WATER USE BY NATURALLY OCCURRING VEGETATION INCLUDING AN ANNOTATED BIBLIOGRAPHY

Edited by
Eldon L. Johns

A REPORT PREPARED BY THE
TASK COMMITTEE ON WATER REQUIREMENTS OF NATURAL VEGETATION
COMMITTEE ON IRRIGATION WATER REQUIREMENTS
IRRIGATION AND DRAINAGE DIVISION
AMERICAN SOCIETY OF CIVIL ENGINEERS

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ABSTRACT

This report was prepared by the Task Committee on Water Requirements of Natural Vegetation Committee, a special subcommittee of the Committee on Irrigation Water Requirements, Irrigation and Drainage Division of the American Society of Civil Engineers. Its purpose is to make the task of obtaining reasonable estimates of water use easier for the practicing hydrologist or engineers. By providing a summary of significant research in the area of vegetation water use and an abstract bibliography of pertinent references, this report will help a user to narrow his efforts quickly and easily. Thus, the practicing hydrologist or engineer will then be able to produce reasonable estimates of vegetation water use without extensive reference research.

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PREFACE

This report was prepared by the Task Committee on Water Requirements of Natural (Naturally Occurring) Vegetation–a special subcommittee of the Irrigation and Drainage Division, American Society of Civil Engineers. Early in its existence, the American Society of Civil Engineers' Irrigation Water Requirements Committee recognized the need for compiled water use information covering not only irrigated crops, but a wide variety of vegetation. This information is needed, for instance, to obtain estimates of basin or regional evapotranspiration, particularly when employing the use of complex hydrologic models. Although this was a long-standing goal of the committee, it was not until late 1984 that a task committee (subcommittee) was established to investigate published reports on water use by naturally occurring vegetation.

The Task Committee was authorized for two years, beginning in late 1984 by the Executive Committee of the Irrigation and Drainage Division. The Task Committee met twice in Denver, Colorado; November 2, 1984 and a work session November 6-8, 1985. It was changed to subcommittee status in October 1986 to complete and review the report before publication in 1989.

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INTRODUCTION

A more accurate assessment of the hydrologic balance is possible by accurately estimating or measuring the evapotranspiration over a basin or study area. Having such information is important in assessing water resource development and management options. Evapotranspiration (plant transpiration and surface evaporation) is one of the largest outflow components of the hydrologic (water) budget, particularly in arid areas. It is probably the least understood, often estimated simply as the residual of the hydrologic budget once the other budget items are known. A goal of this document is to further an understanding of water use by naturally occurring vegetation.

Water use information is the basis for planning and implementing water salvage or vegetation management projects. Robinson, 1964, classified vegetation control projects as simply taking three forms: (1) taking the plants away from water, i.e., eradication, (2) taking water away from the plants, e.g., lowering the ground water level and (3) substituting or modifying plants. A prerequisite to any such control measures is an accurate vegetation survey. Horton et al., 1964, is an established guide for accomplishing such surveys in an acceptable manner.

The success and failure of water salvage projects are well documented. A few selected references are discussed below.

Harr, 1983, provided a general assessment of water yield potential from logging forests in western Oregon and Washington. In another notable paper, Gifford et al., 1983, described the impacts of succession of Aspen forest to conifer forest. Bowie and Kam, 1968, demonstrated water salvage from phreatophyte defoliation and eradication along several miles of Cottonwood Wash, Arizona. Hibbert, 1971, documented increases in streamflow after converting chaparral to grass. Also, Hibbert, 1979, outlined the potential water yield from vegetation management in the Colorado River Basin. Not all watershed vegetation management resulted in demonstrated water savings, however. The effects of Juniper and Pinyon eradication in the Corduroy Creek Basin of Arizona were not noticeable according to Collings and Myrick, 1966. McQueen and Miller, 1972, raised questions about whether decreased transpiration due to the removal of saltcedar would be partially offset by increased evaporation from the soil. They also wondered if the water table would rise until increased evaporation would balance the reduction in transpiration. Several references document the effects of chemical antitranspirants used to suppress phreatophyte evapotranspiration; Davenport et al., 1982, covered saltcedar and Hart et al., 1969, reported work on aspen. A proposal to remove exotic phreatophytes from spring and seep areas of Death Valley National Monument in order to restore their discharge is described in an environmental impact statement by the National Park Service, 1981.

Estimating evapotranspiration from relatively large geographical areas is difficult. In many instances, adequate information about the specific types of vegetation may be limited. Also, in contrast to agronomic crops, naturally occurring vegetation may vary in density and vigor. This variation occurs because of greater variability in soil conditions or availability of water and other conditions related to slope and aspect of the terrain. This is especially true of many types of range and desert plants. Even when evapotranspiration is determined at a location with reasonable accuracy, it remains extremely difficult to extrapolate this information to another geographical location or even to the surrounding area. A major task in many water use studies is to apply research results to the study area, which in many cases, may include an entire basin having conditions more heterogeneous than those in the study area. Examples of how water use information is typically applied to river basin study areas are found in the following selected publications: Mower et al., 1964, (Pecos River, New Mexico); Sumsion, 1971, (Spanish Valley, Utah); Patt, 1978, (Las Vegas Wash, Nevada) and Thomsen and Schumann, 1968, (Sycamore Creek, Arizona).

The results, of an improperly designed experiment can lead to erroneous water use estimates. An example of this was the common belief that large areas of hydrophytes such as water hyacinth were capable of evapotranspiration rates many times higher than the free water evaporation or pan evaporation rates. Recent research about the "oasis effect" (Anderson and Idso, 1985) has verified that the published results of many such water use experiments may not be representative, particularly where the experiments were conducted in small isolated containers. As the result of such misinformation, the estimates of water savings from water salvage projects are often optimistic. The following discusses the probable salvage that can be expected. Larner et al., 1974, estimated about one acre-foot (acre-ft) per acre (31 centimeters (cm)) net water salvage potential along the Colorado River in Texas. Culler et al., 1982, documented the successful salvage from phreatophytes along the Gila River, Arizona. Salvage ranged from 14 to 26 inches (in.), or 36-66 cm, but was expected to decrease with the establishment of replacement vegetation. Horton, 1972, and Horton and Campbell, 1974, point out that it is difficult to extrapolate research results to field conditions, and that net salvage when clearing dense phreatophytes is lower than first estimated in many cases. For example, although it appeared that 2.5–3.0 acre-feet (acre-ft) per acre (76-91 cm) of salvage was possible along the Pecos River, New Mexico, it was finally determined that only 1.8 acre-ft per acre (55 cm) was realistically possible. This was thought to probably further decline to less than one acre-ft per acre (31 cm) if replacement vegetation was allowed to become established.

Special categories of plants are mentioned throughout the literature. These categories and typical references are as follows: Xerophytes or desert plants–Evans et al., 1981; Phreatophytes–Fletcher and Elmendorf, 1955; Hydrophytes or water plants–Eisenlohr, 1972; Halophytes or salt tolerant plants–Glenn and O'Leary, 1983; Forest Vegetation–Fritschen and Simpson, 1985; and Range vegetation–Branson et al., 1981. Regarding desert plants, Evans et al., 1981, stated that, "In general, the total annual evapotranspiration for desert conditions is equal to the cumulative water infiltration into the soil for the year, or it is equal to the total annual precipitation minus the runoff." That report also pointed out that the principal interest concerning water use by desert plants centered on temporal distribution.

Considerable research has centered on phreatophytes–a type of plant that obtains a significant portion of its water by extending roots down to the water table. The removal or management of phreatophytes offers a feasible means of water salvage or potential increase of water supply particularly in the arid southwestern United States. Phreatophytes, however, only make up a part of the overall plant community found in the western United States. Therefore, this document covers the water use of all types of naturally occurring vegetation including that found in forest, rangeland and riparian settings.

In summary, the process of estimating or determining evapotranspiration of naturally occurring vegetation is fraught with uncertainty. Not only is it difficult to accurately determine the appropriate water use, but it is even more difficult to extrapolate the results to larger areas. The purpose of this publication is to make the task of obtaining reasonable estimates of water use easier for the practicing hydrologist or engineer. This publication is designed for the casual user who cannot afford to become acquainted with every facet of vegetation water use research. It should enable users to narrow their effort quickly and easily. Pertinent references are screened, primarily for water use information, and brought together in an abstract bibliography. The report further identifies significant research in a summary table and a range of annual water use for specific species. A computer database generated by this effort is also described. These tools should enable the user to produce reasonable estimates without extensive reference research.

