federal employees have direct bearing on the interpretation of the results of the U. S. Geological Survey Phreatophyte Project. The first was by P. C. Quimby and C. J. Campbell in 1971 providing a general overview of the phreatophyte problem at the time. The second report was a 1982 memorandum by D. Kato of the Corps of Engineers specifically evaluating the U. S. Geological Survey Project. Neither report was for public release.

2.3.1. Quimby-Campbell Report

At the time of their 1971 report, "A New Look at the Phreatophyte Problem," P. C. Quimby, Jr., was a plant physiologist with the Agricultural Research Service and C. J. Campbell was a botanist with the Forest Service, both of the U. S. Department of Agriculture. According to Quimby (personal communication, 1977), their report represented their personal views based on lengthy research experience, but according to a personal communication from Quimby, the report was not published because of inter-agency conflicts.

The authors concluded that although some data were available regarding the water use by phreatophytes, especially tamarisk, the data were not reliable because of highly variable environmental conditions and plant physiology. They stated their opinion that if tamarisk were to be cleared from flood plain areas, replacement species would be likely to require 70-100% of the water saved by phreatophyte removal. They observed that the justification of large-scale clearing projects in the American southwest were based on the assumption that phreatophytes, especially tamarisk, use quantities of water otherwise directly available for human use and management. However, they found insufficient data to support such an assumption. Although the Quimby-Campbell report predated the U. S. Geological Survey final report by more than a decade, the conclusions of the two reports were the same.

2.3.2. Kato Memorandum

In an SPLPD-EP Memorandum for the Record dated June 4, 1982, Diane Kato (COE Biologist) provided a preliminary evaluation of the Geological Survey report. Kato recommended that the value of approximately 19 inches per year of water savings from phreatophyte clearing not be used for four reasons: the research did not differentiate between evaporation and transpiration, the research did not analyze certain climatic factors and therefore was an oversimplification, failed to account for differences in plant species physiology, and produced values for water savings that were near the upper limit of savings suggested by other workers. Kato recommended use of water savings values of 6 to 13 inches per year in project analysis.

The Kato Memorandum indicates that the Geological Survey report is in error because it fails to differentiate evaporation from transpiration, but this failure is not material to the question addressed. Since definition of water savings values was the objective, and since these values were determined before and after clearing, it is not necessary to define exactly which route accounts for the losses. In any event, it would probably be possible to differentiate the two only in a highly controlled laboratory setting which would sacrifice other desirable aspects of field studies. Presently available data do not permit the detail needed to separate the relative importance of shading and transpiration.

The Kato Memorandum also indicates that the Geological Survey project is oversimplified by eliminating certain climatic variables, but the report clearly demonstrates that when these climatic variables are included in models using radiation values or pan evacration, predictions are not materially improved.

The Kato Memorandum indicates that the report fails to take into account differences in plant physiology from one species to another. The report does discuss such differences in the application of the Blaney-Criddle method whereby density classes are differentiated in the V factor, the consumptive use factor k reflects the responses of different species, and the exponent x varies to account for different species. Values for these components for cottonwood and willow are discussed in the report. In the application of the method to the Gila River study area, however,Kato is correct in pointing out that the authors of the Geological Survey Report did not differentiate among plants with different physiology.

Finally, the Kato Memorandum questions the water savings values because they fall near the upper range of values cited by other authors for similar nearby areas. The other authors mentioned by Kato did not conduct studies that had the advantage of the long period of observation and the extensive instrumentation available in the U. S. Geological Survey study. The other studies reported generalizations or results from New Mexico, while the Geological Survey reported specific more useful results from southeast Arizona.

2.4.0. Error Analysis

The experimental design of the Geological Survey project left open the possibility for large errors in estimations of evapotranspiration. Evapotranspiration was a very small part of the total water balance, less than 2% of the total, so sampling

and measurement errors in the other larger balance components had great potential effects on the evapotranspiration estimates. For example, a 1% error in other parts of the total water budget would result in a 100% error in the estimate of evapotranspiration. It seems unlikely that precise, dependable measurements of evapotranspiration could result from such an analysis.

In addition to the problems of experimental design, users of the U. S. Geological Survey report should be aware of the sources of error in the reported water salvage figure of 18.53 inches and the statistical method used in reporting the errors in the report. As in all statistical analyses of environmental processes, there are two sources of error in the report: sampling error and measurement error. Sampling error occurs when a limited sample is analysed and then used to characterize the entire population from which the sample is drawn. Because the entire population is not used for the generalizations, there is some error inherent in the process of using a restricted sample.

In the case of the Gila River Phreatophyte Project, 321 periods of two to three weeks each were used to characterize the evapotranspiration processes. These sample weeks may not be representative of the time period of interest to water planners, the next fifty years of an anticipated project for example. The evapotranspiration process is so complex that it is not possible to draw a sample of weeks that are completely accurate in their reflection of the behavior of the system in a total population of thousands of weeks.

The situation is further confused from a statistical perspective because of the removal of large amounts of data judged by the researchers to be outside the bounds of acceptable values. A total of 93 measurement periods of two to three weeks each were available but were not used because their values appeared to the researchers to be unreasonable. This selective removal of data, although done according to stated rules, reduced the value of the remaining sample because it was non-random. Random sampling is the foundation assumption for the statistical analyses used, but because it was not met, the results may not be valid. For a review of basic statistical concepts applicable to the following discussion consult Hoel (1966). Applications in the earth sciences are reviewed by Davis (1973). A highly readable and easily understood reference is Blalock (1960).

The authors of the Geological Survey report attempted to give readers an indication of the magnitude of this sampling error by reporting that the standard error of the estimate of the mean figure of 18.53 inches was 5.6 inches. This statement means that 68% of all measured water salvage values on a weekly basis fell within the range 12.93-24.13 inches. A more common figure that might be used by the water planner is to determine the range of salvage values that would include 95% of the recorded values (meaning that 5% of the measured values would fall outside this range). If the 95% figure is used, the range of water salvage values observed by the Geological Survey was 7.33-29.73 inches. This broad range of values is a more accurate reflection of the observed conditions than the simple statement of a mean value of 18.53 inches.

A second source of error in the Geological Survey project is largely hidden because it is measurement error. Measurement error occurs when instruments or experimental design fail to provide a true value that accurately assesses the process being measured. Well level readings provide an example. Seventy-eight wells provided groundwater measurements in the project, with each well providing data for the area around it. However, groundwater levels are highly variable over short distances, so the network of wells provides only an approximation to the actual groundwater surface. Similar problems also occur in the measurement of channel discharge and precipitation. In all cases the degree of measurement error is unknown, but because the system is complex, it is likely that measurement error is at least equal to the sampling error described above. If so, the most accurate estimate of water salvage values possible with the given data is that 95% of the time the observed values are between -3.87 and 40.93. In summary, it appears that the mean value of 18.53 is not an accurate characterization of evapotranspiration.

2.5.0. Evaluation and Recommendations

Although the Geological Survey project is the best available information in the literature concerning likely rates of evapotranspiration and water savings in the Gila River Valley between the Camelsback Damsite and Kelvin, it should not be used to calculate potential water salvage in the area. As shown in part 3.0.0. of this report there are numerous values in the literature for evapotranspiration rates, and the Geological Survey's data falls within the range of values reported elsewhere. The Survey's data is likely to be the best available for the Safford to San Carlos reach of the Gila River because it was accomplished within the reach in question. Despite the fact that the study is the best, however, it is not good enough for making predictions of anticipated water savings because of sampling and measurement errors and because of the inherent complexity and variability of the evapotranspiration process.

<u>Phreatophyte control is not likely to produce any water</u> <u>savings in the Corps of Engineers project area.</u> Phreatophyte control consists of two required steps. First, the existing phreatophytes must be cleared, which may result in a water savings value of 18.53 inches per year. Second, in order to prevent reinvasion by phreatophytes a cleared channel must be maintained or replacement species must be established. A flood plain maintained as a clear zone is entirely unnatural and is highly unlikely to be a stable arrangement. (Culler and others, 1982). Replacement is an effort which is likely to use at least as much water as was saved in the first step, and based on figures quoted in the report is likely to require more water than is saved. The Geological Survey attempted to grow replacement species with irrigation, and was unsuccessful.

2.6.0. References

Blalock, H. M. Jr., 1960. Social Statistics, New York: McGraw-Hill, 465 p.

Culler, R. C., Hanson, R. L., Murick, R. M., Turner, R. M., and Kipple, F. P., 1982. Evapotranspiration before and after clearing phreatophytes, Gila River flood plain, Graham County, Arizona, U. S. Geological Survey Professional Paper 665-P.

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3.0.0 REVIEW OF EVAPOTRANSPIRATION/WATER SALVAGE RESEARCH

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3.1.0. Introduction

Reviewing the research literature reporting the investigation of phreatophyte evapotranspiration rates and possible water salvage values is a frustrating experience. Data are sparse, collected from widely scattered localities with a variety of techniques, and reported in a variety of ways that are often not compatible. It is clear from the literature that the measurement of evapotranspiration from phreatophytes in the natural environment entails the evaluation of a process so complex and so difficult to measure that values resulting from such efforts must be viewed as first approximations. The reliability of the measurements is impossible to assess from many of the published reports, but errors of 50% or greater are probable.

3.2.0. Review of Measured Evapotranspiration

The purpose of this section is to present a review of the literature that provides measures of evapotranspiration for riparian vegetation common in the American Southwest. In reviewing the data the provisions of advantages and disadvantages of each technique should be kept in mind, and the problems associated with errors as outlined above should caution the reader not to depend too heavily on any one figure. Tables 3-1 through 3-4 summarize the available literature. The tables provide data only for species studied as phreatophytes. For other species see Chapter 4.

Reference	River	Technique Rate
Sebenick and Thomas, 1967	San Pedro, AZ	Tent 13.2
Bur. of Rec., 1973a	Rio Grande, NM	Lysimeter 34.3-44.3
Bur. of Rec., 1973b	Rio Grande, NM	Lysimeter 39.6-90.6
van Hylckama, 1974	Gila, AZ	Lysimeter 40.0-80.0
Turner and Halpenny, 1941	Gila, AZ	Lysimeter 47.9-61.1
Blaney, 1961	Pecos, NM and TX	Various 51.6-72.0
Blaney, 1961	Pecos, NM	Various 59.3-62.9
Gay and Hartman, 1982	Colorado, AZ	Wat. Bal. 65.5
Gatewood, 1950	Salt, AZ	Various 83.4
Horton and Campbell, 1974	Gila, AZ	Various 84.0
Muckel, 1966	Western U.S.	Various 84.0-110.0
Blaney, 1961	Gila, AZ	Various 86.4
Other Studie	es With Non-Standar	d Rates
Gay and Fritschen, 1979	Rio Grande, NM	Wat. Bal. 8.2 mm/dy
Gay and Fritschen, 1979	Rio Grande, NM	Lysimeter 7.9 mm/dy
Fomanek and Ziegler, 1961	Smokey Hill, KN	Tent 0.05-0.129 gm/sq cm/hr
Tromble, 1977	Greenhouse	Lysimeter 0.158 gm/sq cm/hr
Campbell, 1966	Salt, AZ	Tent 212-218 gm/hr
Culler, 1970 yr in a reach befor	Gila, AZ ce clearing, 13 ac	Wat. Bal. 21 ac ft/ ft/yr after clearing
Decker et al., 1962	Salt, AZ	Tent 50-120 gm/min

EVAPOTRANSPIRATION RATES (IN/YR) REPORTED FOR TAMARISK

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Reference	River	Technique	Rate
Muckel, 1966	Western U.S.	Various	60.0-72.0
Robinson, 1958	Western U.S.	Lysimeter	62.4-97.2
Blaney, 1961	S. L. Rey, CA	Various	62.5-91.5
Blaney, 1961	Gila, AZ	Various	72.0
Gatewood, 1950	Gila, AZ	Various	72.0
Other Studie	es With Non-Standar	d Rates	
Tomanek and Ziegler, 1961	Smokey Hill, KN	Tent	0.052 gm/sq cm/hr
Tomanek, 1958	Greenhouse	Lysimeter	0.231 gm/sq cm/hr

EVAPOTRANSPIRATION RATES (IN/YR) REPORTED FOR COTTONWOOD

.