EVAPOTRANSPIRATION RESEARCH SUMMARY

Measurement Methods

Next to precipitation, evapotranspiration is generally the second largest quantity in a basin water budget. Evapotranspiration can be measured and estimated by the following methods: (1) mass-transport (flux-gradient and eddy-correlation), (2) mass balance methods (hydrologic [watershed] and soil water [lysimetry and soil-water profiles]), and (3) energy-balance methods (Bowen-ratio, radiation and temperature models). Generally, we must rely on simplified procedures to calculate evapotranspiration. The reason for simplification is because we do not know enough about the complexities in the factors affecting the hydrology of the basin and the factors affecting evapotranspiration to permit adequate representation with appropriate calculations. Thus, we must resort to using simplistic algorithms, recognizing that sizeable errors may result. Many of the methods outlined above may be used to calibrate simplified models. These, in turn, can be used to extrapolate the information temporally or spatially. Many hydrologic models employ the concept of potential evapotranspiration in combination with empirically determined crop coefficients. In some cases a soil moisture balance is also maintained in the model. Evapotranspiration can be more directly determined as the residual of a water balance study either by use of lysimeters or tanks; by inflow-outflow monitoring of a drainage basin or river reach or by monitoring of soil moisture. The latter has been successfully used to study the soil moisture dynamics of forests.

Significant Research

During the literature search, we felt several papers and articles described unique or outstanding research. These studies are summarized in Table 1. It is emphasized that papers and articles not included in Table 1 may contain significant information and should not be discounted in accomplishing a proper background investigation. Table 1 may be especially useful in quick searches for key references.

Table 1
Summary - Basic Research Studies
Use of Water by Naturally Occurring Vegetation

Authors	Location	Years of Study	Type of Vegetation	Methodology
Aase, J. and Wight, J., 1970, 1972	Sidney, Montana	1968-1969	Native Range (Blue Grama)	Lysimeter and energy balance
Anderson, M. and Idso, S., 1985	Tempe, Arizona	1983-1984	Water Hyacinths, Water Ferns, Water Lilies, Cattails	Tanks (4 sizes)
Bailey, L., 1940	Ann Arbor, Michigan	1937 1938	Grass (3 Varieties)	Tanks (above ground) or potometers
Ben-Asher, J., 1981	Patagonia, Arizona	1958 1972	Riparian (Gen)	Watershed budget
Berndt, H., 1960	Manitou Expt. Forest, Colorado	1940-1958	Ponderosa Pine	Watershed budget
Blaney, H. et al., 1933	Santa Ana, California Incl. stations at San Bernardino and Mojave River	1929-1932	Salt Grass, Bermuda Grass, Tules (Triangular Stem and Round Stem), Cattails, Wire Rush, Willow	Tanks and water balance
Bleak, A. and Keller, W., 1973	Logan, Utah		Range Grasses	Greenhouse - tank studies
Borrelli, J., Burman, R. and Davidson, S., 1981	Laramie, Wyoming	1979-1980	Mountain Meadow Grasses	Non-weighing lysimeters
Bowie, J. and Kam, W., 1968	Cottonwood Wash, Arizona	1959-1963	Mixed riparian Cottonwood, Willow, Ash, and Woody species	Watershed water budget and transpiration well
Branson, F., Miller, R. and McQueen, I., 1970	Ft. Peck, Montana	1960	14 types, Incl. Sagebrush, Greasewood, Saltbush, Wheat Grass	Soil moisture monitoring

Table 1 (continued)
Summary – Basic Research Studies
Use of Water by Naturally Occurring Vegetation

Authors	Location	Years of Study	Type of Vegetation	Methodology
Branson, F., Miller, R. and McQueen, I., 1976	Grand Junction, Colorado	1971	12 Types of Desert Plants	Soil moisture monitoring
Brown, H. and Thompson, J., 1965	Black Mesa, Colorado	1955-1958	Aspen, Spruce, Grassland	Soil moisture monitoring
Buckhouse, J. and Coltharp, G., 1976	Ephraim, Utah and Wasatch Plateau	1966 1967	Wheat Grass & Alfalfa, Needle Grass & Yarrow	Soil moisture monitoring (neutron probe)
Bureau of Reclamation, 1973 (rev. 1979)	Bernardo, New Mexico	1962-1979	Saltcedar, Salt Grass, Russian Olive	Non-weighing Lysimeters
Bureau of Reclamation, 1977	Vernal, Utah	1971-1972	Salt and Broom Grass, Pasture Grasses, Wire Grass, Salt Grass and Foxtail	Lysimeters
Burman, R. D. and Pochop, L. O., 1986	Little Laramie, R., & Upper Green R., Wyoming	1979-81 1984-85	High Altitude Meadow	Non-weighing Lysimeters
California State Dept. of Water Resources, 1975	Alturas, Lookout, Coleville, California	1957 1964	Native Meadows	Tank & water balance
Carman, R., 1986	Smith Creek Valley, Nevada, Soda Lake, Nevada	1983 (?)	Rabbitbrush, Greasewood	Eddy Correlation and Bowen Ratio
Christiansen, J. and Low, J., 1970	Great Salt Lake, Utah USBR Study at Ogden Bay	1954 1955	Salt Grass, Cattails	Tanks in natural setting
Christiansen, J. and Low, J., 1970	Great Salt Lake, Utah Christiansen Study at Howard Slough	1960-1963	Mixed Hydrophytes	Water Budget

Table 1 (continued)
Summary – Basic Research Studies
Use of Water by Naturally Occurring Vegetation

Authors	Location	Years of Study	Type of Vegetation	Methodology
Cline, J., Uresk, D. and Rickard, W., 1977	South-central Washington	1974	Bunch Grass, Cheat Grass	Soil moisture monitoring
Cohen, P., et al., 1965	Winnemucca, Nevada	1961-1962	Greasewood, Willow	Tanks
Criddle, W., Bagley, J., Higginson, R. and Hendricks, D., 1964	Washington, Utah Virgin R. Vy.	1955-1957	Salt Grass, Willow (Dwarf), Willow (Black), Saltcedar	Tanks
Croft, A. and Monniger L., 1953	Farmington, Utah	1947-1949	Aspen-Herbaceous, Herbaceous, Bare	Soil moisture
Culler, R., Hanson, R., Myrick, R., Turner, R. and Kipple, F., 1982	Gila River, Arizona (above San Carlos Reservoir)	1963-1971	Saltcedar	Water budget
Cunningham, G., Fraser, J., Grieve, R. and Wolfe, H., 1973	La Mesilla, New Mexico	1971	Popular, Screw Bush, Baccharis, Wolf Berry, Willows, Saltcedar	Short-term enclosure and leaf area – transpiration rate per area-model
Dylla, A. and Muckel, D; 1964	Winnemucca, Nevada	1961-1963	Native Grasses	Lysimeters
Dylla, A., Stuart, D; and Michener, D., 1972	Winnemucca, Nevada	1967-1969	Sedges, Salt Grass, Bluejoint, Wheat Grass, Alta Fescue	Lysimeters
Eisenlohr, W., 1972	South-central North Dakota	1963-1964	Mixed hydrophytes	Mass transfer, water budget

Table 1 (continued)
Summary – Basic Research Studies
Use of Water by Naturally Occurring Vegetation

Authors	Location	Years of Study	Type of Vegetation	Methodology
Evans, D., Sammis, T. and Cable, D., 1981	Silverbell near Tucson, Arizona	1973-1976	Creosote Bush, Bursage, Bare Soil	Lysimeter and water budget (soil)
	Santa Rita near Tucson, Arizona	1973-1976	Mesquite, Desert Hackberry, Grasses (5)	Water budget (soil)
	Washtucna, Washington	1973-1976	Sagebrush and Sagebrush-Grass Mix	Water budget (soil)
	Curlew site-Great Salt Lake, Utah	1973-1976	Saltbush, Shadscale, Winter Fat	Water budget (soil)
Fritschen, L., Hsia, J. and Doraiswamy, P., 1977	Cedar River, Washington	1972-1974	Douglas Fir	Lysimeter
Gatewood, J., Robinson, T., Colby, B., Hem, J., and Halpenny, L., 1950	Safford Valley, Arizona	1943-1944	Saltcedar, Baccharis, Cottonwood Mesquite	Tanks (and other)
Gay, L. and Hartman R., 1982	Blythe, California	1980-1981	Saltcedar	Energy budget-Bowen ratio
Gee, G. and Kirkham, R., 1984	Hanford, Washington	1983-1984	Cheat Grass	Lysimeters
Gifford, G., 1975	Milford, Utah and Blanding, Utah	1969-1972	Pinyon-Juniper range	Water balance (ET as residual)

Table 1 (continued)
Summary – Basic Research Studies
Use of Water by Naturally Occurring Vegetation

Authors	Location	Years of Study	Type of Vegetation	Methodology
Grable, A., Hanks, R., Willhite, F., and Haise, H., 1966	Gunnison, Colorado	1963-1964	Native Mountain Meadow	Lysimeters
Grosz, O., 1972	Winnemucca, Nevada	1963-1972	Saltcedar, Salt Grass Rabbitbrush, Greasewood	Tanks
Hammatt, W., 1920	Chewaucan R., Oregon, Burns, Oregon	1915-1916	Meadow Grass	Tanks (soil moisture balance)
Hanson, C., 1976	Gillette, Wyoming Newell, South Dakota Sidney, Montana	1969& 1971	Mixed Grasses	Lysimeters and soil
Harr, R. and Price, K., 1972	Hanford, Washington	1970	Greasewood, Cheat Grass Community	Soil moisture monitoring
Harrison, A., 1983	Sandhills, Nebraska	1981	Native Grass	Soil moisture monitoring
Houk, I., 1930	Los Griegos, New Mexico	1926-1928	Salt Grass, Tules	Tanks
Johnston, R., 1970	Bountiful, Utah	1963-1966	Aspen-Herbaceous, Herbaceous and Bare	Soil moisture monitoring
Johnston, R., Tew, R., and Doty, R., 1969	Logan River, Utah Bountiful, Utah and Ephraim, Utah	1963-1967	Aspen, Douglas Fir, Gambel Oak, Snowberry, Sagebrush-Grass, Grass	Water budget-plots (soil moisture)
Kruse, E. and Haise, H., 1974	Garo, Colorado Gunnison, Colorado	1968-1971	Mountain Meadow	Tank

Table 1 (continued)
Summary – Basic Research Studies
Use of Water by Naturally Occurring Vegetation

Authors	Location	Years of Study	Type of Vegetation	Methodology
Lauenroth, W. and Sims, P., 1976	Pawnee Grassland, Colorado	1971-1973	Short Grass prairie	Soil moisture monitoring
Leaf, C., 1975	General Watersheds – Colorado and Wyoming		5 vegetation zones	watershed water balance
Leaf, C. and Alexander, R., 1975	Fraser Expt. Forest, Colorado	1947 1971	Subalpine forest	Watershed water balance
Lee, C., 1915	Owens Valley, California	1911	Salt Grass	Tanks
Leppanen, O., 1981	Gila River, Arizona (San Carlos Reservoir)	1971	Young Saltcedar	Energy budget
Luxmoore, R., Huff, D., McConathy, R. and Dinger, B., 1978	Oak Ridge, Tennessee	1972-1973	Yellow Poplar	Soil moisture water budget
Mace, A., 1968	Gila River, Arizona	1965	Saltcedar	Evapotranspiration tent
McDonald, C. and Hughes, G., 1968	Yuma, Arizona	1961-1966	Arrowweed, Quailbrush, Fourwing Saltbush, Bermuda Grass, Cattails	Tanks
McGinnies, W., and Arnold, J., 1939	Tucson, Arizona	1931-1936	28 species of Range Plants	Tanks – above ground
Meyboom, P., 1964	Moose Jaw, Saskatchewan	1963-1964	Willows, Rush, Cottonwood & Tules, Buffalo Berry	Ground water diural fluctuation
Muckle, D. and Blaney, H., 1945	San Luis Rey Vy., California	1963-1964	Willows, Rush, Cottonwood & Tules, Buffalo Berry	Ground water diural fluctuation

Table 1 (continued)
Summary – Basic Research Studies
Use of Water by Naturally Occurring Vegetation

Authors	Location	Years of Study	Type of Vegetation	Methodology
Naff, R., Baker, A. and Gross, G., 1975	Socorro, New Mexico		Cottonwood	Ground water diurnal fluctuation
Nnyamah, J. and Black, T., 1977	Courtenay, British Columbia	1974-1975	Douglas Fir	Soil moisture monitoring
Otis, C., 1914	Ann Arbor, Michigan	1910-1911	Cattail, Pickerel Weed, Arrowhead Great Bullrush, Three-Square Rush and Water Lilly	Floating tanks
Parshall, R., 1937	Fort Collins, Colorado	1929-1932	Cattails, Rushes, Sunflowers, Redroot, Sedge Grass, Bluegrass, Russian Thistle	Tanks
Parton, W., Lauenroth, W. and Smith, F., 1981	Northeastern Colorado	1972-1975	Grass (Blue Gramma etc.)	Weighing lysimeter
Patric, J., 1961	San Dimas, California	1937-1956	Grass, Pine, Chamise, Scrub Oak, Buckwheat, Ceanothus	26 lysimeters
Petersen, M. and Hill, R., 1985	Logan, Utah	1982-1983	Scotch Pine (Christmas Trees)	Lysimeters
Philipp, K. and Gallagher, J., 1985	Lewes, Delaware	1984	Atriplex, Kosteletzkya	Lysimeters
Pochop, I., Burman, R. Borrelli, J. and Crump, T., 1985	Upper Green River, Wyoming	1982-1984	Mountain Meadow	Lysimeters
Pochop, L., Smith F. and Smith, R., 1985	Northeast Colorado (Pawnee Grasslands)	1972-1975	Prairie Grassland	Weighing lysimeters

Table 1 (continued)
Summary – Basic Research Studies
Use of Water by Naturally Occurring Vegetation

Authors	Location	Years of Study	Type of Vegetation	Methodology
Pratt, D., Dubbe, D. and Garver, E., 1985	St. Paul, Minnesota	1984	Cattails	Water balance
Qashu, H. and Evans, D., 1967	Walnut Gulch near Tombstone, Arizona	1964-1965	Mesquite (mixed)	Soil moisture monitoring
Rawles, W., Zuzel, J. and Schumaker,	Reynolds Creek Watershed, Idaho	1966-1967	Sagebrush	Soil moisture monitoring
Reed, J. and Dwyer, D., 1971	Ft. Stanton Coop Range Research Station, New Mexico		Blue Gramma	Tanks (above ground)
Rich, L., 1952	Sierra Ancha Expt. Forest, Arizona	1935-1948	Bare Soil, Grasses, Shrubs	Lysimeters and water budget
Richardson, C., Burnett, E. and Bovey, R., 1979	Riesel, Texas	1971-1977	Mesquite	Watershed water budget
Riekerk, H., 1985	Gainesville, Florida	1981-1984	Pine	Weighing lysimeters
Ritchie, J., Rhoades, E. and Richardson, C., 1976	Chickasha, Oklahoma	1969-1972	Mixed range grasses	Watershed water budget
Robinson, T., 1970	Winnemucca, Nevada	1961-1967	Greasewood, Rabbitbrush, Willow, Wildrose, Bare Soil	Tank
Rowe, P. and Relmann, L., 1961	San Gabriel Mtns., California	1953-1956	Brush (Scrub Oak-Mountain Mahogany, Grass, Grass-Forb)	Water budget-controlled plots

Table 1 (continued)
Summary – Basic Research Studies
Use of Water by Naturally Occurring Vegetation

Authors	Location	Years of Study	Type of Vegetation	Methodology
Sammis, T. and Gay, L., 1979	Silverbell, Arizona (near Tucson)		Creosote Bush	Weighing lysimeter
Scholl, D., 1976	Three Bar Expt. Watersheds, Arizona	1972-1973	Chaparral	Watershed budget
Shown, L., Lusby, G. and Branson, F., 1972	Wolcott, Colorado	1969-1971	Sagebrush, Wheatgrass	Watershed budgets
Stearns, H., Bryan, L. and Crandall, L., 1939	Mud Lake, Idaho	1921-1923	Tules	Tank
Sturges, D., 1980	Saratoga, Wyoming	1968-1972	Sagebrush	Soil moisture budgets
Swartz, T., Burman, R. and Rechard, P., 1972	Mill Creek, Wyoming Cow Camp, Wyoming	1970-1971	High mountain meadows	Lysimeters
Tew, R., 1966	Bountiful, Utah	1962-1966	Gambel Oak	Soil moisture budgets
Tew, R., 1967	Ephraim Canyon, Utah	1964-1966	Aspen	Soil moisture budgets
Thompson, J., 1974	Alpine, Arizona	1969-1970	Pine	Energy budget (Bowen ratio)
Tomanek, G., and Ziegler, R., 1962	Hays, Kansas	1956	Salt Cedar, Cottonwood and Willow	Gravimetric, Portable chamber

Table 1 (continued)
Summary – Basic Research Studies
Use of Water by Naturally Occurring Vegetation

Authors	Location	Years of Study	Type of Vegetation	Methodology
Tromble, J., 1972	Walnut Gulch Watershed, Arizona	1965-1967	Mesquite	Water table elevations and Water budget
Turner, S. and Halpenny, L., 1941	Upper Gila R., Arizona (Safford Vy), Duncan–Virden Vy., NM	1940	Saltcedar, Baccharis	Tanks and budgets
van Hyickama, T., 1974	Buckeye, Arizona	1961-1967	Saltcedar	Tanks
Weeks, E. and Sorey, M., 1973	Arkansas R. Valley, Colorado	1966-1969	Cottonwood, Saltcedar and Salt Grass mix	Water budget-ground water
Weeks, E., Weaver, H. Campbell, G. and Tanner, B. 1987	Pecos R., New Mexico	1980-1982	Saltcedar, Kochla	Energy budget
White, L. and Brown, J., 1972	Culbertson, Montana	1968-1970	Needle Grass	Soil moisture budget
White, W., 1932	Escalante Vy., Utah	1926-1927	Salt Grass, Greaseweed	Tank and water table elevation
Wight, J., and Black, A., 1977	Sidney, Montana	1967-1972	Range Grasses	Soil moisture monitoring and Lysimeters
Wight, J. and Hanks, R., 1981	Sidney, Montana	1967-1978	Range Grasses	Soil moisture monitoring
Wight, J., Hanson, C. and Cooley, K., 1986	Reynolds Creek Watershed, Idaho	1977-1979	Sagebrush, Bluegrass, Bottlebrush Squirreltail Mix	Lysimeters and basin water balance

Table 1 (continued)
Summary – Basic Research Studies
Use of Water by Naturally Occurring Vegetation

Authors	Location	Years of Study	Type of Vegetation	Methodology
Young, A. and Blaney, H., 1942	Isleta, New Mexico Messilla, New Mexico	1936-1937	Salt Grass, Cattails, Sedge, Willow	Tanks
(Summary of Misc. Significant Studies)	Parma, Colorado	1936	Tules	Tanks
	San Luis Vy., Colorado	1927-1931	Salt Grass	Tanks
	Temescal Cr., California	1929-1930	Tules	Tanks
	Clarksburg, California	1930	Tules, Cattails	Tanks
	King Island, California	1932	Tules, Cattails	Tanks

Certain references are judged to be significant enough for special mention. One of the most comprehensive vegetation water use studies ever accomplished is summarized by Culler et al., 1982. The study was initiated by the United States Geological Survey in 1962. The study ran for almost ten years resulting in a series of sixteen publications under the USGS Professional Paper Number 655.