Reference	River	Technique	Rate	
Robinson, 1958	Western U.S.	Lysimeter	30.0-52.8	
Young and Blaney, 1942	Rio Grande, NM	Lysimeter	30.5	
Blaney, 1961	Santa Ana, CA	Various	45.0	
Young and Blaney, 1942	Santa Ana, CA	Lysimeter	52.7	
Muckel, 1966	Western U.S.	Various	54.0	
Other Studies With Non-Standard Rates				
Tomanek and Ziegler, 1961	Smokey Hill, KN	Tent g	0.080 m/sq cm/hr	
Tomanek, 1958	Greenhouse	Lysimeter g	0.343 m/sq cm/hr	
Robinson, 1970	Humbolt, NV	Lysimeter (Apr	1.2-7.9 in -Oct only)	

EVAPOTRANSPIRATION RATES (IN/YR) REPORTED FOR WILLOW

Reference	River	Technique	Rate		
Mesquite					
Gatewood, 1950	Gila, AZ	Various	39.6		
Blaney, 1961	Gila, AZ	Various	39.6		
Tromble, 1977	Walnut Gulch, AZ	Wat. Bal.	1.28-10.0 mm/dy		
	Baccharis				
Halpenny, 1950	Gila, AZ	Various	56.4		
Blaney, 1961	Gila, AZ	Various	56.4		
Turner and Halpenny, 1941	Gila, AZ	Lysimeter (May	31.0-52.0 -Dec only)		
	Saltgrass				
Muckel, 1966	Western U.S.	Various	9.6-48.0		
Young and Blaney, 1942	Santa Ana, CA	Lysimeter	13.4-42.8		
Young and Blaney, 1942	Owens Valley, CA	Lysimeter	13.4-48.8		
Young and Blaney, 1942	Rio Grande, NM	Lysimeter	18.1-46.4		
Bur. of Rec., 1973b	Rio Grande, NM	Lysimeter	19.0-33.1		
	Greasewood				
Muckel, 1966	Western U.S.	Various	2.1-16.2		
Robinson, 1970	Humbolt, NV	Lysimeter (Apr	2.9-7.7 -Oct only)		
	Wildrose				
Muckel, 1966	Western U.S.	Various	16.4		
Robinson, 1970	Humbolt, NV	Lysimeter (Apr	0.4-3.24 -Oct only)		

EVAPOTRANSPIRATION RATES (IN/YR) REPORTED FOR OTHER PHREATOPHYTES

	Rabbitbrush		
Muckel, 1966	Western U.S.	Various	24.0
Robinson, 1970	Humbolt, NV	Lysimeter (Apr	1.1-7.8 -Oct only)
	Bermuda Grass		
Young and Blaney, 1942	S. Bernadino, CA	Lysimeter	28.2-30.5
McDonald and Hughes, 1968	Colorado, AZ	Lysimeter	73.0
	Russian Olive		
Bur. of Rec., 1973b	Rio Grande, NM	Lysimeter	21.1-51.2
	Alder		
Muckel, 1966	Western U.S.	Various	60.0
We	et Meadow Grass		
Muckel, 1966	Western U.S.	Various	18.0
	Arrowweed		
McDonald and Hughes, 1968	Colorado, AZ	Lysimeter	96.0
	Quailbush		
McDonald and Hughes, 1968	Colorado, AZ	Lysimeter	44.0
Fou	ır-Wing Saltbush		
McDonald and Hughes, 1968	Colorado, AZ	Lysimeter	38.0
	Sacaton Grass		
Blaney, 1961	Pecos, NM	Various	48.1

Tables 3-1 through 3-4 clearly show a wide range of values for measured evapotranspiration for any species that might be considered. This spatial variability is probably related to the variety of soil, hydrologic, climatologic, and plant physiologic differences from one study area to another. At the present time, no satisfactory generalizations exist that allow accurate predictions of evapotranspiration rates in areas without measurements because much of the variability shown in the tables is unaccounted for.

A comparison of the data shown in Table 3-1 with the results of the U. S. Geological Survey Phreatophyte Project indicates that the reported average rate of evapotranpiration for the Gila River phreatophyte community of 43 in/yr is a reasonable one. The reported rate is for a variety of environments, none of which has completely pure stands of any one species, but tamarisk dominates most areas with varying degrees of density. The range of reported evapotranspiration rates from other areas is 13-110 in/yr (Table 3-1), but the fact that 43 in/yr falls in the lower half of that range may be because many areas measured along the Gila River were not completely covered with tamarisk.

The data from Tables 3-2 through 3-4 indicate that if tamarisk is removed from the Gila River flood plain, it is likely that replacement species will require nearly as much water for survival if not more than was used by the tamarisk that was removed. Even grasses which might be considered as conservative users of water will require for survival all the water salvaged from clearing of the phreatophytes.

The data reported above are broadly applicable to the Gila River in the Safford and Kearney valley areas. All the studies concerned phreatophyte communities in alluvial soils and in arid to semi-arid climates similar to the Gila River. Because of elevation differences and variation of the ecological make-up of the communities tested, none of the data are precisely transferable, however, so the estimates of evapotranspiration provide only general guidelines rather than exact estimates. The results of Culler and others (1982) appear reasonable in a broad sense because they fall within the range of evapotranspiration values from other studies.

3.3.0. Review of Measured Water Salvage

A review of the available published literature shows that the U. S. Geological Survey Phreatophyte Project was the only large-scale effort to directly measure water salvage from a phreatophyte clearing project. Two other very limited projects have been reported elsewhere. First, Rowe (1963) described a comparison of two watersheds on the San Dimas Experimental Forest in the San Gabriel Mountains near Los Angeles, California. One watershed of 740 acres provided control data, while the riparian vegetation was cleared along the major channel in a nearby 875 acre watershed. Streamflow yields were increased by the clearing project but accurate measures are not available. The project results do not appear to provide a useful comparison with the Gila River project because the California study areas are small mountain watersheds with steep slopes, narrow canyons, and vegetation/climatic conditions unlike those in southcentral Arizona.

In a study of Cottonwood Wash, Mohave County, Arizona, Bowie and Kam (1968) reported that after a clearing project involving phreatophytes along a 1.5 mile reach of the stream, average water loss was reduced by about 50%. The study is a useful if imperfect comparison for the Gila River project because the vegetation was similar in both projects and the results were at least broadly similar. However, after clearing in the Cottonwood Wash area, regrowth of shrub vegetation further reduced water savings, so that the final measure of salvage is not known.

3.4.0. Evaluation and Recommendation

A review of the evapotranspiration and water salvage literature for the American Southwest indicates the following conclusions.

The average evapotranspiration rate for the phreatophyte communities along the Gila River between Safford and San Carlos Reservoir as reported by the U.S. Geological Survey is reasonable in light of other reported studies. The reported rate of about 43 in/yr is similar to reports from other areas and falls within the range of other reported values.

The average reported evapotranspiration rate is likely to be highly variable and no values exist that are reliable for the Gila River project area. When all the published rates are assembled, a high degree of variability is evident in the data. Part of this variability is the result of sampling error, part is the result of measurement error, and part is the result of natural variability in the vegetation systems being measured. The natural processes under consideration are radically different from engineered processes where many of the limits and relationships are known and can be mathematically summarized. The natural processes related to the hydrology of evapotranspiration are poorly understood and poorly measured so that predictions are merely broad indicators and cannot provide exact indications of water salvage.

3.5.0. References

Culler, R. C., Hanson, R. L., Murick, R. M., Turner, R. M., and Kipple, F. P., 1982. Evapotranspiration before and after clearing phreatophytes, Gila River flood plain, Graham County, Arizona, U. S. Geological Survey Professional Paper 665-P. All other references given in the Annoted Bibliography of Chapter 5.

4.0.0. REVEGETATION EVALUATION

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4.1.0. Introduction and Purpose

Revegetation of areas cleared of phreatophytes is considered to be one alternative to managing the bared areas. Selection of plant species for revegetation must seriously consider water use of the replacement species if phreatophyte removal is done primarily to "salvage" ground water. The purpose of this section is, therefore, to evaluate replacement species and the factors that influence water use. One species that will be considered in detail is barley (<u>Hordeum vulgare</u>) because it apparently is being used with some success as a replacement species in southern Utah. Also, there will be an evaluation of the different costs for alternative methods of revegetation following phreatophyte removal.

All plants consume water as a normal part of their physiological processes. Physiologists have looked at this water loss or transpiration as necessary for maintenance of leaf temperatures or as a necessary consequence of having leaf stomata open for carbon dioxide exchange for photosynthesis. Many plants have developed methods whereby water can be conserved while photosynthetic rates are not hindered. Succulent plants tend to be very water efficient although their growth rate is slow.

Plants growing in environments with no water limitations tend to be poor water conservers. If the atmospheric humidity is high, transpiration is reduced. However, when the atmosphere is dry and soil water is readily available, soil water depletion through plant transpiration and soil evaporation, together called evapotranspiration, can be very high. Even cacti will increase their water loss under these conditions. When soil moisture is limiting, stomatal closure will also reduce transpiration rates. In some cases, stomatal closure can occur under hot dry winds even when soil moisture is unlimited as found for saltcedar (Van Hylckama 1980).

Phreatophytes in the Southwest fall under that group of plants that live in an environment with high atmospheric moisture stress but with little soil water limitations because they either grow where the water table is shallow or they have deep roots or both. Hydrologists and other scientists have held that water can be "salvaged" from flood plains, deltas and other habitats of phreatophytes by removing or clearing the consumptive phreatophytes and by either maintaining their elimination or replacing them with plants that may be lower water users.

Removal of phreatophytes creates some problems.

Phreatophytes, which may form dense stands of vegetation, are not totally nonbeneficial plants as considered by most hydrologists and engineers. Phreatophytes create valuable wildlife habitat and tend to prevent surface erosion by wind and water. Habitats where phreatophytes have been removed are usually barren with few wildlife species, especially birds, and the blowing surface soils create dusty conditions. If phreatophytes are to be removed, replacement vegetation would maintain some sort of wildlife habitat and stabilize the soil or at least keep wind movement from scouring the surface and creating dust. Phreatophytes are also a source of honey production and aesthetic appeal. These benefits should be considered when removing phreatophytes and selecting replacement species.

If the purpose of removal of phreatophyte species is to "salvage" water, then the selection of one or more replacement species must be based on maintaining the "salvaged" water. On the other hand, enhancement of wildlife habitat may also be an important consideration. Obviously, the habitat variation found along a stream course will also influence the selection of replacement species since some species will be more tolerant of the saline or alkaline conditions in the lower flood plain while others will do better on particular soils such as the sands and gravels near the river channels.

Potential replacement species for an area like the Safford-Gila Valley can be grouped into four categories: (1) Shrubs that grow well in semi-arid regions but will tolerate the alkaline conditions of the flood plain, (2) grasses that grow in the Southwest, both native and exotic, and can tolerate floodplain conditions, (3) trees, especially phreatophyte species other than saltcedar and arrowweed, and (4) crops that through constant management can survive and flourish in the floodplain or at least parts of the floodplain.

Of the shrubs, <u>Atriplex</u> (saltbush) is one of the few genera of shrubs that might possibly establish and survive in the floodplain conditions. Two species, <u>A</u>. <u>canescens</u> and <u>A</u>. <u>polycarpa</u>, are found at elevations lower than the study area on the Gila River floodplain. Other arid-land shrubs such as creosote bush (<u>Larrea divaricata</u>) or bursage (<u>Ambrosia</u> <u>deltoidea</u>) do not tolerate the alkaline or periodic moist conditions of the floodplain.

There are many grasses that might be considered as replacement species. Bermuda grass, widely used in the Southwest, is presently found as a common component of some riparian communities. Others such as alta fescue and blue panic grass have been used for reclamation purposes. One aspect of grass physiology that should be considered is water efficiency. Grasses that have the C-3 photosynthetic metabolism are not as water efficient as those with the C-4 metabolism (Biran et al 1981). These are photosynthetic pathways in which the first photosynthetic compound is either a three or four carbon compound. Fescue belongs to the former and Bermuda grass and zoysia to the latter. High water efficiency plants have more plant growth per water used than low water efficiency plants, thus they are potentially better ground cover for a certain amount of water used.

Crops must be considered as possible replacement species because, in addition to hopefully retaining most of the water "salvaged" through phreatophyte removal, the crops might give an economic return and therefore can be considered beneficial replacements. Thousands of acres along the Gila River in the Safford Valley have been converted from phreatophyte habitat to cropland. Plowing, disking and irrigating have permitted the farmers in this area to produce sufficiently good returns on their crops over the years to be willing to maintain farming against the potential reinvasion of phreatophytes. Some farm fields have been abandoned and these have rapidly been reestablished as phreatophyte communities, especially saltcedar.

Evaluation of replacement species must consider all criteria presented in section 1.4.2. Water consumption is the primary criterion however the data as presented in Table 4-1 are not truly comparable because the method used for determining water use was not under similar soil, climatic and vegetational community conditions. However, for the purpose of this report, these are the best data available and, therefore, are used to evaluate and compare species as potential replacement species for phreatophytes.

Of the other evaluation criteria, potential for forming successful wildlife habitat to replace the habitat lost through removal of the existing phreatophytes needs further explanation.

Various studies have attempted to evaluate the quality of habitat for wildlife (Carothers et al 1974, Vitt et al 1976, Anderson et al 1977 a and b, Stamp and Ohmart 1979). Many of these studies emphasized the density and diversity of the avian population while others evaluated habitat or occurrence of other animals such as reptiles and rodents. Large mammals are seldom used because they usually do not use riparian habitat as a permanent location but migrate in and out of the stream-side communities. Carothers et al (1974) found a mixed deciduous riparian woodland to have fewer breeding bird populations than pure cottonwood stands. A phreatophyte area they studied that had been manipulated had the most depauperate avifauna. Anderson et al (1983) found cottonwood-willow communities to have the richest and most diverse assemblages of bird species of all communities studied. Honey mesquite and saltcedar-honey mesquite were intermediate while pure saltcedar stands were the lowest.

Of other species, rodent populations and activity were found to be much greater in riparian woodlands than in desert shrub habitat (Stamp and Ohmart 1979). Lizards, on the other hand, generally prefered mesquite over cottonwood-willow habitat (Vitt et al 1976). Saltcedar-arrowweed stands and desert scrub were quite low for all lizard species.

Wildlife habitat is obviously quite variable but large phreatophytes such as cottonwood and willow apparently provide best habitat. Phreatophyte communities of mixed heights also provide better wildlife habitat than phsyiognomically homogeneous low stands of shrubs or herbaceous plants. The ranking given to replacement species as potential wildlife habitat is thus based on the ability of the species, generally in a pure stand, to support a wide diversity and density of animals, especially avian species.