Gatewood et al., 1950, describes an incredibly comprehensive study covering saltcedar, baccharis, cottonwood, and mesquite. Study methods included tank, transpiration well, seepage run, inflow-outflow, chloride increase, and slope seepage.

The title “Phreatophytes” (Robinson, 1958) simply describes the classic publication.

No list would be complete without mention of the work of Horton, particularly US Forest Service Miscellaneous Publication Number 1234, 1973, a classic bibliographic report that summarizes research up to the early 1970s.

Bouwer, 1975, presented a physically based analytical procedure for calculating water losses from open channels by phreatophyte control. The procedure does not account for plant density, however. The key requirement for Bouwer’s procedure is a depth to, water-evapotranspiration relationship. The depth to ground, water-evapotranspiration curves are useful in estimating the potential water salvage due to lowering of the ground water table as well as providing a partial means of representing the spatial variability throughout a drainage basin. The following are a sample of references containing depth to water-evapotranspiration relationships: Anderson, T.W., 1976; Cox and Havens, 1974; Gatewood et al., 1950; Houck, 1930; Robinson, 1958; and Thompson, 1958. A unique use of the depth to water-evapotranspiration relationship is found in Rantz, 1968. Rantz combined this concept with the Blaney-Criddle method (described in Blaney and Hanson, 1965) of estimating plant consumptive use.

Water Use

The literature review yielded information about expected water use by various types of vegetation. Table 2 contains a summary of ranges of expected water use by each vegetation type along with the source of that information. The table is not intended to be all-inclusive. Further, it is recommended that the specific references be consulted to become acquainted with the context of the research before using or quoting the values presented.

Table 2
Seasonal Water Use

A CAUTION: Length of growing season may vary considerably. Individual papers should be obtained and reviewed in all instances.

Common Name	Scientific Name	Consumptive Use	Reference
Arrowweed	Pluches Serices	96[N]	McDonald and Hughes, 1968
Aspen	Populus	9.9-16.5[N]	Tew, 1967
Aspen	Populus	10.3-24.18[N]	Johnston et al., 1969
Aspen	Populus	18.53-24.15[N]	Johnston, 1970
Aspen	Populus	18.7[N]	Croft and Monniger, 1953
Aspen	Populus	19.2[N]	Brown and Thompson, 1965
Baccharis	Baccharis	31.6-52.0[N]	Turner and Halpenny
Baccharis	Baccharis	56[N]	Gatewood et al., 1950
Buckwheat	Fagopyrum Esculentum	3.1[N]	Branson et al., 1970
Buckwheat	Fagopyrum Esculentum	24.3[N]	Patric, 1961
Buffaloberry		3.5-9.0[N]	Meyboom, 1964
Cattail	Typha	35-45[N]	Pratt et al., 1985
Cattail	Typha	52.5-77[N]	Parshall, 1937
Cattail	Typha	60.4[N]	Christiansen, 1970
Cattail	Typha	63.4[N]	Blaney et al., 1933
Cattail	Typha	90-198[N]	Young and Blaney, 1942
Cattail	Typha	100[N]	McDonald and Hughes, 1968
Ceanothus	Ceanothus Crassifolius	23.6[N]	Patric, 1961
Chamise	Adenostoma Fasciculatum	25.5[N]	Patric, 1961
Chaparral		21.6-42[N]	Scholl, 1976
Cottonwood	Populus	40.6N	Meyboom, 1964
Cottonwood	Populus	60.0-92.7[N]	Mixed w/willow, Muckel & Blaney, 1945, see Weeks & Sorey, 1973
Cottonwood	Populus	72[N]	Gatewood et al., 1950
Creosote Bush	Larrea Tridentata	10.2[N]	Sammis and Gay, 1979
Creosote Bush	Larrea Tridentata	9.25[N]	Evans et al. 1981
Fir–Douglas	Pseudotsuga Menziesii	12.0-13.7[N]	Johnston et al., 1969
Fir–Douglas	Pseudotsuga Menziesii	18-20[N]	Fritschen et al., 1977
Fir–General	Abies	6-9N	Bethell et al., 1980
Forbs and Grass Mix		17.0-29.6[N]	Rowe and Reimann, 1961
Forest (General)		14.5-21.0[N]	Leaf, 1975a
Forest (General)		16.8[N]	Leaf, 1975b
Foxtail	Lycopodium Clavatum	5.5[N]	Branson et al. 1970
Grass		8.9[N]	Brown and Thompson, 1965
Grass		16.0[N]	Patric, 1961
Grass–Alta Fescue		19.4-29.9[N]	Dylla et al., 1972
Grass–Bermuda		28.8-36.2[N]	Blaney et al., 1933

Table 2 (continued)

Common Name	Scientific Name	Consumptive Use	Reference
Grass–Bermuda		73^{N}	McDonald and Hughes, 1968
Grass–Blue Grama Native		$2.9\text{-}17.6^{N}$	Bailey, 1940
Grass–Blue Grama Native		3.9^{N}	Branson et al., 1970
Grass–Blue Grama Native		$5.6\text{-}10.6^{N}$	Aase, 1970
Grass–Blue Grama Native		0.75^{N}	Reed and Dwyer, 1971
Grass–Blue Grama Native		$24.0\text{-}41.0^{N}$	Parshall, 1937
Grass–Bluejoint		$21.9\text{-}34.6^{N}$	Dylla et al., 1972
Grass–Cheat	Bromus Tectorum	3^{N}	Cline et al., 1977
Grass–Cheat	Bromus Tectorum	??	Gee and Kirkham, 1984, see Harr and Price, 1972
Grass–Meadow Mixed		$4.8\text{-}10.2^{N}$	Wight and Hanks, 1981
Grass–Meadow Mixed		$6.9\text{-}10.0^{N}$	Wight and Black, 1977
Grass–Meadow Mixed		$8.9\text{-}10.0^{N}$	Wight, 1971
Grass–Meadow Mixed		$13.0\text{-}24.15^{N}$	Hammat, 1920
Grass–Meadow Mixed		$17.36\text{-}33.47^{N}$	USBR, 1977
Grass–Meadow Native		$6.8\text{-}10.5^{N}$	Hanson, 1976
Grass–Meadow Native		$23.2\text{-}27.9^{N}$	Kruse and Haise, 1974
Grass–Mix		$10.08\text{-}48.36^{N}$	Houk, 1930
Grass–Mix		14.6^{N}	Weeks and Sorey, 1973
Grass–Mix		$14.7\text{-}22.6^{N}$	White, 1932
Grass–Mix		$19.57\text{-}22.58^{N}$	Dylla and Muckel, 1964
Grass–Mix		$20.75\text{-}28.32^{N}$	USBR, 1977
Grass–Native		$5.12\text{-}19.60^{N}$	Johnston et al., 1969
Grass–Native		9.1^{N}	Harrison, 1983
Grass–Native		$18.5\text{-}24.3^{N}$	Rich, 1952
Grass–Needle Mix		10.6^{N}	Buckhouse and Coltharp, 1976
Grass–Needle Mix		12.2^{N}	White and Brown, 1972
Grass–Pasture		$8.4\text{-}16.1^{N}$	Rowe and Reimann, 1961
Grass–Pasture		$20.6\text{-}27.2^{N}$	Ritchie et al., 1976
Grass–Prairie		7.6^{N}	Lauenroth and Sims, 1976
Grass–Prairie		$9.4\text{-}11.9^{N}$	Pochop et al., 1985
Grass–Prairie		$10.0\text{-}36.3^{N}$	Reported in Young and Blaney, 1942
Grass–Prairie		12^{N}	Parton et al., 1981
Grass–Salt		$6.2\text{-}21.7^{N}$	Grosz, 1972
Grass–Salt		$13.2\text{-}42.1^{N}$	Young and Blaney, 1933

Table 2 (continued)