The first criterion in section 1.4.2, that is, ability to be established, eliminated many species from any consideration. All species presented in Table 4-1 could be established although some would take considerable effort. The last criterion, that is, ability to compete with saltcedar, is difficult to evaluate. For example, if a grass such as Bermuda grass is kept well watered, it will flourish and produce a dense mat often impenetrable by saltcedar seeds. In this way, it and other grasses might prevent saltcedar reinvasion. However, if the grass cover or that of any replacement species is sparse, the interspaces would make ideal microsites for trapping windblown saltcedar seeds. Germination of saltcedar, although low, occurs in any moist condition (Tomanek and Ziegler 1961) and thus over a few years saltcedar would reestablish. This is obvious if one observes abandoned farm fields in the Safford Valley.

4.2.0. Evaluation by Species

Table 4-1 presents twenty one species that might be considered as replacement species. More species might have been considered, however, adequate water consumption information was not available in the literature. Table 3-4 presents other species found in some riparian communities, however these were not included because most could not be established or would be difficult to establish in the Gila River after clearing. For comparison, information on two of the common phreatophytes along the Gila River, saltcedar and arrowweed (<u>Tessaria sericea</u>), are included in the table. The ability to withstand periodic inundation and potential for wildlife habitat are also presented in Table 4-1.

The following paragraphs briefly discuss the positive and negative aspects of each species as a replacement for phreatophytes. Economic information on the most likely crop species is presented in Table 4-2 in the Cost Analysis section.

4.2.1. Alfalfa (Medicago sativa)

Alfalfa is a common crop in the Safford Valley. It uses over 80 inches of irrigation water a year (Hathorn and Cluff 1982) and is found to consume from 70 to over 120 inches of water a year (Gay 1981). If it were used as a replacement species, not
Table 4-1

CHARACTERISTICS OF POTENTIAL REVEGETATION SPECIES

wildlife habitat of for revegetation alo and arrowweed are re averages of a number the water use measur good, very good, and	crops, shrubs and grass ong the Gila River, Gral epresented for compariso r of measurements. The rement method. Rankings d excellent.	and poter ses that m nam County on. Most reference are poor,	night be 7. Sal- quanti- e () in , moders	s e used tcedar ties are ndicates ate,	
PLANTS	WATER USE (INCHES)	RESISTANO INUNDAT	CE TO N FION 1	WILDLIFE HABITAT	
Crops Alfalfa	74.3 seasonal[Feb-Nov] 10mm/day(2.)[est 122/10 84 irrigation required 69 (10.)	(1.) n D mo] (3.)	nod.	poor	
Barley	25 seasonal[Nov-May](1 44 irrigation required 12 seasonal (India)(8.	.) I (3.)	boor	poor	
Cotton	41.2 seasonal[April-Nov 60 irrigation required 25.6 seasonal (Sudan)('	v](1.) p (3.) 7.)	boor	poor	
Safflower	45.4 seasonal [Jan-Jul]	y](1.) p	boor	poor	
Sorghum (forage)	54.2 seasonal[April-Dec	c](1.) F	poor	mod.	
Wheat	25.8 seasonal[Nov-May] 44 irrigation required	(1.) F (3.)	ooor	poor	
Shrubs and Trees					
Arrowweed	96 annual (4.)	Ę	good	mod.	
Fourwing saltbush	41 annual (4.)	п	nod.	good	
Quailbush	42.9 annual (4.)	п	nod.	good	
Saltcedar (community) (monotypic)	86.4 annual (5.) 43 avg. density (10.) 56 high density (10.) 22.1(Aug-Oct)(11.)[est 9.0mm/day(12.)[est 108,	9 50] /10mo]	good	v.good	
Cottonwood	72.0 annual (5.)	n	nod.	excel.	
Willow	54.0 annual (13.)	e	good	excel.	
Mesquite	39.6 annual (5.)	п	nod.	v.good	

Table 4-1 (cont.)				
Shrubs and Trees (co	ont.)			
Baccharis	56.4 annual (14.)		mod.	mod.
Russian Olive	21.2-51.2 annual (15.)	mod.	good
Grasses				
Bermuda	43.5 seasonal(April-06 51.6-65.1 annual (6.) 69.3 annual (4.) 42 annual (10.)	ct)(1.)	excel.	poor
Blue Panic	52.3 seasonal (April-) 49 annual (10.)	Nov)(1.)	mod.	mod.
Alta fescue	71.5 annual (6.)		good	mod.
St. Augustine	65.2 annual (6.)		good	poor
Alkali sacaton	17 (Aug-Oct)(11.)[est	40/yr]	good	mod.
Saltgrass	21.1 (Aug-Oct)(11.)[e:	st 46/yr]	mod.	poor
Switchgrass	20.5 no irrigation (9 33.7 med.irrigation (9 45.9 high irrigation	.) 9.) (9.)	good	mod.
Zoysia	51.6-65.1 annual (6.)		good	poor
Bare Ground	31.9 annual (11.) 25 annual (10.)			
References		Water Use	e Method	
 Erie et al 1982 Gay 1981 Hathorn and Cluff McDonald and Hugh Gatewood et al 19 Kneebone and Pepp Rijks 1976 Yadav and Singh 1 Koski et al Culler et al 198 Blaney et al 194 Gay 1982 Muckel, 1966 Blaney, 1961 Bureau of Reclam 	moisture depletion energy budget irrigation uses lysimeter lysimeter lysimeter moisture depletion neutron probe, moist dep Blaney-Criddle equation and water budget lysimeter energy budget lysimeter and others lysimeter			

only would it consume more water than the phreatophytes, but supplementary irrigation would be needed to maintain it. Alfalfa roots might be able to penetrate to the water table in some areas along the Gila River but irrigation will still be needed. Alfalfa is moderately resistant to inundation as it may be covered temporarily by irrigation water. Because alfalfa is a low crop, it would make poor wildlife habitat, although, at times it has been observed to attract a greater density and diversity of birds than other crops (Anderson and Ohmart 1982). Like all crops considered for replacement, use of alfalfa would keep out phreatophytes because of periodic disking and field maintenance. Although alfalfa is one of few crops that gives an economic return, it is too great a water consumer to be of value for maintenance of water salvaged by phreatophyte removal.

4.2.2. Barley (Hordeum vulgare)

The potential of barley as a replacement crop is developed in detail in following section 4.4.0. Because it requires irrigation, it is questionable as a replacement. In Table 4-1, one study on barley in India shows a very low water consumption. This study was done on irrigated and non-irrigated fields. Low or no irrigation, although perhaps a water savings technique, would cause barley to be a disaster to a farmer in the U.S. economy. In Graham County barley does not return an economic profit and it will produce poor wildlife habitat. Its ability to withstand much inundation is of little importance because it is an annual crop. See section 4.4.0. on Barley As A Replacement Crop for more information.

4.2.3. Cotton (Gossypium spp.)

Cotton is the most extensively planted crop in Graham County. For this reason it should be considered as a replacement crop after phreatophyte removal. Irrigation requirements of 60 inches are higher than for barley but considerably lower than for alfalfa. Studies show that water consumption of cotton on a seasonal basis is about 41 inches (Erie, French and Harris 1982). This is lower than the average annual 43 inches of water consumption by phreatophytes determined by Cullen et al (1982). Unfortunately, the 41 inches of water consumption is seasonal (eight months), leaving fallow fields and bare soil evaporation for the remaining four months. Excluding the need for irrigation, cotton might save water or create a water-use balance equal to phreatophytes. As a commercial crop, irrigation will be needed, thus the use of cotton will not create any water salvage and will probably cause an overall increase in water use. Cotton like most crops is not resistant to inundation of the foliage and it makes poor wildlife habitat. Economically, cotton is not very profitable in Graham County unless the farmer is well established and some of the non-variable costs are ignored.

4.2.4. Safflower (Carthamus tinctorius)

Safflower is not presently grown in Graham County. It is presented in Table 4-1 because it is one of few crops on which there are water consumptive data. Its seasonal (seven months) water use is relatively high (45.4 inches) (Erie, French and Harris 1982). The remaining five months occur during a period when evaporative demand is high and bare soil evaporation would be expected to be at least 10-15 inches. These figures indicate no maintenance of water salvage by safflower if it were used as a replacement species. Safflower is not resistant to foliage inundation and would make poor wildlife habitat. Economic data for safflower in Graham County were not available.

4.2.5. Sorghum (Sorghum spp.)

Sorghum, like safflower, is presented because water consumption data are available although sorghum is not a common crop in Graham County. Sorghum is a very high water consumer and although it might offer better wildlife habitat than other crops if raised as forage, its water use probably excludes it as a potential replacement crop. Economic data for sorghum in Graham County were not available.

4.2.6. Wheat (Triticum aestivum)

Wheat is another crop presently grown in Graham County but on a limited basis. In all characteristics it is very similar to barley. Water use and irrigation requirements are about the same as barley and its resistance to inundation and use as wildlife habitat are poor. If a choice were to be made between wheat and barley, the fact that local farmers raise more barley indicates that wheat probably should be the second choice.

4.2.7. Fourwing Saltbush (Atriplex canescens)

Fourwing saltbush grows naturally in dry areas of the Gila River floodplain where the water table is not near the surface allowing phreatophytes to establish. It could be seeded into the areas where phreatophytes have been removed, but to ensure establishment, the areas would have to be disked after seed dispersal to bury the seeds under adequate soil cover. This could be part of the site preparation procedure mentioned in the Cost Analysis section. Fourwing saltbush has been found to use about 41 inches of water a year. If fourwing saltbush were established in areas where dense phreatophytes were removed, there might be a water savings of about 15 inches for those areas. If saltbush was used uniformly over the cleared areas that averaged 43 inches of water use, then the savings would be inconsequential. Fourwing saltbush can withstand some periodic inundation typical of floodplains but how well it might do in areas with a very shallow water table is questionable. These are the areas with the most dense phreatophytes and therefore the areas with the greatest potential for water savings by using fourwing saltbush. Fourwing

saltbush can make good wildlife habitat. It grows in moderately spaced clumps that create enough vertical diversity to encourage a wide variety of wildlife species. This spacing, however, will also make it a poor competitor with saltcedar. Saltcedar seeds need to be kept from contacting wet soil if seedling establishment is to be prevented.

4.2.8. <u>Quailbush</u> (<u>Atriplex</u> <u>lentiformis</u>)

Quailbush has been widely used as a reclamation species, especially in areas with alkaline soils. It establishes best on these areas but will grow elsewhere. It tends to form larger and tighter clumps than fourwing saltbush and usually has a higher growth form. For these reasons, it might make better wildlife habitat than fourwing saltbush but probabably not as good as saltcedar because it does not have as much height diversity. Its water consumption is very similar to fourwing saltbush (McDonald and Hughes 1968) and its characteristics are similar enough that the comments on water salvage and competitiveness made for fourwing saltbush hold true here.

4.2.9. Cottonwood (Populus fremontii)

Cottonwood is a common phreatphyte growing along the margins of the Gila River valley. It is not found within the floodplain because it cannot withstand long-term inundation, although short-term inundation is not lethal. Cottonwood naturally seeds in near the normal high water line. Cottonwood makes excellent wildlife habitat but because (1) its water consumption is very high, (2) it can't withstand long-term inundation, (3) transplanted cottonwoods may require supplemental watering to survive, and (4) the potential cost of transplanting sufficient numbers to attempt to outcompete saltcedar is very high, use of cottonwood as a replacement species throughout the floodplain should not be considered, although it might be used along the margins.

4.2.10. <u>Willow</u> (<u>Salix gooddingii</u>)

Willow tolerates much more inundation than cottonwood and uses less water. It is nearly equal to cottonwood in providing wildlife habitat; however, its water use is still high enough to eliminate any water salvage. It cannot be seeded in and therefore must be transplanted or plugged using cuttings and may require supplemental watering. Manual labor costs would be very high and water savings low. Wildlife habitat is the only benefit from willow.

4.2.11. Mesquite (Prosopis spp.)

Mesquite generally grows on the upper riparian terraces. It could not withstand the saturated soils of the floodplain and therefore would be difficult to establish. It also would probably have to be transplanted to be established although seeding might have limited success. Mesquite would give only a little water savings but relatively good wildlife habitat. Its limitations are that it could not survive in most of the areas presently dominated by saltcedar.

4.2.12. <u>Baccharis</u> (<u>Baccharis</u> spp.)

Most <u>Baccharis</u> species can readily be established by seed. <u>Baccharis glutinosa</u> (seepwillow) is usually found along river edges along with another <u>Baccharis</u>, <u>B. sarothroides</u> (desert broom), which inhabits gravel bars that periodically are inundated. Unfortunately, use of <u>Baccharis</u> species would not create water savings and it does not make very good wildlife habitat. It could be established in better drained, coarse soil areas that are being considered for clearing.

4.2.13. <u>Russian Olive</u> (<u>Eleagnus angustifolia</u>)

Russian olive has often been used for wind breaks and for limited reclamation purposes. It grows best at cooler locations and/or higher elevations where it easily escapes and naturalizes. Although it might create some water savings, it would be difficult to permanenetly establish in the Gila River floodplain in large enough populations to slow or prevent reinvasion by saltcedar.

4.2.14. <u>Bermuda Grass</u> (<u>Cynodon dactylon</u>)

Bermuda grass is commonly found in open, disturbed sites in riparian areas and therefore is a possible "natural" replacement species. As a grass, it grows seasonally but then maintains a soil stabilizing ground cover during the non-growth season which reduces bare soil evaporation. Bermuda grass can be readily established by seed where moisture is available. Information on its water consumption is not encouraging. Seasonally, it uses water equal to the average phreatophyte use and, annually, Bermuda grass plots use water equal to the high density phreatophyte areas (McDonald and Hughes 1968). Most of the information is based on turf studies and the high density of grass achieved on turf will not be achieved along the Gila River floodplain. The water use thus can be expected to be lower than that reported in Table 4-1 because the grass roots may not penetrate to the water table; however, if they do, water use will be higher. Lower density cover of Bermuda grass will, however, permit ready establishment of reinvading saltcedar. If a higher density of Bermuda grass is desired, supplemental watering will be required negating any water savings. If Bermuda grass is cut for hay, a small water savings may be achieved. Bermuda grass can withstand periodic inundation as shown by its popularity as an irrigated lawn grass. Because of its low growth, it makes very poor wildlife habitat.

4.2.15. <u>Blue Panic Grass</u> (Panicum <u>antidotale</u>)

Blue panic grass is often used as a replacement or reclamation species. It uses about as much water as Bermuda grass but has a tall growth habit over 2 m. Water consumption data are variable, but annual use is probably about 50 inches. In general, the comments on water savings made for Bermuda grass hold true for blue panic grass. It is not, however, a common riparian species in the Southwest as is Bermuda grass. It can take some periodic inundation but not as well as Bermuda grass and if left uncut, may grow tall enough to form acceptable habitat for some wildlife species. Without supplemental water, its ability to grow dense enough to compete with or prevent reinvasion of saltcedar is greatly limited.

4.2.16. Alta Fescue (Festuca arundinacea)

Alta fescue, another tall grass (up to 1.5 m) sometimes used for reclamation, is a high water user. Because it is a C-3 grass, it lacks the water use efficiency of the C-4 grasses such as Bermuda, St. Augustine and zoysia. Its annual water consumption far exceeds that of high density phreatophytes. Although Alta fescue can withstand some inundation and form a semblence of wildlife habitat, its water consumption is too high to consider it as a replacement species.

4.2.17. <u>St. Augustine Grass</u> (<u>Stenotaphrum</u> <u>secundatum</u>)

St. Augustine grass is a coarse leaved, mat forming grass that has many of the same characteristics as Bermuda grass. In a study in which the two were compared, along with alta fescue and zoysia, St. Augustine consumed water equal to the highest levels of Bermuda grass and zoysia but less than the fescue (Kneebone and Pepper 1982). To maintain an adequate stand of St. Augustine to stabilize the area, supplemental watering will be necessary. If a choice is to be made, Bermuda grass should be selected over St. Augustine grass as a possible replacement species.

4.2.18. <u>Alkali Sacaton</u> (Sporobolus airoides)

Alkali sacaton is a native grass found commonly in riparian areas in mid to upper desert regions in the Southwest. It creates dense, tall (often over 2 m) stands that make moderately good wildlife habitat. It can also withstand the saline or alkaline conditions often found in floodplains. It is a relatively low water user and would permit maintenance of some of the water salvage from phreatophyte removal if used as a replacement species. It is questionable whether it could be established over the thousands of acres to be cleared. It might do well in the floodplain near the stream channel and if dense enough might prevent rapid reinvasion of saltcedar.

4.2.19. <u>Saltgrass</u> (<u>Distichlis</u> <u>stricta</u>)

Saltgrass is another grass that does well in saline, floodplain conditions. Its water use is slightly higher than alkali sacaton and therefore would be a second choice between these two. It does not grow as tall as sacaton and therefore does not provide good wildlife habitat. Seeds of saltgrass are not readily available in any quantities thus its use as a replacement species over extensive areas would be limited.

4.2.20. <u>Switchgrass</u> (<u>Panicum</u> <u>virgatum</u>)

Switchgrass is another potential floodplain revegetation grass. It does well under relatively dry conditions using less than half the water of the average saltcedar community (Koski et al 1982). However, when irrigated in a manner approximating periodic inundation and a shallow water table, water use by switchgrass is equal to or greater than the average saltcedar stand. If it was used to replace only dense saltcedars, some water saving (ca. 10 in.) might be realized. The ability to establish switchgrass along the Gila River is unknown and use would be experimental.

4.2.21. Zoysia (Zoysia spp.)

Zoysia grass has many of the characteristics of Bermuda grass and should be considered comparable to Bermuda grass. It has not become naturally established in riparian areas as has Bermuda grass and therefore may not be as tolerant of those conditions. It would be a second choice to Bermuda grass and experimental if used for revegetation. It probably could be established with more success than St. Augustine grass although supplemental watering still might be needed.

4.3.0. Revegetation Recommendations

There is no one optimum plant species that can be used to replace phreatophytes following clearing and salvage water as a result of reductions in evapotranspiration. Bermuda grass and the <u>Atriplex</u> species probably come closest to permitting some maintenance of the water salvage. However, the amount of water saved by using these plants probably would not be worth the effort of removing the phreatophytes. There is also a great probability that over a very few years the phreatophytes would reinvade from the 100 foot strips of phreatophytes to be left intact along the edges of the floodplain, negating any hopes of maintaining water salvage.

In order to retain the water salvage of 18.53 inches projected by Culler et al (1982), mowing might be the best alternative rather than revegetation. Mowing, however, will create the potential of wind erosion and dust from the floodplain areas. This potential should be compared to the actual amounts of dust produced by barren fields in the Safford Valley. Another negative aspect to maintenance of phreatophyte removal by mowing is the total loss of wildlife habitat. This will probably be unacceptable to conservation groups and wildlife management agencies. If wildlife is of great importance, use of cottonwood and willow should be considered although cost of establishment and lack of water salvage practically eliminates these species from consideration.

Assuming revegetation will be done, then how and where should it be done? If water savings and wildlife habitat are not the only issues and economics are important in that income from crops might buy water, then replacement with a mixture of crop and non-crop species should be considered.

In areas where the phreatophyte stands are narrow and the floodplain is too irregular for farming, non-crop species should be used. Where the floodplain is broad as in the Safford Valley, revegetation with farm crops should be considered. Some large phreatophytes such as cottonwood and willow might also be used in gallery-like rows of transplants.

Upstream from Safford, the riparian community becomes narrow and the potential for farming decreases. Based on planimeter data using aerial photographs, this whole area only makes up about 3000 acres of the area to be cleared. In these areas revegetation might be done through use of quailbush and/or fourwing saltbush on the upper terraces with a mix of Bermuda grass and alkali sacaton on the lower, wetter areas near the river channel. The mixtures will allow each species to establish in those areas for which it is best suited. Use of tree transplants for better wildlife habitat is questionable.

On the lower reaches of the Gila River between Winkleman and Kelvin, the phreatophyte community is again narrow and the terraces rise steeply to the bordering desert. This area includes about 2000 acres (Kato 1982-see 2.3.2.) of that to be cleared. In this area a mixture of Bermuda grass and <u>Atriplex</u> species should be used. The Bermuda grass will help stabilize the area and the <u>Atriplex</u> will offer wildlife habitat and a gradient into the desert. Again, some trees might be transplanted to give habitat diversity.

The largest area for revegetation is the area to be cleared downstream of Safford to the San Carlos Reservoir, about 10,000 acres based on photoplanimetry. This area includes a variety of habitats and substrates. Immediately in the channel are gravels and sands. Outside these channels are the lower terraces with silty and sandy soils. These are the soils used primarily for farming in the Safford Valley. Above these are the upper terraces where finer silty soils mix with the coarse gravel float that comes off the desert. Each of these areas should be considered separately.

The gravel and sandy areas immediately in the channel, once cleared, will be difficult to revegetate. Assuming some continued river flows, these areas will shift. Only plants like saltcedar and coyote willow (<u>Salix exigua</u>) have the ability to stabilize this type of area. The soils will probably be too wet at times for use of <u>Atriplex</u> species. Bermuda grass and alkali sacaton would probably be eroded away. Species such as desert broom (<u>Baccharis sarothroides</u>) or burrobush (<u>Hymenoclea</u> sp.), often found on river gravels, might be useful, but water use data on these plants is unavailable. If they naturally occur in these areas why don't they occur at present in any number? Also, if they could occur, they obviously could not compete well with saltcedar over time.

The lower terraces might be farmed where possible if water savings are not the only consideration. The farming might be established in the same ratio of crops as found in Graham County. This ratio and the costs are presented in the Cost Analysis section. The likelihood for water savings by farming is small and the economic picture is bleak. Farming, however, will keep out reinvasion by phreatophytes.

The upper terraces might be farmed but more irrigation water will probably be needed in these areas than the lower terraces because of depth to water table. Upper terraces could be seeded with a mix of <u>Atriplex</u> species (quailbush and fourwing saltbush) thus creating a semidesert habitat. Reinvasion by saltcedar and other phreatophytes can still be expected over time. Mesquite might also be planted on the upper part of these terraces and cottonwood on the lower areas. These would increase water use but also improve habitat characteristics.

The area that San Carlos Reservoir inundates at high water probably cannot be revegetated by crops or non-crop species. This is prime phreatophyte habitat and only species that can withstand long periods of inundation, such as willow and saltcedar, will survive here. Mowing may be an answer to this area but the fine silt that surfaces these soils will then disperse.

4.3.1. <u>Summary</u>

Removal of phreatophytes along the Gila River in Graham County, Arizona may or may not create water salvage depending on one's interpretation of the work by Culler et al (1982). It will, however, create an area that has significantly decreased wildlife values and from which dust storms may develop. Revegetation of the cleared areas with any mixture of plant species whether crop or non-crop will totally or almost completely negate the apparent water salvaged by phreatophyte removal. None of the potential revegetation species can compete with saltcedar under the natural conditions that occur along the Gila River. To increase the competitive potential of the species, supplemental irrigation or physical retardation (e.g., mowing) of the phreatophytes must take place. In both cases,

costs increase while water savings are not guaranteed.

A mixture of trees such as cottonwood and willow can be used to create excellent wildlife habitat but these are phreatophytes and will prevent any water savings. In addition, the potential for establishing an adequate stand of cottonwood and willow throughout the floodplain that is to be cleared is slight.

The use of crops for replacement species, in most cases, negates the water savings because of irrigation requirements. Economic returns are also low if existant at all. Only the trade off of dollars for water can justify farming the cleared areas.

We have brought too many exotic species into this country. Some of the replacement species considered are exotic and only were considered because they have become naturalized. Saltcedar is an exotic that is out of control. It can outcompete all other plant species under the right environmental conditions along southwestern streams and is persistent and will continue to be persistent unless regularly removed by mechanical means. We do not want to replace it with another exotic that is not presently in this country and repeat our past mistakes. For this reason no non-naturalized exotics were considered as replacement species.

4.4.0. Barley as a Replacement Crop

Barley (<u>Hordeum vulgare</u>) apparently is being used with some success as a replacement species following phreatophyte removal in southern Utah. For this reason, barley is considered separately in more detail. Barley is a common crop grown in the Safford Valley, Graham County, Arizona. It is second to cotton as a crop for Graham County and over 6100 acres were planted in the county in 1982 (Arizona Ag. Statistics 1982). For these reasons, barley might seriously be considered as a replacement crop for areas where phreatophytes are removed.

To evaluate the potentials for using barley, one must look at both its relative use of water and the real costs or benefits from planting barley.

4.4.1. <u>Water Use</u>

Estimates of water use by barley are highly variable depending on both the environments in which it is tested and the actual methods of testing. Based on years of background data, Hathorn and Cluff (1982) show that to get a good double crop of barley in the Safford Valley, 44 inches of supplemental irrigation per year are necessary. In a more controlled series of experiments in Mesa, Arizona, the seasonal consumptive use of barley was shown to be 25 inches (Erie, French and Harris 1982). This latter figure was based on the barley growing season of mid-November to mid-May. Open soil evaporation losses from June through October should almost equal this because the summer rains (at least half of the annual 8.75 inches of precipitation) will keep the upper soil layers moist allowing continued upward capillary movement during a period when there is a high evaporative demand.

If the stubble is left on the fields after the harvest (June in Safford), and if the stubble is thick enough to act as mulch, it may act to reduce evaporation from the soil surface. The mulch will be dry, however, and thus will be dispersed by wind creating a spotty ground cover.

If one assumes that following harvest the mulch creates a 50% ground cover, which probably is high, then the expected reduction in evaporation from the soil surface will be cut by somewhat less than 50% because the movement of gases through openings is more closely related to perimeter than area. Wind and water movement of the mulch will likely reduce its cover to less than 25%. With this assumption, only 10-15% of potential soil evaporation is retained.

A study with field corn in the heat of summer in the Midwest showed that 50% of the evapotranspiration loss of water from the field was due to soil evaporation (Peters and Russell 1959). Although the locations are quite different between the Midwest and Arizona this study shows that if the soil in any agricultural field could be completely covered, there would be greater water savings, but a loose stubble and dispersed mulch covering probably will have only a small impact on soil moisture evaporative losses from harvested barley fields.

4.4.2. <u>Costs</u>

If one assumes that the costs of phreatophyte removal will be realized no matter what type of revegetation is used, then the figures to evaluate the cost benefit relationship of barley should be only the costs, receipts and profits from growing barley.