Common Name	Scientific Name	Consumptive Use	Reference
Grass–Salt		13.43-48.8[N]	Lee, 1915
Grass–Salt		16.2-39.8[N]	Reported in Young and Blaney, 1942
Grass–Salt		18.7-29.2[N]	USBR, 1973, 1979
Grass–Salt		19.1-22.4[N]	Dylla et al., 1972
Grass–Salt		27.7[N]	Criddle et al., 1964
Grass–Salt		33.2[N]	Christiansen, 1970
Grass–Sedge		41.5-60.2[N]	Parshall, 1937
Grass–Sugar		16.1-22.28[N]	Hammat, 1920
Grass–Wheat (Bluebunch)	Agropyron Inerme	8-11[N]	Shown et al., 1972
Grass–Wheat (Tall)	Agropyron Elongatum	23.6-32.2[N]	Dylla et al., 1972
Grass–Wheat (Western)	Agropyron Smithii	12.3[N]	Branson et al., 1970
Greasewood	Sarcobatus Vermiculatus	2.6[N]	Branson et al., 1970
Greasewood	Sarcobatus Vermiculatus	3.7[N]	Branson et al., 1976
Greasewood	Sarcobatus Vermiculatus	11.3[N]	Carman, 1986
Greasewood	Sarcobatus Vermiculatus	11.8-25.2[N]	White, 1932
Greasewood	Sarcobatus Vermiculatus	12.2-22.1[N]	Grosz, 1972
Greasewood	Sarcobatus Vermiculatus	14.5-17.5[N]	Robinson, 1970
Greasewood	Sarcobatus Vermiculatus	20.8-24.8[N]	Harr and Price, 1972
Herbaceous		14.8[N]	Croft and Monninger, 1953
Hydrophytes		22-24[N]	Eisenlohr, 1972
Hydrophytes		45[N]	Christiansen, 1970
Kochia (Burning Bush)	Kochia Scoporia	22-26[N]	Weeks et al., 1987
Mallow	Kosteletzkya Virginica	13.7-51.1[N]	Philipp and Gallagher, 1985
Maple–Manitoba, Boxeider	Acer Negundo	16.1-20.8[N]	Meyboom, 1964
Meadow–Mountain		8.5-31.1[N]	Borrelli, 1981
Meadow–Mountain		14.0-19.4[N]	Swartz et al., 1972
Meadow–Mountain		16-20[N]	Burman and Pochop, 1986
Meadow–Mountain		16.5-27.6[N]	Pochop et al., 1985
Meadow–Native Pasture		13.2 [N]	Thompson, 1974
Meadow–Native Pasture		19.6-22.6[N]	Dylla and Muckel, 1964

Table 2 (continued)

Common Name	Scientific Name	Consumptive Use	Reference
Meadow– Native Pasture		38.4-38.7[N]	California Water Resources, 1975
Mesquite	Prosopis	14.5[N]	Qusahu and Evans, 1967, April-June
Mesquite	Prosopis	20[N]	Richardson et al., 1979
Mesquite	Prosopis	40[N]	Gatewood et al., 1950
Oak–Gambel	Quercus Gambelii	11.39-18.64[N]	Johnston et al., 1969
Oak–Gambel	Quercus Gambelii	14.8-18.8[N]	Tew, 1966
Oak–Scrub	Quercus Dumosa	16.3-23.4[N]	Rowe and Reimann, 1961, with mahogany
Oak–Scrub	Quercus Dumosa	24.8[N]	Patric, 1961
Pine	Pinus	19.4[N]	Thompson, 1974
Pine	Pinus	36.3-47.0[N]	Riekerk, 1985
Pine–Coulter	Pinus Coulteri	25.1[N]	Patric, 1961
Pine–Ponderosa	Pinus Ponderosa	15.5[N]	Berndt, 1960
Pine–Scotch (Xmas trees)	Pinus Sylvestris	12.3-39.22[N]	Petersen and Hill, 1985
Pinyon–Juniper		14.53-27.53[N]	Gifford, 1975
Poplar–Yellow	Liriodendron Tulipifera	26.2[N]	Luxmoore et al., 1978
Quailbrush– Saltbush	Atriplex Lentiformis	44[N]	McDonald and Hughes, 1968
Rabbitbrush	Chrysothamnus	12.7[N]	Carman, 1986
Rabbitbrush	Chrysothamnus	12.8-26.3[N]	Grosz, 1972
Rabbitbrush	Chrysothamnus	19.92[N]	Robinson, 1970
Rabbitbrush	Chrysothamnus Greenei	2.4-4.8[N]	Branson et al., 1976
Redroot– Pigweed	Amaranthus	31.7[N]	Parshall, 1937
Riparian Vegetation		13.2[N]	Schumann, 1967
Riparian Vegetation		17.1[N]	Ben-Asher, Jr., 1981
Riparian Vegetation		22.4[N]	Sammis, 1972
Rose–Wild	Rosa	20.5[N]	Robinson, 1970
Rush	Juncus	20.8[N]	Meyboom, 1964
Rush	Juncus	52.6-86.6[N]	Parshall, 1937
Rush–Baltic (Wire Grass)	Juncus Balticus	84.5[N]	Blaney et al., 1933
Russian Olive	Elaeagnus Angustifolia	18.6-114.6[N]	USBR, 1873-1979
Russian Thistle	Salsola Kali	22.9-26.1[N]	Parshall, 1937
Sagebrush & Cheatgrass	Artemisia Tridentata	9.37[N]	Gutknecht et al., 1980
Sagebrush–Big	Artemisia Tridentata	3.7-7.0[N]	Branson et al., 1970
Sagebrush–Big		3.9	Branson et al., 1976
Sagebrush–Big		6.4-9.6[N]	Sturges, 1980
Sagebrush–Big		8-12[N]	Shown et al., 1972

Table 2 (continued)

Common Name	Scientific Name	Consumptive Use	Reference
Sagebrush– Silver	Artemisia Cana	3.7[N]	Branson et al., 1970
Sagebrush– Silver	Artemisia Cana	5.12-8.97[N]	Johnston et al., 1969
Sagebrush– Silver	Artemisia Cana	6[N]	Cline et al., 1977
Saltbush	Atriplex	2.4-3.3[N]	Branson et al., 1976
Saltbush	Atriplex	25.9-53.9[N]	Phillip and Gallagher, 1985
Saltbush– Fourwing	Atriplex Canescens	38[N]	McDonald and Hughes, 1968
Saltbush– Nuttall	Atriplex Muttallii	1.0-1.6[N]	Branson et al., 1970
Saltbush– Quailbrush	Atriplex Lentiformis	44[N]	McDonald and Hughes, 1968
Saltcedar	Tamarix Chinensis	14.9-29.2[N]	Grosz, 1972
Saltcedar	Tamarix Chinensis	15.6-56.4[N]	USBR, 1973, 1979
Saltcedar	Tamarix Chinensis	25-56[N]	Culler et al., 1982
Saltcedar	Tamarix Chinensis	30-42[N]	Weeks et al., 1987
Saltcedar	Tamarix Chinensis	32.6[N]	Criddle et al., 1964
Saltcedar	Tamarix Chinensis	40-85[N]	VanHylckama, 1974
Saltcedar	Tamarix Chinensis	47.9-61.1[N]	Turner and Halpenny, 1941
Saltcedar	Tamarix Chinensis	68[N]	Gay and Hartman, 1982
Saltcedar	Tamarix Chinensis	69-71[N]	Gay, 1984
Saltcedar	Tamarix Chinensis	86[N]	Gatewood et al., 1950
Saltcedar and Cottonwood	Tamarix Chinensis	20.9-29.7[N]	Weeks and Sorey, 1973, Cottonwood Mix
Sedge	Carex	21.8-27.3[N]	Dylla et al., 1972
Sedge	Carex	76.9[N]	Reported in Young and Blaney, 1942
Shrub–Mixed		8.7[N]	Branson et al., 1970
Snowberry	Symphoricarpos Racemosus	12.32-13.75[N]	Johnston et al., 1969
Spruce	Picea	14.9[N]	Brown and Thompson, 1965
Tules	Scirpus	40-221[N]	Reported in Young and Blaney, 1942
Tules	Scirpus	51.9[N]	Stearns et al., 1939
Tules	Scirpus	62.9-63.4[N]	Blaney et al., 1933
Tules	Scirpus	63.4-73.6[N]	Blaney et al., 1933
Tules	Scirpus	64.68[N]	Nouk, 1930
Willow	Salix	13.2[N]	Meyboom, 1964

Table 2 (continued)

Common Name	Scientific Name	Consumptive Use	Reference
Willow	Salix	30.5^N	Reported in Young and Blaney, 1942
Willow	Salix	35.3^N	Criddle et al., 1964
Willow	Salix	35.3^N	See Muckel and Blaney, 1945
Willow	Salix	36.4^N	Robinson, 1970
Willow	Salix	47.8^N	Blaney et al., 1933
Willow–Dwarf	Salix	33.6^N	Criddle et al., 1964
Willow–Wolf	Elaeagnus Commutata	21.8^N	Meyboom, 1964

Note: ^{N} represents inches.
1 inch = 2.54 centimeters.

CONTEMPORARY RESEARCH

The following describes several research studies that were underway while the literature search was in progress. These studies should eventually yield significant information.