The estimated cost for growing barley in Graham County is \$265 per acre (Hathorn and Cluff 1982). This excludes taxes, depreciation and other non-variable costs that might not be realized under a Corps managed project but it is unrealistic to exclude these in determining long term costs. With these costs included the total is estimated to be \$339 per acre.

Over the past three years the barley yield in Graham County has averaged 2.25 tons per acre. During this period the average price per ton was \$124 (Brantner et al 1983). This means that the expected income per acre is \$279, creating a very small profit (actually a break even situation) or a substantial loss depending on which cost figure one uses. The loss is a more realistic figure.

4.4.3. Barley Competition With Saltcedar

Using barley as a replacement plant after removal of saltcedar will necessitate regular disking and plowing in December. This regular turning over of the soil will prevent establishment of new saltcedar stands. This can be observed in the Safford Valley where farm fields immediately adjacent to patches of riparian saltcedar stands are kept clear of saltcedar with regular plowing. On the other hand, fields that have been abandoned for only a few years have dense stands of young saltcedar, showing that stubble does not prevent saltcedar invasion.

A plowed field is irregular with many microsites to catch the wind-blown saltcedar seeds. There is no dense shade or litter layer that might influence saltcedar seedling establishment. Saltcedar germinates under most conditions as long as adequate moisture is available. Saltcedar germination percentage is generally low, i.e., 17% on the surface, 9% with a light soil cover and 4% with 1/4 to 1/2 inch soil cover (Tomanek and Ziegler 1961). Seedling survival is twice as high for seeds germinated with cover compared to those exposed. If the stubble were left thick enough, saltcedar invasion might be enhanced, assuming the wind blown seeds penetrate the stubble, a very good possibility.

4.4.4. Conclusions

The use of barley as a replacement crop along the Gila River in Graham County, Arizona following phreatophyte removal is not recommended. In order to have a successful barley crop irrigation is needed. The expected water amendment of 44 inches is more than twice the water savings of 18.53 inches calculated by Culler et al (1982). The six month seasonal water consumption by barley of 25 inches combined with bare soil evaporation of 12 to 15 inches for the remaining six months creates a water use nearly equivalent to the 43 inch water consumption calculated as the average water use for saltcedar by Culler et al (1982). If barley could be grown in the high density phreatophyte areas using no irrigation, a water savings of about 16 inches might be achieved. It is unlikely, however, that barley can be established as a viable crop without adequate irrigation.

Economically, the use of barley is questionable. The price of barley is highly variable. Recent years with greater production were years with lower prices for barley. An increase in productive acreage for barley might drive the price down while the costs of production would remain the same or continue to rise.

Any form of agriculture entailing plowing along the Gila River will tend to prevent saltcedar reinvasion if practiced annually. Barley, when evaluated on water savings and cost benefit relationships, is not unique in being highly tolerant of

arid environments or as a high income crop. Some of the other crops evaluated may have equal or greater potentials for water savings and/or economic return, a decision that can only be made in light of the goals of the total phreatophyte removal project.

4.5.0. Cost Analysis

Decisions on whether phreatophytes should be removed and how the cleared areas should be managed is not solely a decision based on water salvage but also must include costs. An analysis of the costs must take into account estimates on clearing as well as revegetation or maintenance of cleared areas. The purpose of this section is to develop a per acre cost analysis for phreatophyte removal and revegetation. This is presented in tabular form in Table 4-2. The table is developed in two parts. The first part presents for each stage of the removal and revegetation processes the costs, receipts and profits of varous revegetation alternatives. The second part presents a summary of costs of alternatives for total removal-revegetation procedures.

4.5.1. <u>Costs</u>

Using data from Public Law 88-594 (1964), which appropriated funds for phreatophyte control in the Southwest, and from clearing experiences from the 1960's (Lowry 1966), the costs for 1985 can be estimated as \$180 per acre for dense phreatophytes and \$140 per acre for less dense or sparse phreatophytes. Multiplying these costs by the acreage for dense (6675 acres) and sparse (9950 acres) phreatophytes along the Gila River, determined by planimetering recent aerial photographs, the average cost for removal of phreatophyes along the Gila River is \$156 per acre. The average cost of \$156 per acre is extremely conservative because Graf (1982) reported a per acre cost of \$781 (\$370 for plowing and grubbing and \$411 for raking, piling and burning) based on a discussion with Maricopa County Flood Control District. For calculation purposes in this report, Graf's figures have been used because they are based on more recent information.

Early cost figures were used to determine simple maintenance of cleared areas with no revegetation. Converting these cost figures to 1985 values gives an estimate of \$30 per acre for maintenance. Graf (1982) reported a second year maintenance cost covering spot plowing, raking and burning of \$104 per acre which is used here. Third year maintenance costs in this report included mechanical maintenance with a mower of \$30 per acre.

4.5.2. Revegetation With Non-Crops

Revegetation with non-crop plants includes, in addition to phreatophyte removal, site preparation, seeding and seed costs. Site preparation depending on the condition following phreatophyte removal will cost between \$40 and \$70 per acre. Seeding for the area along the Gila River is best done by fixed wing airplane. The cost for aerial seeding is about \$3 per acre

Table 4-2

PER ACRE COST ANALYSIS FOR REVEGETATION OF THE PROJECT. COSTS REMOVAL Plowing and/or Grubbing 1964 PL 88-594 \$2,500,000 for 40,000 A = \$62.5/A\$45/A 1960-65 Dense phreatophytes = 1985 \$180/A 1960-65 Sparse phreatophytes \$35/A = 1985 \$140/A Gila River phreatophyte removal: Dense (>80% cover) $6675A \times $180 = $1,201,500$ Sparse (<80% cover) $9950A \times $140 = 1,393,000$ \$2,594,500 2,594,000 -- 16,625A = 156/A1982 (Graf 1982) Plowing and grubbing \$370/A Raking, Piling and Burning 1982 (Graf 1982) \$411/A MAINTENANCE Second Year (spot plowing, raking and burning) 1982 (Graf 1982) \$104/A Third Year, etc. (mowing, no use of herbicides) 1985 Estimate \$30/A NON-CROP REVEGETATION Site preparation (if removal leaves site relatively level) Plowing (1 hr/A @\$30/hr) and disking (.25 hr/A @\$40/hr) = \$40/ASite preparation (if removal leaves site very rough) Disking (.67 hr/A @\$40/hr), plowing (1 hr/A @\$30/hr) and disking (.33 hr/A $\overline{@}$ \$40/hr) = \$70/ASeeding--Aerial seeding \$3/A at 20 lbs. seed/A Seed imprinting \$25/A Hydromulch seeding \$330/A Transplanting (trees, augering, fertilizer, irrigation, labor, etc.) = \$1000/A Maintenance (2nd year on: labor, irrigation) = ca \$250/A Table 4-2 (cont.)

Seeds*				
Alkali sacaton	6	lbs.	х	10.00/lb. = 60/A
Bermuda grass	12	lbs.	х	2.25/lb. = 27/A
Blue panic grass	12	lbs.	х	\$10.50/lb. = \$126/A
Fourwing saltbush	5	lbs.	х	8.50/1b. = 42.50/A
Quailbush	5	lbs.	х	10.75/lb. = 53.75/A
* Prices are for	Pı	ire L:	iv€	e Seed (not bulk)

CROP REVEGETATION (Costs, Receipts and Profits)

Site Preparation: Disking (.25 hr/A @\$40/hr) = \$10/A Multiple Crop (Four major crops grown in Graham County)

Total Cost Table

Crop	Acres %	Cost/A	Rcpts/A	Pft or loss/A	Proportional Pft or loss/A	
Cotton Barley Alfalfa hay Wheat	60 16 13 11	\$780 339 585 352	\$650 279 675 319	-\$130 - 60 90 - 33	-\$78.00 - 9.60 + 11.70 - 3.60	
	Total	per acre	;		-\$79.50	

Total costs: include variable costs plus machinery costs, depreciation, taxes and other fixed costs.

Limited Cost Table

Crop	Acres %	Cost/A	Rcpts/A	Pft or loss/A	Proportional Pft or loss/A
Cotton	60	\$450	\$650	\$200	\$120.00
Barley	16	187	279	92	14.72
Alfalfa hay	13	216	675	459	59.67
Wheat	11	198	319	121	13.31

Total per acre

\$207.70

Limited Costs: exclude taxes, depreciation, machinery fixed costs, etc.

Table 4-2 (cont.)

Single Crop Revegetation (Profit or loss based on total or limited costs)

Crop	Pft or loss (total costs)	Pft or loss (limited costs)
Cotton	-\$130	\$200
Barley	- 60	92
Alfalfa hay	+ 90	459
Wheat	- 33	121

REVEGETATION Summary Cost Analysis

REMOVAL AND MAINTENANCE

Year One: Removal and Burning: \$781/A Year Two: Spot Removal and Burning: \$104/A Subsequent Years (if mowing is used): \$30/A

REMOVAL AND REVEGETATION WITH NON-CROPS (Year One Only)

Year One: Removal + Site Prep. + Seeding(aerial) + Seeds

Alkali sacaton (Yr. one)	\$781	+	\$70	+	\$3	+	\$ 60	=	\$914/A
Bermuda grass (Yr. one)	781	+	70	+	3	+	27	=	881/A
Blue panic grass (Yr. one)	781	+	70	+	3	+	126	=	980/A
Fourwing saltbush (Yr. one)	781	+	70	+	3	+	43	=	897/A
Quailbush (Yr. one)	781	+	70	+	3	+	54	=	908/A

REMOVAL AND REVEGETATION WITH TREES

Year One: Removal, Site Prep. and Transplanting Year Two and Subsequent Years: Hand Weeding and Irrigation

Mixture of Trees (Yr. one) \$781 + \$70 + \$1000 = \$1851/A (cottonwood, willow, etc.)

Maintenance (Yr. Two on)

= ca \$250/A

REMOVAL AND REVEGETATION WITH CROPS

Year One: Removal + Site Prep. + Farming [(Profit) or loss] Year Two and Subsequent Years: Farming [(Profit) or loss]

Multiple Crops: Year One--Total Costs: \$781 + \$10 + \$80 = \$871/A Limited Costs: \$781 + \$10 + (\$208) = \$583/A Table 4-2 (cont.) Multiple Crops (cont.) Year Two--Total Costs: \$80/A Limited Costs: \$208/A credit Single Crops (Total Costs Only) Cotton (1) (2) \$781 + \$10 + \$130 \$921/A = 130 130/A = \$851/A \$60 Barley (1) \$781 + \$10 + = (2)60 60/A = Alfalfa (1) hay (2) 781 + 10 + (90) =\$701/A (90) =90/A credit \$824/A (1) (2) \$781 + \$10 + \$33 Wheat = 33/A 33 ==

based on estimates given by an aerial application contractor. Other seeding techniques are so much more expensive than aerial seeding that they were not considered feasible. Seed costs are also variable depending on the species. Only five plant species are presented in Table 4-2. These are the species that have the potential of fulfilling the requirements of water saving, resistance to inundation and good wildlife habitat. Obviously, each does not satisfy all these characteristics but they are species that should be considered. The seed costs range from \$126 per acre for blue panic grass to \$27 per acre for Bermuda grass.

Transplanting of trees such as cottonwood and willow is extremely expensive because it requires hand labor and often supplemental irrigation and fencing. Estimates based on studies along the Colorado River (Ohmart, personal communication) put transplanting costs at \$1066-\$1294 per acre for 100 trees (20 foot centers) and \$811-\$991 per acre for 76 trees (23 foot centers). These costs include trees, fertilizer, augering, irrigation, labor and fencing. An average cost of \$1000 per acre is used for all transplanting calculations.

4.5.3. Revegetation With Crops

Revegetation with crops can be calculated in two ways, as planting of multiple crop species or planting of single crop species. The Safford Valley represents an area that has been cleared of large tracts of phreatophytes for farming. This type of revegetation following phreatophyte removal might be considered because none of the potential revegetation species are significant water savers. Revegetating with economic plants that might return a profit is an alternative to use of non-crops.

The four primary crop species which have been used to determine both multiple and single crop revegetation are cotton, barley, alfalfa hay and wheat. The figures used for costs and receipts are taken from Hathorn and Cluff (1982). Using total costs, i.e., variable and non-variable costs, and revegetating the area with the same proportion of crops presently planted in Graham County, the cost or dollar loss per acre is \$79.50. Using limited cost figures, i.e., only variable costs, there is a profit realized per acre of \$207.70. The limited cost figures are presented because a project under U.S. Army Corps management might be able to ignore non-variable costs such as taxes, depreciation and machinery costs. It is, however, unreasonable to use the limited cost figure if the true cost analysis is to be presented.

Using single crop revegetation, three of the four crops realize a loss using total cost figures. Only alfalfa hay returns a profit. Using limited cost figures all four crops realize a profit.

4.5.4. <u>Revegetation-Summary</u>

The revegetation summary cost analysis in Table 4-2 puts all the costs of the revegetation procedures together for each alternative. The costs are presented for the first year which will always include the cost of phreatophyte removal and burning, and for the second and subsequent years.

If the decision is to only remove the phreatophytes and maintain cleared areas, the cost is estimated at \$781 per acre for the first year, \$104 per acre for the second year and \$30 per acre thereafter. Removal of phreatophytes and revegetation with non-crops includes removal, site preparation (disking, plowing and disking), seeding and seed costs the first year. The cost of this ranges from \$881 per acre for Bermuda grass to \$980 for blue panic grass. Second year maintenance of \$104 per acre for spot plowing, raking and burning is anticipated. No action after the second year is calculated; however, reseeding of some areas might be necessary. These reseeding costs will be the sum of the aerial seeding and the seed costs as presented in Table 4-2.

Revegetation by transplanting a mixture of trees is quite costly. The first year which includes phreatophyte removal, site preparation and transplanting will cost \$1851 per acre. Subsequent years cannot involve any more root plowing because of the potential damage to the transplants, so hand weeding of undesireable invasion species will be necessary. This, along with irrigation, may have to continue for many years after the initial transplanting at a cost of approximately \$250 per acre.

Revegetation with farm crops will include phreatophyte removal, site preparation (only disking) and farming costs for the first year, and only farming costs thereafter. Revegetating with multiple crops gives an overall cost of \$871 per acre using total costs and a cost of \$583 per acre using the limited cost figures. This assumes a marketable crop during the first year. Subsequent years would produce an annual cost of \$80 per acre using total costs and a credit of \$208 per acre using limited costs.

Because the use of the limited costs is not truly representative of the costs of revegetation, only total costs were used to calculate costs for revegetating with single crop species. All of the four crops used in this analysis showed a loss (cost) during the first year, again assuming a marketable crop during that year. First year costs ranged from \$701 per acre for alfalfa hay to \$921 for cotton. Three of the crops continue to show losses during subsequent years, alfalfa hay being the only exception.

There does not appear to be a suitable crop for revegetation if both water savings and economic benefits must be met. Alflafa hay, which returns some economic benefit, is a major water user. Barley, which might save some water, creates economic losses. Use of non-crops creates major costs the first year and in some cases the second year, and only limited costs in subsequent years. Water savings and wildlife habitat for these non-crop species thus become prime considerations.

4.6.0. References (those not included in annotated bibliography).

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- Anderson, B., R. D. Ohmart, and J. Rice. 1983. Avian and vegetation community structure and their seasonal relationships in the lower Colorado River valley. Condor 85:392-405.
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- Carothers, S. and R. R. Johnson. 1974. Population structure and social organization of southwestern riparian birds. American Zoologist 14:97-108.
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- Graf, W. 1982. Dynamics and control of phreatophytes along the upper Gila River, southeast Arizona. Report to the U.S. Army Corps of Engineers, Los Angeles, CA. 108 pp.
- Peters, D.B. and M.B. Russell. 1959. Relative losses by evaporation and transpiration in field corn. Proceedings of the Soil Science Society of America 23:170-173.
- Stamp, N. E., and R. D. Ohmart. 1979. Rodents of desert shrub and riparian woodland habitats in the Sonoran Desert. Southwestern Naturalist 24:279-289.

Vitt, L., R. C. VanLobenSels, and R. D. Ohmart. 1976. The herpatofauna of the proposed Orme Dam site. Final Report. Contract 14-06-300-2541, Bureau of Reclamation, Phoenix, Arizona.

5.0.0. ANNOTATED BIBLIOGRAPHY

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Anderson, W. D.

1980. Some water use responses of barley, lupin and rapeseed. Australian Journal of Experimental Agriculture and Animal Husbandry 20:202-209.

At Woogenellup, Western Australia, barley, lupin and rapeseed were sown in the field on five occasions. Water use and other factors were measured for each crop. Potential evapotranspiration functions were calculated for each crop, showing that barley required less water per unit of dry matter when water was not limiting than either of the other crops.

Bauder, J. W., A. Bauer, J. M. Ramirez, and D. K. Cassel

1978. Alfalfa water use and production on dryland and irrigated sandy loam. Agronomy Journal 70:95-99.

Field studies were conducted from 1972 to 1976 on the Oakes Irrigation Field Trials site in southeastern North Dakota to determine alfalfa dry matter yield in response to irrigation and fertilization variables. Evapotranspiration increased as level of water applied increased in all four years. The results demonstrated that the amount of dry matter produced per unit of water use increased linearly with the increase in availability of soil water. Maximum yields in the site were realized when the total available water from all sources equalled approximately 60 cm during the growing season.

Biran, I., B. Bravdo, I. Bushkin-Harav, and E. Rawitz

1981. Water consumption and growth rate of 11 turfgrasses as affected by mowing height, irrigation frequency, and soil moisture. Agronomy Journal. 73:85-90.

Alta fescue (C-3) was found to have high drought tolerance and high water consumption compared to a zoysiagrass (C-4) which had low drought tolerance but lower water consumption as well in this study which compared 2 C-3 species and 9 C-4 species of grasses during June to August (maximum ave. daytime temperature was 33.3 C) in Rehovot, Israel. C-3 species used more water at growing heights of 6 cm than at 3 cm, while C-4 species, after acclimating for a short period used essentially the same amount of water at both growing heights. Both yield loss and water consumption were similar for the C-3 and C-4 species when they were subjected to water stress. Blaney, H. F.

1961. Consumptive use and water waste by phreatophytes. ASCE Journal Irrigation and Drainage Division 87(IR3):37-46.

This is a summary of various phreatophyte water consumption studies which had been made in parts of Texas, New Mexico and Arizona. It gives an estimate of water that might be saved by replacing salt cedar with Bermuda grass along portions of the Pecos River, New Mexico.

Bowie, J. E. and W. Kam

1968. Use of water by riparian vegetation, Cottonwood Wash, Arizona. U.S. Geological Survey Water-Supply Paper 1858, 62 p.

The change in water use as a result of the modification of riparian vegetation was measured in Cottonwood Wash, Mohave County, Arizona. Measurements of streamflow, ground-water levels, vegetation and meteorological data in the area defined the use of water by riparian vegetation under natural hydrologic conditions. Subsequent defoliation and eradication of the vegetation in the lower reach permitted the determination of the change in water use as a result of the modification. The average loss after eradication was 42 acre-feet per growing season compared to 80 acre-feet before eradication. Cottonwood, willow and seepwillow accounted for 95 percent of the vegetation sampled.

Brantner, R., S. D. Wiyatt, S. Manheimer, G. L. Shepler, G. H. Sullivan, L. Hoffman, E. S. Dye

1983. 1982 Arizona Agricultural Statistics. Arizona Crop and Livestock Reporting Service, U.S.D.A., Phoenix, Arizona, 105 p.

This report gives a variety of agricultural statistics including the latest information on individual crop production amounts and prices in Graham County, Arizona.

Bureau of Reclamation

1973. Evapotranspirometer studies of saltcedar near Bernardo, New Mexico, March 1973. Pacific S.W. Interagency Subcommittee Report, 31 p.

This report presents data obtained from 1962 through 1968

on consumptive use of water by saltcedar and evaporation from bare ground close to the Rio Grande River, Bernardo, N.M. The data indicate 1) the rate of water use by saltcedar is not necessarily dependent on the depth to water table. 2) Consumptive use of water decreases as the plants mature. 3) There is a straightline relationship between consumptive use and volume density for the different stages of growth. 4) Saltcedar may or may not take a comparatively long time to reach 100% volume density. 5) Consumptive use data for saltcedar in the Bernardo area are not similar to data obtained in other areas. Saltgrass studies were carried out during the years 1969-1973 and are reported in the following reference.

Bureau of Reclamation

1973. Progress Report: Phreatophyte investigations, Bernardo evapotranspirometers. Middle Rio Grande Project Office, 50 p.

The purpose of this report is to evaluate results of lysimeter studies near Bernardo, N.M. (Rio Grande River) which took place from 1969 through 1973.

Conclusions of the study to date include: 1) Russian olive water loss data show a comparable water use to saltcedar in the Bernardo area. 2) The salinity profile for saltcedar shows a decline in growth and water use with increasing salinity. 3) Differences in consumptive use of water by saltcedar may be dependent more on root development during a critical period in the life of the plant. 4) A rapid increase in depth to water table results in a reduction in water loss by saltcedar. 5) Consumptive use of water by saltgrass decreases as the depth to water increases. Small tanks show a higher water use by saltgrass than large tanks. 6) Saltgrass not shaded will use about 40 percent more water than if covered by 50 percent shade.

Bureau of Reclamation

1969. Pecos River Basin Water Salvage Project, New Mexico-Texas: Joint Ecology Observations and Studies. U.S. Department of Interior, Bureau of Reclamation Southwest Region, Amarillo, Texas.

Photographs and observations made on the saltcedar clearing initiated in 1967 along the Pecos River. Photos show before and after treatments of vegetation. There are no written comments or conclusions made within the report but the photos provide information on how quickly saltcedar may become re-established.

Campbell, C. J.

1966. Periodic mowings suppress tamarisk growth, increase forage for browsing. U.S. Forest Service Research Note RM-76, 4 p. Saltcedar plants were clipped (complete defoliation) and mowed to within 1 foot of soil surface in 2-, 4-, 8-, and 24-week clipping intervals comparing plant mortality with each treatment. Tent evapotranspiration studies on treated and untreated plants showed that saltcedar with mowing treatment transpires 50 percent as much as untreated plants. Study took place near the Granite Reef Diversion Dam, on the Salt River in central Arizona.

Croft, A. R.

1948. Water loss by stream surface evaporation and transpirtion by riparian vegetation. American Geophysical Union Transactions 29(2):235-239.

For the period August to October 1944, evapotranspiration losses from streamflow in Farmington Creek, in northern Utah, have been estimated to be about one-third of the total streamflow. Observations were made of streamflow, wet and dry bulb air temperatures, evaporation from several cans exposed in the stream, and water temperature. The analysis considered fluctuations in streamflow diurnally, seasonally, with changes in weather, and with the freezing of leaves.

Culler, R. C.

1970. Water conservation by removal of phreatophytes. American Geophysical Union Transactions 51(10):684-689.

The comparative data presented in this report indicate that removal of phreatophytes (88 percent saltcedar, 12 percent mesquite) from the Gila River floodplain in southeastern Arizona produces a significant reduction in evapotranspiration from the area cleared. The long-term hydrologic effects of phreatophyte removal will depend on the successful establishment of vegetation having a low consumptive use of water. Continuing maintenance will undoubtedly be required to resist invasion by saltcedar.

Decker, J. P., W. G. Gaylor, and F. D. Cole

1962. Measuring transpiration of undisturbed tamarisk shrubs. Plant Physiology 37:393-397.

Plastic tent field studies along the lower stretches of the Salt River, Arizona were conducted in the summer of 1959. Evapotranspiration of Bermuda grass-tamarisk plots increased linearly with amount of tamarisk. A reduction of evapotranspiration could be expected to follow conversion of tamarisk stands to grass cover. Problems with the tent study included increased temperature and humidity within the tent which somewhat clouded the results for practical application to other sites. Erie, L. J., O. F. French, D. A. Bucks, and K. Harris

1982. Consumptive use of water by major crops in the southwestern United States. U.S.D.A. Agricultural Research Service Conservation Research Report No.29, 40 p.

As the title implies, this report lists and clarifies aspects of water use by the most common field crops in the southwestern United States. Estimates of consumptive use in the Salt River Valley, Arizona, as measured by soil moisture depletion, are reported. A method is described for using the reported data to develop consumptive use estimates for other irrigated areas.

Fairbourn, M. L.

1982. Water use by forage species. Agronomy Journal 74:62-66.

This study took place at the High Plains Grasslands Research Station in Cheyenne, Wyoming to determine water-use efficiency and ability to use available soil water during a harvest growing period. Both greenhouse and field experiments were used on 24 forage species including 9 legumes, 6 pasture grasses (including tall fescue), and 5 range grasses. Growing plants in a field environment increased evapotranspiration by 100 to 200 percent compared with that in the greenhouse. Water use was monitored by tensiometers in the field studies. Generally, the ET requirements were relatively high for the alfalfa varieties and most of the pasture grasses compared to range grasses but their water use efficiency was low compared to the range grasses.

Fritschen, L. J.

1966. Evapotranspiration rates of field crops determined by the Bowen ratio method. Agronomy Journal 58:339-342.

Simultaneous evapotranspiration rates were determined biweekly for the crop combinations of alfalfa and barley, alfalfa and cotton, alfalfa and sorghum, wheat and oats, and cotton from meteorological data by the Bowen ratio method. The crops were grown under irrigated conditions in south central Arizona. Calculated evapotranspiration rates ranged from 1.0 to 1.8 times net radiation, indicating that large amounts of energy were extracted from the air mass. Alfalfa prior to cutting tended to use more water than the other crops. Water use by cotton after canopy development approached that of alfalfa. Barley, wheat, and grain sorghum appeared to require the least water.

Garrity, D. P., D. G. Watts, C. Y. Sullivan, and J. R. Gilley

1982. Moisture deficits and grain sorghum performance: Evapotranspiration-yield relationships. Agronomy Journal 74:815-820. In two seasons, the relationship between evapotranspiration (ET) and grain yield (Y) was linear in a study conducted near Lincoln, Nebraska. Water use efficiency consistently decreased as ET declined below the maximum. It appeared that water stress, regardless of timing, tended to reduce water use efficiency. The reductions were smallest when stress increased gradually throughout the growing season.