Reynolds Creek, Idaho

Hydrologic research has been conducted on the Reynolds Creek Experimental Watershed in southwest Idaho by the USDA Agricultural Research Service since 1960. The 90.3-square mile (mi^2), or 234-square kilometer (km^2), watershed is a Snake River tributary located approximately 40 mi (64 km) southwest of Boise, Idaho. Water use and evapotranspiration studies on the watershed are based on periodic soil moisture measurements and lysimeter data. Information from these studies is being used to calibrate and verify rangeland resource models.

Owens Valley, California

The City of Los Angeles imports over one-half of its water supply from the Owens River Watershed. A portion of this is pumped from ground water. In recent years, concern has been expressed regarding the effects this pumping may have on the vegetation of the valley floor. Recent studies have been conducted to provide the necessary insight to properly manage the ground water resource to meet water supply and environmental goals. The studies conducted during the past four years are the cooperative work of the City of Los Angeles, the United States Geologic Survey and the County of Inyo. Two of the studies center on the vegetation. The Vegetation Survivability Study is designed to evaluate the response of vegetation to changes in depth to the shallow water table. The Cooperative Vegetation Study is intended to provide data on plant water use and moisture stress. The naturally occurring vegetation consists of greasewood, rabbit-brush and saltgrass. A variety of measurement techniques are being employed including soil moisture monitoring, the eddy correlation method and the Bowen ratio method.

San Luis Valley, Colorado

This is a cooperative research project with USDA/Agricultural Research Service, Bureau of Reclamation, and the Colorado Division of Water Resources. It is designed to improve the estimate of evapotranspiration from naturally occurring vegetation in the Closed Basin Division, San Luis Valley Project, located in the Rio Grande River Basin of Colorado.

The water supply for the Closed Basin Division is projected to result from the salvage of non-beneficial evapotranspiration. This will be accomplished by a general lowering of the water table. A network of wells will be used to lower the water table. The water will be discharged into the Rio Grande River where it will help meet Colorado's compact obligations to New Mexico and Texas. It will also assist the United States in meeting its commitments to Mexico under the Rio Grande Convention of 1906.

Researchers in the cooperative research project are using gas-analysis technology to instantaneously measure evapotranspiration of each type of vegetation. A plastic chamber is momentarily placed over a plant or a grass area and the increase in water vapor is measured. Measurements are being taken on bare ground, saltgrass, rabbitbrush and greasewood. The data will complement evapotranspiration measurements at nearby Bureau of Reclamation lysimeters. The period of study is basically 1985-1987 although the Bureau of Reclamation lysimeters may continue to be operated somewhat longer.

To complement this cooperative research work, the U.S. Geological Survey is using micro-meteorological techniques to measure daily evapotranspiration continuously during the growing season and periodically during the winter months. Bowen ratio and eddy correlation measurements, which were collected during 1985-1988, will be compared with the measurements obtained by the cooperative research effort.

South Park, Colorado

South Park is a high mountain meadow that historically was wild flood irrigated. Recent water right sales to downstream municipalities have triggered extensive litigation over quantification of transferable evapotranspiration. The natural evapotranspiration occurring before irrigation should not be transferable and will remain after transfer of the water right. A cooperative project was implemented by the Denver Water Department with Colorado State University and the University of Wyoming to study the problem and to quantify this natural evapotranspiration.

The study objective is to determine the water table contribution to evapotranspiration by analyzing data from lysimeters, neutron probe measurements, and plant growth. Two sites were set up with each having four 3-ft (0.9-meter (m)) diameter × 7-ft (2.1-m) deep, non-weighing lysimeters, two 1-square meter (m^2) × 18-in. (46-cm) deep non-weighing lysimeters, and a complete weather station. Additionally, single 3 ft (0.9 m) × 7 ft (2.1 m) lysimeters were installed in a riparian zone. Neutron probe access tubes were installed in a dozen locations across South Park and in 5 of the 8 deep lysimeters. The deep lysimeters were placed in-situ by driving steel pipe through the soil profile, leaving the original soil profile and plant regime intact.

Data were collected from 1981 through 1985. Plant growth was monitored and lysimeters and neutron probe sites harvested. The major species included sedges, rushes, irrigated grasses, Muhlenbergia, arrowgrass, spikerush, herbaceous cinquefoil and forbs. The four shallow and two-of the deep lysimeters had water tables set at or near the surface and these data will be compared to accepted evapotranspiration prediction equations.

Burns, Oregon

The Squaw Butte Experimental Station, which was established in 1934, is a 16,600 acre (6,700 ha) range unit located 42 miles (67.6 km) west of Burns, Oregon. Research is-conducted by the USDA Agricultural Research Service. The major research thrusts are range plant ecophysiology and water use, range improvement, grazing management, animal behavior, and animal nutrition.

Hanford, Washington

The vegetative studies at the United States Department of Energy's Hanford site near Richland, Washington, are part of the National Low Level Waste Management Program. The studies are to develop and assess modeling technology that will predict the transport of water and radionuclides through unsaturated sediment. Related hydrometeorological studies investigated a means of applying the results to ground water models covering the entire basin. The buried waste test facility consists of two weighing lysimeters and seven 20-ft (6-m) long circular caissons or tanks. Basic evapotranspiration data has been gathered during the period 1978-1982. The semi-arid grassland vegetation includes cheatgrass and sagebrush.

Logan, Utah

Non-weighing lysimeters were installed in late 1985 at the Utah Agricultural Experiment Station (Utah State University) near Logan. Water use will be measured for cattails, willows, alfalfa, grass, rushes, and sedges.

Manhattan, Kansas

A comprehensive surface-atmosphere field experiment referred to as "FIFE," First ISLSCP (International Satellite Land Surface Climatology Project) Field Experiment, is being conducted at a 15-km × 15-km tall grass Konza Prairie Long Term Ecological Research site near Manhattan, Kansas. The principal objectives of this 3-year project (1987-1989) are to obtain the necessary soil, water, vegetation, and meteorological data so that climatologically significant land surface parameters can be inferred from space. This interdisciplinary effort includes a total of 29 separate investigations and involves the cooperation of numerous federal and university researchers, including scientists from other countries who specialize in the areas of remote sensing, atmospheric physics, meteorology, hydrology, and biology. The FIFE experiment offers the opportunity for intensive in situ data collection as well as remote observations at various altitudes. In situ measurements include soil moisture, biophysical properties of plants and soil, surface optical characteristics and surface fluxes of sensible heat, water, vapor, momentum, carbon dioxide, ozone, and radiation. Some measurements of surface fluxes are being made from transacts flown by aircraft. Remote soundings of the atmosphere will yield measurements of atmospheric properties and fluxes at various levels.

Central Florida

A five-year study of evapotranspiration from areas of naturally occurring vegetation is being conducted in central Florida by the U.S. Geological Survey in cooperation with the State of Florida. This study, scheduled for completion in 1991, seeks to obtain accurate estimates of evapotranspiration for four types of common vegetation (palmetto prairie, pine flat woods, grass ponds, and cypress heads). Evapotranspiration will be determined by selectively applying the following techniques: basic Penman, energy-budget, Bowen ratio, eddy-correlation, lysimeters, and evapotranspirometers. The derived evapotranspiration values will then be utilized to perform an error analysis for each of the techniques. The findings from this investigation should provide significant new knowledge about developing more accurate evapotranspiration values for extensive and ecologically important wetland areas.

Bear River, Utah, Idaho, and Wyoming

In a field study for the Bear River Commission (cooperating with Utah State University, the University of Idaho, and the University of Wyoming), water use for irrigated meadow was measured with non-weighing lysimeters over a five-year period (1983-1987) at Montpelier, Idaho, Randolph, Utah, and Hillard Flat, Wyoming. Sufficient climate data were gathered at each location for calculating Penman reference evapotranspiration. The information gathered will be used in managing the Bear River and assuring equitable allotment of water resources among the three states.

Los Alamos, New Mexico

Researchers at the Los Alamos National Laboratory are developing a LIDAR (Light Detection and Ranging) instrument system for non-invasive remote measurement of atmospheric water vapor in three dimensions. Field testing will be in pinyon-juniper woodland and other community types near Los Alamos. The equipment will permit measurement at locations that are now inaccessible to point monitors. Another project utilizes water balance techniques to determine plant water use for waste trench cap designs.

Reno, Nevada

The University of Nevada-Reno Department of Range, Wildlife and Forestry is investigating the spatial and temporal variability of plant water relations within forested riparian zones. Investigations are also being conducted in the control of cheatgrass by grazing management and the interactions of cheatgrass and native species following a fire. Plant water use is expected to be an important component in each of these experiments.

The researcher involved in these studies had also been involved in water use studies of rangeland species commonly used in revegetation and rehabilitation of rangeland. The objective is to determine if a combination of plant species such as crested wheat-grass, giant wildrye, streambank wheatgrass and Wyoming big sagebrush could more effectively and completely remove moisture from the soil profile than a monoculture under the same circumstances. This research, conducted in Idaho, indicated little difference in water use between the diverse culture and the monoculture. Naturally occurring rangeland vegetation appears to use the water available to the maximum extent possible.