Gary, H. L. and C. J. Campbell

1965. Water table characteristics under tamarisk in Arizona. U. S. Forest Service Research Note RM-58, 7 p.

This note describes the water-table characteristics under a stand of saltcedar on the Salt River in central Arizona. Water table fluctuations in 39 ground-water wells within a circular area of about 40 ft in diameter are discussed before and after vegetation removal. Data showed that the water table is not a smooth plane at any given time and in one test on June 6, 1964, the range of variation between wells was 0.235 ft. Standard deviations about the mean (0.109 ft) was 0.043 ft, which illustrates the variability in water-table elevation when the area was intensively sampled. The question is raised: where should wells be located to give an unbiased estimate of average rate and amount of ET losses for a plant or land area?

Gatewood, J. S., T. W. Robinson, B. R. Colby, J. D. Hem, and L. C. Halpenny

1950. Use of water by bottom-land vegetation in lower Safford Valley, Arizona. U. S. Geological Survey Water-Supply Paper 1103, 210 p.

This study took place in lower Safford Valley, Graham County, Arizona, within the lowland alluvial floodplain, with some irrigated farmlands and a belt of natural vegetation in the bottomlands along the river consisting of phreatophytes, principally saltcedar, baccharis, cottonwood, and mesquite.

Six methods of determining use of water were applied during the investigation: Tank, transpiration well, seepage-run, inflow-outflow, chloride-increase, and slope-seepage. These methods are described in detail with discussions of their applicability to river-reach studies of water losses.

Although the methods differed greatly, the figure for use of ground water computed by each method was within 20 percent of the mean determined by averaging the results of all six methods. Based on the results, the total use of water by vegetation during the 12-month period ending September 30, 1944, was 28,000 acre-feet in a total of 9,303 acres in the 46 mile reach of Gila River from Thatcher to Calva. Of the total ground water used, 23,000 acre-feet were derived from the ground water reservoir and the remainder was derived from precipitation on the area. Of the 23,000 feet used, more than 75 percent was used by saltcedar.

Gay, L. W. and R. K. Hartman

1982. ET measurements over riparian saltcedar on the Colorado River. Hydrology and Water Resources of Arizona and the Southwest 12:9-15.

Evapotranspiration from an extensive stand of saltcedar on the Colorado River floodplain was defined throughout the growing season by a series of Bowen ratio energy budget measurements in 1980-1981. Water table depth was about 3 m during measurements. Daily ET totals ranged from 2.9 mm/day in early April up to 11.0 mm/day in late June, and dropped to 1.8 mm/day in late October. These values are means from two separate measurement systems averaged over measurement periods of two to four days. The seasonal saltcedar water use of 172.7 cm is somewhat lower, however, than earlier more speculative estimates for saltcedar that ranged as high as 210 cm per year.

Gay, L. W. and R. K. Hartman

1981. Energy budget measurements over irrigated alfalfa. Arizona-Nevada Academy of Sciences Proceedings 11:73-79.

Bowen ratio measurements over irrigated alfalfa in southern Arizona for four days in June of 1980 indicated a mean daily evapotranspiration slightly in excess of 10 mm. Advective conditions prevailed throughout the study. This study sought: (1) to test a new, dual-mast measurement system; and (2) to develop baseline data of evapotranspiration losses from a standard crop under the warm, dry environmental conditions that characterize summer in southern Arizona.

Gay, L. W. and L. J. Fritschen

1979. An energy budget analysis of water by saltcedar. Water Resources Research 15(6):1589-1592.

Bowen ratio estimates of evapotranspiration (ET) over a stand of saltcedar on the Rio Grande floodplain in central New Mexico provided estimates of water use by saltcedar during hot, dry weather. The mean ET for 5 consecutive days (June 14-18, 1977) was 8.2 mm/day by the Bowen ratio and 7.9 mm/day by the lysimeters. Vegetation in the lysimeters and at the Bowen ratio sites differed in density and vigor in a manner consistent with the evapotranspiration measurements.

Hathorn, S. and R. Cluff

1982. 1982 Arizona Field Crop Budgets: Graham County. Department of Agricultural Economics, University of Arizona, Tucson, Arizona, 49 p.

This is an annual report of crop budgets for use as a general guide to the cost of producing the major crops in Graham

County, Arizona. Six tables for each crop are presented: 1. Cost by operations of producing an acre; 2. Calendar of operations and tooling used per acre; 3. Materials used to produce an acre; 4. Variable cost of major inputs per acre; 5. Receipts, costs, and profit per acre; and 6. Cost summary per acre. The crops described in the report include alfalfa (establishment), alfalfa hay, upland cotton, Pima cotton, barley (double crop), milling wheat (double crop), and milo (double crop).

Hibbert, A. R.

1969. Precipitation affects increases in streamflow after converting brush to grass in Arizona. Presented at the 50th Annual Meeting of the American Geophysical Union, Washington, D. C., April 21-25, 1969.

Water yield has increased substantially on two small chapparal watersheds in central Arizona following control of brush and conversion to grass. The increases in streamflow on the treated watersheds have varied from 1.5 to 14.0 in/yr during the past 7 years. Winter precipitation appears to be the dominant factor controlling the amount of increase. When annual precipitation is less than 16 inches, the increase in water yield for that year is likely to be less than 2 inches. At 34 inches of annual precipitation, the increase in flow may reach 12 inches or more, depending on the seasonal distribution in rainfall.

Hoffman, G. J. and J. A. Jobes

1978. Growth and water relations of cereal crops as influenced by salinity and relative humidity. Agronomy Journal 70:765-768.

The interactive effect of salinity and relative humidity (RH) on how wheat, barley and corn use water and their relative salt tolerance was studied in climate chambers during 1970-71. With a non-saline root medium, increasing RH from 45% to 90% increased the wheat yield by 24%, had no influence on corn yield, and reduced barley yield by 16%. Transpiration (1/plant) was reduced from 17.9 l to 1.3 l with increasing salinity levels in barley at 45% RH, from 18.5 to 1.2 l in wheat, and from 58.9 to 14.3 l in corn.

Horton, J. S. and C. J. Campbell

1974. Management of phreatophyte and riparian vegetation for maximum multiple use values. U.S.D.A. Forest Service Research Paper RM-117, 23 p.

The report summarizes the status of knowledge in 1974 about environmental relations of vegetation along water courses in the southwestern U.S., including the Gila River, and impacts of vegetation management to reduce evapotranspiration on other resource values. It suggests approaches to management of moist-site areas by zones based primarily on water table depth, elevation and tree species.

Hughes, W.

1971. Effects on water supply due to salt cedar removal. ASCE National Water Resources Engineering Meeting, Phoenix, Arizona, Preprint No. 1290, 30 p.

The investigation involved the development of a model, based on empirical mass transfer equations, which would simulate the water losses due to evapotranspiration from saltcedar in place, and evaporation (soil) without the plants and which employed as variables: temperature, humidity, wind speed, plant density, and water table depth. The model was used to determine the sensitivity of the net water gain to each of the variables and to several combinations of variables, from which estimates of the effective water gain resulting from the removal of salt cedar plants were made. Results from the model indicated that under conditions which exist in the Middle Rio Grande Valley, as much as 2.5 acre feet/acre of water might be gained by removal. However, it was also found that the quantity of water varies greatly with variations in the volume density of foliage and on the depth to the water table. Also, it was found that there were topographic conditions for which no increase in water would result from the removal of saltcedar.

Joy, R. J., H. T. Poole, and A. K. Dobrenz

1972. The effect of soil moisture regimes on water-use efficiency and growth components of alfalfa. Progressive Agriculture in Arizona 24(5):9-11.

An alfalfa irrigation study was conducted at Tucson, Arizona from 1968 through 1970 to investigate water-use efficiency, yield and other factors of four alfalfa cultivars grown under three soil moisture regimes. Alfalfa plants grown under the low moisture regime were the most efficient for all three years of study, however, increased evaporation resulting from frequent irrigation will increase the consumptive use of crops, and water use efficiency will be reduced unless there is a corresponding increase in forage production.

Kneebone, W. R. and I. L. Pepper

1982. Consumptive water use by sub-irrigated turfgrasses under desert conditions. Agronomy Journal. 74:419-423.

This study evaluated effects of management, local climate,

species, and cultivars upon water use. Three bermudagrasses, a zoysiagrass, St. Augustinegrass, and tall fescue were grown in a local washed mortar sand in percolation lysimeters with measured subirrigation at Tucson, Arizona. There were no significant differences in consumptive water use among the bermudagrasses and zoysiagrass at either of two managements. Raising the water table 10 cm and overseeding with annual ryegrass significantly increased consumptive use. Consumptive use values expressed as percentage of evaporative pan losses ranged from 42 to 80 percent depending upon management and grass. Mean annual percentages were 46 for bermudagrasses and zoysiagrass, 58 for St. Augustinegrass, and 64 for tall fescue grown with the same water table.

Koshi, P. T., J. Stubbendieck, H. V. Eck, and W. G. McCully

1982. Switchgrasses: Forage yield, forage quality, and water-use efficiency. Journal of Range Management 35(5):623-627.

The purpose of the study was to evaluate 3 strains of switchgrass under 3 water and 3 harvest regimes. Maximum production was obtained with 116.5 cm of water use but maximum water use efficiency was obtained with about 85.5 cm of water use. The switchgrasses are adapted for use both without irrigation and when varying amounts of irrigation water are available. The study was conducted at the U.S. Big Spring Field Station, Big Spring, Texas on Amarillo fine sandy loam soil. Soil water was measured by the neutron scattering technique. Time period of study was from 1970-1973.

Lowry, O. J.

1966. Establishment, operation, and maintenance of phreatophyte control projects. In Phreatophyte Symposium 66-3 Meeting, Pacific S.W. Inter-Agency Committee, Albuquerque, New Mexico, p 26-35.

This report summarizes the authorizing legislation for the Middle Rio Grande Project and gives the methods and costs for clearing phreatophytes along the Rio Grande. Various types of ground-operated equipment are evaluated.

McDonald, C. C. and G. H. Hughes

1968. Studies of consumptive use of water by phreatophytes and hydrophytes near Yuma, Arizona. U.S.G.S. Professional Paper 486-F, 24 p.

Studies of transpiration by several species of floodplain vegetation and evaporation from water surfaces and bare soil were carried out near the Colorado River, Yuma, Arizona during a 6 year period. Arrowweed, fourwing saltbush, quailbush, and bermuda grass were grown under controlled conditions in large tanks about 1,000 sq ft in area. Annual consumptive use by the several species increased with the volume of vegetation, but the consumptive use per unit volume decreased as plants matured. Depth to ground water strongly influenced evaporation from bare soil; for water table depths of 2.0-4.0 ft, evaporation varied from 3 to 20 inches yearly. Average water use yearly for the vegetation was: arrowweed, 96 in/year, 5.5 ft to water table; quailbush, 44 in/year, 3.5-5.5 ft to water table; fourwing saltbush, 38 in/year, 3.5-5.5 ft to water table; and bermuda grass, 73 in/year, 3.5 ft to water table.

McGinnies, W. G. and J. F. Arnold

1939. Relative water requirements of Arizona range plants. Arizona Agricultureal Experiment Station Technical Bulletin 80:167-246.

Water requirements of 28 species of Arizona range plants and 5 crop plants were determined under varying climatic conditions during the period from 1931-1936, at the Santa Rita Experimental Range near Tucson, Arizona. As a group, perennial grasses were fairly uniform in their water requirement. There was less difference between geographical groups than there was within the groups. The summer annuals had lower water requirement values than the winter annuals. The trees and shrubs had much higher water requirements than any other group.

Meinzer, O. E.

1927. Plants as indicators of ground water. U.S. Geological Survey Water-Supply Paper 557, 95 p.

Common phreatophyte species are listed and some general information is given about them with respect to growth habit, geography, depth of water table reached, and quality of ground water endured.

Muckel, D. C.

1966. Phreatophytes--water use and potential water savings. Proceedings ASCE Journal Irrigation and Drainage Division (IR4):27-34.

Problems related to the measurement of water use by phreatophyte species in California, Nevada and Arizona are reviewed. Different methodologies are discussed and some of their limitations are defined.

Nilsen, E. T., P. W. Rundel, and M. R. Sharifi

1981. Summer water relations of the desert phreatophyte <u>Prosopis glandulosa</u> in the Sonoran desert of southern California. Oecologia 50:271-276. Water relations components for honey mesquite were studied at Harper's Well, near the Salton Sea, California, during the summer months of 1980. This is the first in a series of studies to be published on seasonal water use and water use efficiency of mesquite and gives background information on summer water potentials, vapor pressure deficit, and leaf conductance for this species compared to other desert plants.

Olson, T. C.

1971. Yield and water use by different populations of dryland corn, grain sorghum, and forage sorghum in the western corn belt. Agronomy Journal. 63:104-106.

Corn, grain sorghum, and forage sorghum all gave increasing total dry-matter yields with increasing population throughout the range of populations used. Water use was nearly the same for all crops within each year, although grain sorghum grown at the lowest population tended to use slightly less water. Study was conducted at the Eastern South Dakota Soil and Water Conservation Research Farm near Madison, South Dakota from 1965-68.

Qashu, H. K. and D. D. Evans

1967. Water disposition in a stream channel with riparian vegetation. Soil Science Society of America Proceedings 31(2):263-269.

An analysis is described for estimating the disposition along a reach of a natural stream channel with riparian vegetation and impermeable bedrock at a shallow depth. Walnut Gulch stream near Tombstone, Arizona was used for the study. The dominant vegetation is mesquite and at certain times of the year, the area along the channel is also covered by lush herbaceous vegetation attaining heights up to 3 feet.