Temple, Texas

The Agricultural Research Service is studying the causes and consequences of vegetation change on rangeland. The competition for water between woody and herbaceous plants will be quantified. Honey mesquite, ash juniper and pricklypear cactus are the woody species designated for study. The herbaceous species include common Bermuda grass and Texas wintergrass.

In another cooperative project with the Texas Agricultural Experiment Station, micro-meteorological techniques will be used to measure evapotranspiration of honey mesquite. The location of this research will be the Texas Experimental Ranch north of Throckmorton, Texas. Comparisons will be made of evapotranspiration from areas with and without mesquite.

Ft. Collins, Colorado

The Central Plains Experimental Range in northcentral Colorado, northeast of Ft. Collins, embraces 15,500 acres (6,280 ha) of steppe vegetation administered by the USDA Agricultural Research Service. Research is conducted by the Agricultural Research Service and Colorado State University. The experimental range is one of a network of long-term ecological research sites funded by the National Science Foundation.

The Agricultural Research Service has instrumentation in place to monitor runoff from areas having varying lengths, slopes and aspects. The objective is to validate a hydraulic simulation model of water dynamics in semiarid grasslands.

The Colorado State University research monitors soil water amounts at soil depths of 30-150 cm at 46 locations using a neutron probe. Some of the locations have been monitored since 1979. Beginning in 1986, a data logger has been used to monitor hourly weight changes from a 3-m diameter by 1-m deep weighing lysimeter. The information on soil water content is combined with plant production data to compare water use efficiencies among steppe communities.

FUTURE RESEARCH

Lysimetry is the most commonly accepted means of determining water use information for specific plant species. Some of the earliest water use studies were accomplished with simple tanks, a technique that is still successfully used. Hammatt, 1920, covers early tank studies of native grasses in Oregon. The use of tanks and lysimeters has particular drawbacks when used to study native vegetation, however. The tanks or lysimeters may not be suited for trees and other large types of vegetation where the root growth may be restricted (Patric 1961). Also, transplanting mature plants into a lysimeter may adversely affect the plant's vigor and water use, thus giving erroneous results. In addition, it is time consuming to grow plants to maturity in the tanks and lysimeters. Also, tanks and lysimeters must be located in natural surroundings to avoid errors from the "oasis effect." Anderson and Idso, 1985, have conducted research on the effect of isolation on water use. This should eventually provide guidelines on how to design experiments in order to avoid such errors.

A major problem with all lysimeters is their lack of flexibility. The installation is permanent, therefore the site must be truly representative of vegetative and soil conditions in the study area. The "oasis effect," described earlier, should be avoided.

The more sophisticated lysimeters such as the weighing type are most valuable for accurately determining water use rates over relatively short time periods. Their-main disadvantage is cost. In addition, the soil mass is disturbed during installation with probable changes in soil horizons and soil porosities. This may result in different vigor and growth of plants in the lysimeter compared to those in a nearby, undisturbed setting. Weighing lysimeters also require significant labor and are difficult to maintain at remote locations.

In contrast, simple lysimeters or tanks can be a more economical means of accomplishing such studies. Innovative installation techniques can result in a minimum of disturbance within the tank–a major goal in studying perennial vegetation. For example, a large diameter steel pipe can be driven into the ground to contain the vegetation in question, thus isolating it hydrologically from its surroundings with a minimum of disturbance to the soil and plants.

Although it is beyond the scope of this report to discuss in detail all evapotranspiration research methods, mention is made of some of the other research methods found in the literature. Gas analysis techniques are covered in Cunningham et al., 1973;

Decker, 1960; and Decker et al., 1962. Thermocouple psychrometry was described by Easter and Sosebee, 1975. Stark, 1967 and 1968, described a "transpirometer" that was used to measure the transpiration of greasewood, rabbitbrush and saltgrass.

There appears to have been considerable effort directed toward calibrating certain empirical evapotranspiration equations, primarily through the development of "crop coefficients." These equations (and key references) include

(1) The Blaney-Criddle equation (original version): Christiansen and Low, 1970; Culler et al., 1976 and 1982; Hanson et al., 1972; Nagel, 1979, Rantz, 1968; and Toy, 1979
(2) The Soil Conservation service modified Blaney-Criddle equation: Borrelli et al., 1981; Burman, 1979; Hall and Taylor, 1973; Perkins, 1981; Petersen and Hill, 1985; and Williams, 1985
(3) Jensen-Haise equation: Culler et al., 1982; Petersen and Hill, 1985; and Wymore, 1974
(4) Penman equation: Aase et al., 1973; and both Hughes, 1972 papers.

A promising technique is the use of micro-meteorological equipment to measure conditions in the atmosphere above the plant canopy. Typical research using this type of equipment is described by Gay and Hartman, 1982 and Carman, 1986. Duell and Nork, 1985, and Duell, 1985, compared three types of micro-meteorological methods. The equipment is portable enabling the researcher to better-define spatial differences in evapotranspiration throughout a watershed or study area. The technique is particularly suited for determining evapotranspiration during short time intervals. The equipment is rather sophisticated requiring considerable attention, particularly if measurements are to be made for long time intervals.

Overall, additional site specific research would be beneficial in furthering the general knowledge of vegetative water use. Specifically, more information would be desirable about the rates of water use by forest vegetation. It is also recommended that a better means of extrapolating water use information to large geographic areas be further explored.

ABSTRACT BIBLIOGRAPHY

An extensive literature search was conducted, centering primarily on natural vegetative water use in the Western United States. The resulting bibliography contains over 307 selections gleaned from over 400 reviewed references. The literature search was accomplished in two steps. First, a computer search was conducted using appropriate databases including AGRICOLA and WORISC. The computer search centered on the period from 1970 to the present. It was initially assumed that existing bibliographies such as the Forest Service Miscellaneous Bulletin No. 1234 (Horton, 1973) would cover many of the earlier publications. Next, the reference lists from each of the references obtained in the computer search were checked by hand for additional references. This ensured that virtually all available references were reviewed. Only about half of the final bibliography listed in this report resulted from the initial computer search.

Several decisions were made to narrow and simplify the literature search. The first was to exclude bare soil evaporation or free water evaporation from the search, although it is acknowledged that many study basins and study areas include significant areas of bare soil and open water. Another decision made to expedite the study was to limit the literature search to research conducted in the United States with emphasis on the conterminous 17 Western States. However, a few pertinent references covering research in Canada and the eastern United States were included.

The literature search produced the following bibliographic reports or reports summarizing research:

Robinson, USGS Circular 41B, 1959, "Phreatophyte Research."

Robinson & Johnson, Water Supply Paper 1539-R, 1961, "Selected Bibliography on Evaporation and Transpiration."

Robinson, USGS Water Supply Paper 495, 1964, "Phreatophyte Research in the Western States, March 1959 to July 1964."

Horton, USDA Misc. Pub. No. 1234, 1973, "Evapotranspiration and Watershed Research as Related to Riparian and Phreatophyte Management."

Paylore, OWRR, 1974, "Phreatophytes."

Sopper, 1971, "Watershed Management."

Chow (Ed.), 1964, "Handbook of Applied Hydrology."

Branson et al., 1981, "Rangeland Hydrology."

Other significant efforts to summarize previous work are worth mentioning. Affleck, 1975, compiled a detailed summary of water use research centered on and around Arizona. The Bureau of Reclamation, 1979, published a final environmental statement containing an excellent discussion of water use information gleaned from an extensive literature search. Christiansen and Low, 1970, contains an excellent review of literature covering water use by marshland vegetation. The United States Senate, 1960, Select Committee on Natural Resources summarized expected annual use rates for various vegetative types as well as basin wide estimates of water use by phreatophytes. These reports mainly center on the narrow field of phreatophytes, covering most aspects of this group of plants. In contrast, the following abstract bibliography focuses on plant water use over the entire range of naturally occurring vegetation.

The author's abstract is presented when it is available. If no special notation follows the abstract, it can be assumed that it is the author's abstract. Special notation following the abstract indicates sources such as a compiler's summary or use of the author's introduction or conclusion. Most of the articles and publications cited are available in major libraries or are on file at the Bureau of Reclamation's Denver Office, Denver, Colorado.

A database (dBASE III plus) containing key information from the references in this publication has also been created.

BIBLIOGRAPHY

1. Aase, J. K., and Wight, J. R.

"Energy Balance Investigations on a Native Range Vegetation in the Northern Great Plains," *Ecology*, Vol. 53, No. 6, 1972, pp. 1200–1203.

Evapotranspiration (ET) to net radiation (R_{nv}) ratios for native vegetation on semiarid western rangeland were less than 1 throughout the season except for a rainy period, illustrating the contributing role of semiarid range to downwind advection. Ratios of pan evaporation (E_p) to net radiation over an evaporation pan (R_{nv}) were consistently greater than 1, indicating the contribution of advective energy to free water evaporation. Net radiation over both vegetation and an evaporation pan were similar except for early and late growing season. The relationship between R_{nv} and solar radiation (R_n) was highly variable, with R_{nv}:R_s ratios ranging from 0.2 to 0.7.

2. Aase, J. K., and Wight, J. R.

"Energy Balance Relative to Plant Cover in a Native Community," *Journal of Range Management*, Vol. 23, 1970, pp. 252–255.