Methods were adapted for a particular set of conditions to measure subsurface water flow and water storage in the channel alluvium. Four distinct water-use periods were apparent within a yearly cycle; water losses by evapotranspiration were estimated giving 9 mm of water lost per day by transpiration during the months of May and June, a time of water shortage in the area. Total depth of annual water loss by evapotranspiration from the channel reach was estimated to be 131 cm of water (4.3 acre-feet/ acre).

Reicosky, D. C., B. S. Sharratt, J. E. Ljungkull, and D. G. Baker

1983. Comparison of alfalfa evapotranspiration measured by a weighing lysimeter and a portable chamber. Agricultural Meteorology 28:205-211.

Short term alfalfa evapotranspiration (ET) measured with a portable chamber (CET) was compared with that measured by a weighing lysimeter (LET) at the University of Minnesota campus

on July 2, 1980. Potential evaporation (PET) was calculated using a modified combination equation of van Bavel. Daytime ET values were 7.97, 7.71, and 7.58 mm for LET, CET, and PET, respectively.

Reigner, I. C.

1966. A method of estimating streamflow loss by evapotranspiration from the riparian zone. Forest Science 12(2): 130-139.

Conservative values of daily streamflow loss by evapotranspiration from the riparian zone were obtained by hydrograph analysis from Dilldown Watershed in northeastern Pennsylvania, during June, July, and August of 1955 and 1956. An estimating equation was derived, using as predictor variables: (1) the one-half powers of mean daily streamflow in cfs, and (2) the one-half powers of weighted vapor-pressure deficit. The two individual variables were subsequently eliminated by their product interaction. The equation estimated ripariain water loss with a relatively high degree of accuracy: 76 percent of the total variation was removed by the single complex variable.

Rijks, D. A.

1976. Water use by irrigated cotton in the Sudan. IV. Water use potential evaporation and yield. Journal of Applied Ecology 13(2):491-506.

This study was conducted at the Gezira Research Station, Wad Medani, Sudan during 1965-66 and compared water use by irrigated cotton crops by two methods: gravimetric sampling of soil water and lysimetry. Total amount of water used during the growing season was 650 mm in the lysimeter study. In the gravimetric sampling, most of the water was extracted from the upper 40 cm of soil.

Robinson, T. W.

1970. Evapotranspiration by woody phreatophytes in the Humboldt River Valley near Winnemucca, Nevada. U.S. Geological Survey Professional Paper 491-D, 41 p.

Lysimeter studies were undertaken in the Humboldt River Valley, Nevada for greasewood, rabbitbrush, willow and wildrose. Although the species of willow was not named, it was a shrubby type, similar to that found in Safford Valley, Arizona. For all species, more than 2/3 of the annual water use occurred during June, July, and August (during the years 1961-67). The annual use of water ranged rather widely over the study period, as plants responded to the effect of plant damage, boron toxicity, depth to water table, and warmth and length of growing season. Draft from water table, equivalent to the water supplied to the tanks, varied with rainfall. It was greatest when rainfall was scant, and least when rains were copious.

Robinson, T. W.

1958. Phreatophytes. U.S. Geological Survey Water-Supply Paper 1423, 84 p.

Over 70 phreatophytic species in the west and southwest U.S. are named and specific information is related on saltgrass, alfalfa, cottonwood, willow, and saltcedar. Annual use of water by phreatophytes ranges from a few tenths of an acre foot per acre to more than 7 acre feet per acre.

Rowe, P. B.

1963. Streamflow increases after removing woodland-riparian vegetation from a southern California watershed. Journal of Forestry 61(5):365-370.

A test of applied watershed management carried on in Monroe Canyon on the San Dimas Experimental Forest showed that streamflow yields can be appreciably increased by clearing the deeprooted riparian vegetation from the canyon bottom. The results show that, while streamflow can be increased, this kind of treatment, to be most effective, should be limited to carefully selected areas with conditions of climate, vegetation, soil and water capable of yielding the desired increases; that is, to areas in which (1) the water supply is adequate to exceed evapotranspiration losses after treatment, (2) the water table is within reach of the heavy water-using vegetation, and (3) the soils overlaying the water table are of sufficient extent and depth to permit reduction in evapotranspiration if the deeprooted vegetation is eliminated.

Saleh, H. H. and F. R. Troeh

1982. Salt distribution and water consumption from a water table with and without a crop. Agronomy Journal 74:321-324.

This study was undertaken to quantify the soil salinization process and relate it to soil depth, cropping, and water table variables. Water consumption was increased by the shallower depth to groundwater, by the less saline groundwater and by the presence of a crop. Salt accumulation was increased in the root zone by the presence of a crop. The study was done at the Agricultural Experimental Station, Ames, Iowa.

Sebenik, P. G. and J. L. Thames

1967. Water consumption by phreatophytes. Progressive Agriculture in Arizona 19(2):10-11.

Tent enclosure studies on tamarisk took place in the narrow
floodplain between the San Pedro and Gila Rivers near Winkleman, Arizona during the summer of 1966. On all days of measurement, evapotranspiration from the areas enclosed by the tent exceeded pan evaporation from 3 different stations in central Arizona. The water table was 8-9 feet below ground surface and it was estimated that an average monthly loss of 1.1 acre-feet from July to September occurred because of water consumption by tamarisk.

Tomanek, G. W.

1958. Annual report on ecological research of salt cedar and other vegetation primarily at Cedar Bluffs Reservoir, Kansas. Botany Department, Division of Biological Sciences, Fort Hays State College, Fort Hays, Kansas, 43 p.

The report primarily covers the ecology of saltcedar, including carbohydrate analysis of roots, anatomical studies, and transpiration studies. Both greenhouse and field studies compared transpiration rates of saltcedar to that of cottonwood and willow. Although it appeared that there was no great difference in water loss of any three species, the saltcedar plants had considerably greater leaf surface, thus the differences in loss per plant would be greater than is indicated by the loss per sq dm of leaf surface.

Tomanek, G. W. and R. L. Ziegler

1961. Ecological studies of saltcedar. Division of Biological Sciences, Fort Hays Kansas State College, Fort Hays, Kansas, 128 p.

This report gives information on germination factors affecting saltcedar establishment, seedling survival rates, transpiration comparisons conducted in greenhouse studies between cottonwood, willow and saltcedar plants, the effects of clipping on saltcedar and competition studies comparing saltcedar to several species of grasses. Total water loss was 5,775 grams for saltcedar, 5,047 grams for willow and only 2,791 grams for cottonwood. Plants of all three species were similar in size, but saltcedar had a much greater leaf surface per plant.

Tromble, J. M.

1977. Water requirements for mesquite <u>Prosopis juliflora</u>. Journal of Hydrology 34:171-179.

Evapotranspiration (ET) determined by different field methods are compared with values determined by the White and Troxell methods showing that their values provide reasonable estimates and that utilizing diurnal water table fluctuations furnishes a method of computing ET with less than 100 percent vegetation density. Average daily maximum ET in June for mesquite in southeastern Arizona (Walnut Gulch Experimental Watershed) was 10.0 mm - White, 12.17 - Troxell, and 1.28 - daily rate method.

Tschinkel, H. M.

1963. Short-term fluctuations in streamflow as related to evaporation and transpiration. Journal of Geophysical Research 68(24):6459-6469.

A method of relating fluctuations in streamflow during long dry periods to evaporation from a pan is developed. Data from the East Fork of San Dimas Creek, Los Angeles County, California, were used. The mechanism of the fluctuations is explained by deriving water-balance equations for the riparian zone. From this, it is possible to compute evapotranspiration losses from the watershed during the dry season by measuring the difference between the actual streamflow and a "potential" streamflow depletion curve which represents streamflow in the hypothetical situation of absolutely no evaporation.

Turner, S. F. and Halpenny, L. C.

1941. Ground-water inventory in the upper Gila River Valley, New Mexico and Arizona: Scope of investigation and methods used. American Geophysical Union Transactions 22(3):738-744.

An inventory of water resources of the upper Gila River Valley including inflow-outflow measurements, estimating of transpiration from cultivated crops and phreatophytes, and evaporation from water surfaces and moist soil was started by the USGS in 1940. Tank studies of tamarisk and baccharis gave results of 47.9 inches of water used at a 4 ft water table level, and 61.1 inches of water used at a 2 ft water table level for tamarisk, and 31.6 and 52.0 inches of water used at the same depths for baccharis. Bare soil with a 2 ft water table level evaporated 39.7 inches of water.

Van Hylckama, T. E. A.

1980. Weather and evapotranspiratioin studies in a salt cedar thicket, Arizona. U. S. Geological Survey Professional Paper 491-F, 78 p.

Water use by saltcedar was studied from 1961 to 1967 near Buckeye, Arizona. Rates and quantities of evapotranspiration were observed in six evapotranspirometers. Estimates of potential evapotranspiration rates using various models were plotted against measured values. For short term estimates (of the order of 1 hour) the 1966 combination method of van Bavel gave results that were too high during daytime hours. When appropriate corrections were made by taking stomatal and aerodynamic resistances into account, the calculated values fitted the measured ones very well. This shows that saltcedar reacts to extremely high windspeeds and temperatures by stomatal closure, diminishing evapotranspiration even though water is freely available. That riparian vegetation always uses water at a potential rate cannot be taken for granted, and quantitative estimates of salvageable water based upon that assumption may at times be far too large.

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.

Water use by saltcedar was studied from 1961 to 1967 near Buckeye, Arizona. When depth to ground water was 1.5 m, the average water use was about 215 cm/yr. When the water table was 2.1 m, the use diminished to about 150 cm/yr, and when the water table was 2.7 m, the yearly water use was less than 100 cm/yr. Water use varied greatly with salinity of the soil moisture. When the EC=20, water use was 70 percent; in the tanks with EC=30, the water use was only half that in the tanks with an EC=10. When vegetation was cut twice a year from an original average height of 3 m to a height of about 50 cm, the water use decreased to about half that in tanks where the vegetation was not cut. However, when the vegetation was thinned to 50 percent of the original density, the water use diminished by only 10 percent.

Van Hylckama, T. E. A.

1970. Water use by saltcedar. Water Resources Research 6(3):728-735.

Six years of observations on water use by saltcedar in lysimeters at Buckekye, Arizona, 1960-66, show that thinned out stands use nearly as much water as control tanks if water is of good quality. It is concluded that the method of making a vegetation survey and then extrapolating water use as measured in evapotranspirometers (lysimeters) to a 100 percent density can lead to serious overestimation of water use. When differences in depth to water as small as 1.5 to 2.1 and 2.1 to 2.7 m affect the water use, it seems reasonable to conclude that with a water table at 4 m for instance, saltcedars may still thrive but use comparatively little water.

Van Hylckama, T. E. A.

1968. Water level fluctuation in evapotranspirometers. Water Resources Research 4(4):761-768.

The levels of artificially maintained groundwater in elevdn plastic lined evapotranspirometer tanks near Buckeye, Arizona showed distinct diurnal fluctuations. On bare tanks or on vegetated tanks that were not transpiring, this fluctuation is

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highly correlated with diurnal and semidiurnal atmospheric fluctuations. The graphs presented in the paper show how diurnal atmospheric pressure effects can be masked and yet can have an influence on the water levels in transpiration wells. Data should be treated with caution when derived from evapotranspirometers.

Van Hylckama, T. E. A.

1963. Growth, development and water use by saltcedar <u>Tamarix pentandra</u> under different conditions of weather and access to water. International Association of Scientific Hydrology 62:75-86.

The study records saltcedar growth in six lysimeters at Buckeye, Arizona during 1961 and 1962 with varying water table levels. Results showed that saltcedar does not grow or develop in this area when the depth to water is 18 feet or more. Saltcedar tanks use more water with higher water tables with no significant change in growth or development if the depth to water is 9 feet or less. Saltcedar grows and develops fast in early spring with rapid increase in use of water; by midsummer, both growth and development level off sharply with a drastic reduction in water use, even though accessibility remains the same.

Wright, L. N. and A. K. Dobrenz

1970. Water use in relation to management of blue panicgrass. Jounral of Range Management 23(3):193-196.

Efficiency of water use was determined for blue panicgrass grown in the field at the Tucson Plant Materials Center, Tucson, Arizona. Efficient use of water and root weight decreased when soil moisture stress was increased, while dry weight of forage was unchanged. The most efficient use of water and highest percentage of forage was obtained at the same management treatment of soil being dried to the wilting point at depths of 30 cm.

Yadav, S. K. and D. P. Singh

1981. Effect of irrigation and antitranspirants on evapotranspiration, water use efficiency and moisture extraction patterns of barley. Irrigation Science 2:177-184.

A field experiment with barley was conducted at the Research Farm of Haryana Agricultural University, Hissar, India, during 1977-78 and 1978-79 wintere seasons, in sandy loam soils. Moisture use by barley decreased with soil depth irrespective of treatment. Unirrigated barley extracted relatively more, but absolutely less moisture than the irrigated barley from deeper soil layers. The application of various antitranspirants had no significant effect either on seasonal ET or on the pattern of moisture extraction from the root zone soil.

Young, A. A. and H. F. Blaney

1942. Use of water by native vegetation. California Depart-Ment of Public Works, Division of Water Resources, Bulletin 50, 154 p.

This bulletin brings together the results of studies of consumptive use of water by native species such as saltgrass, willow, Bermuda grass, and others. It discusses four methods by which such studies have been carried on: tank studies, soil-moisture studies, stream-flow investigations, and water-table fluctuations.