Net radiation (R_n) and evapotranspiration (ET) were poorly correlated during both a "wet" and a "dry" period on native range near Sidney, Montana within each of five levels of vegetational cover. The ratio ET:R_n fluctuated greatly in all cases and was generally higher during the period of higher rainfall. During dry periods, substantial amounts of energy were dissipated as heat flux to the atmosphere. Maximum evaporation and/or transpiration from 0%, 25%, 50%, 75%, and 100% cover occurred for 12 days after rainfall and was, respectively, 0.7, 0.8, 1.1, 0.3, and 1.9 times the evaporation from a Class A evaporation pan. Total evapotranspiration for the season was 21% lower and dry matter production was 14% higher with 50% cover than with complete cover. Water use from 75% and 25% cover was similar to that from 50% cover, but forage yields were 5% and 14% less, respectively, than from complete cover.

3. Aase, J. K., Wight, J. R., and Siddoway, F. H.

"Estimating Soil Water Content on Native Rangeland," *Agricultural Meteorology*, Vol. 12, 1973, pp. 185–191.

A model for estimating soil water content on native rangeland was tested at Sidney, Montana. Based on the Penman combination method for estimating potential ET, the model includes factors to account for crop development, limiting soil water content, and increased evaporation after rain. The model gave reasonable estimates of actual soil water conditions with a 15% limit suggested as being practical for rangeland management purposes.

4. Affleck, R. S.

"Potential for Water Yield improvement in Arizona Through Riparian Vegetation Management," Doctor of Philosophy Dissertation, School of Renewable Natural Resources, University of Arizona, Tucson, Ariz., 1975, 238 pp.

New knowledge gained over the past 15 to 20 years on the management of riparian zones in Arizona for water yield improvement has been organized and analyzed. Hydrologic processes and principles applicable to riparian zones, the distribution and nature or riparian vegetation in Arizona, and new resource management methods, needs, and constraints have been evaluated. The relationship between vegetation management for water yield improvement and other resource-based products and uses of riparian zones such as timber, range for livestock, wildlife and fish, recreation, and aesthetics was also assessed.

Past studies and surveys indicate that Arizona has approximately 280,000 to 320,000 acres of riparian vegetation. However, pertinent information such as species composition, vegetation density, depth to groundwater, groundwater quality, and land ownership have not been mapped accurately for many riparian zones in Arizona. A continuous survey of riparian vegetation cover by remote sensing supplemented by ground truth is suggested to remedy this situation.

Analysis of hydrologic studies indicated the following identifiable trends in water used by riparian species. Saltcedar, arrowweed, cottonwood, and hydrophytes are the heaviest users of water (between 4 and 8 feet (ft) of water annually). Intermediate water users (annual use between 2 and 5 ft) are seepwillow, mesquite, quailbrush, four-wing saltbush, and greasewood. Lesser amounts of water are transpired by grasses and sedges and evaporated from bare soil (0.5 to 3 ft annually).

Five water yield improvement methods applicable to riparian zones are evaluated; conversion of one vegetation type to another, channelization, cottonwood thinning, antitranspirant and biological control treatments. Conversion treatments to grasses or crops may yield water savings of up to 2.5 acre-ft per acre annually during the first year. However, some or all of this water may eventually be used by replacement vegetation. Several constraints including possible loss of wildlife habitat, contamination of water supplies by chemical herbicides, lowered aesthetic quality, and increased soil erosion with the removal of riparian vegetation reduce the opportunities for converting a large percentage of riparian vegetation in Arizona. To justify operational conversion programs in Arizona, follow-up studies of current conversion projects should be instituted. Rates at which revegetation takes place, declines in water salvage as revegetation occurs, amount and value of increased herbage production, and long term effects on plant distribution and animal life need to be determined.

Channelization projects in the Southwest have been credited with increasing water yields; however, methods for determining these increases are poorly documented.

Channelization for flood control purposes is limited because flow of flood water is accelerated in the vicinity of the excavation and may contribute to flooding and sedimentation on unchanneled segments.

Cottonwood thinning designed to reduce evapotranspiration and flood hazards has been conducted along the Verde River. Increased water yields have not been measured. Adverse effects on fish and wildlife have been reported as a result of thinning cottonwoods. Limited thinning of cottonwoods to prevent bridges from washing out or to protect existing structures on the floodplain may be beneficial. Application of antitranspirant foliar sprays to reduce plant water use is a potential treatment method for increasing water yield in riparian zones. Antitranspirants were effective in reducing transpiration rates of saltceder plants by up to 38% for three to five weeks in greenhouse and limited field studies. Research on the feasibility of obtaining supplementary water from riparian vegetation through the application of antitranspirants should be expanded. Antitranspirants, if proven safe and effective, may be mutually acceptable to water, recreation, and wildlife interests. Biological control of saltcedar is not effective at present.

5. Anderson, J. E.

"Factors Controlling Transpiration and Photosynthesis in *Tamarix chinensis* Lour," *Ecology*, Vol. 63, No. 1, 1982, pp. 48–56.

Photosynthetic and stomatal responses of *Tamarix chinensis* to temperature, light, and humidity were investigated in the field in New Mexico and in the laboratory. Transpiration rates for *T. chinensis* were similar to those of several herbaceous plants and co-occurring phreatophytes. Net photosynthetic rates and water use efficiency of *T. chinensis* were lower than for other species. Photosynthesis was light saturated at a photon flux density equal to 44% of full sunlight.

Carbon dioxide assimilation was tightly coupled to irradiance below light saturation. Leaf resistances remained low at photon flux densities above one-third of full sunlight, but increased linearly with decreasing photon-flux density below that level. Shading for 5 minutes resulted in a doubling of leaf resistance. The rapid response of stomata to changing light conditions is probably an adaptation to conserve moisture when light is limiting to photosynthesis. Optimal leaf temperatures for photosynthesis were 23°–28° C, which corresponded roughly to ambient temperatures during the early part of the day when evaporative demand was relatively low. *T. chinensis* stomata appeared to respond directly to changes in the leaf-to-air absolute humidity gradient. At constant temperature, leaf resistance increased linearly with increases in the leaf-air humidity gradient. Midday depressions of gas exchange invariably occurred in the field, despite the fact that the plants had an abundant water supply. These depressions resulted from increases in leaf resistance in response to increasing evaporative demand of the air. This response results in improved water use efficiency during the hottest portion of the day. Plant water potential decreased from pre-dawn values of about –0.9 MPa to minimal values of about −2.6 MPa by midmorning. Improvements in bulk water status were often observed during the afternoon when leaf resistances were higher. Diurnal patterns suggested that leaf resistance was largely a function of temperature, light, and humidity, rather than plant water status.

6. Anderson, J. E.

"Transpiration and Photosynthesis in Saltcedar," in *Hydrology and Water Resources in Arizona and the Southwest*, Proceedings of Arizona Section of American Water Resources Association and the Hydrologic Section of the Arizona Academy of Science, Las Vegas, Nev., April 15–16, Vol. 7, 1977, pp. 125–131.

Factors controlling transpiration and photosynthesis of saltcedar were investigated in the field near Bernardo, New Mexico. Transpiration rates were similar to those for several herbaceous species, but photosynthesis and water use efficiency were significantly lower in saltcedar. Photosynthesis was light saturated at an irradiance equal to 44% of full sunlight, while the stomata were apparently fully open at light levels greater than one-third full sunlight. Optimum leaf temperatures for photosynthesis were between 23° and 28° C, considerably lower than typical daytime ambient temperatures. Photosynthesis was reduced about 20% at 35° C. Stomatal resistance increased linearly with increases in leaf temperature between 14° and 50° C, with relative humidity held constant. The increase in stomatal resistance could have been caused by direct effects of temperature on the stomata, by increases in the absolute humidity gradient from leaf to air, or by both. Increased stomatal resistance at high temperatures and low relative humidities would account for observed afternoon depressions in transpiration and photosynthesis and increases in canopy resistance. Estimates of stomatal resistance for twigs in full sunlight ranged from 2 to 6 sec cm^{-1}, with most values falling between 3 and 5 sec cm^{-1} when leaves were at 30° C.

7. Anderson, J. E., and Kreith, F.

"Engineering and Ecological Evaluation of Antitranspirants for Increasing Runoff in Colorado Watersheds," Environmental Resources Center, *Completion Report Series No. 69*, Colorado State University, Fort Collins, Colo., 1975, 37 pp.

Experiments were performed in the laboratory and in the field to determine the effectiveness of three different types of film forming antitranspirants in reducing the evapotranspiration from phreatophytes, with special emphasis on salt cedar. The antitranspirants tested in this study were Mobil-Leaf (Mobil Chemical Co.), Wilt proof (Nursery Specialty Products), and XEF-4-3561 (Dow Corning Corp.). The laboratory experiments indicated that a single antitranspirant treatment can reduce the water loss from salt cedar by as much as 50% for several days and that the long term effectiveness of Mobil-Leaf is significantly better than that of the other two antitranspirants. None of the plants treated with Mobil-Leaf showed any discoloration or other physiological injury within a month after treatment. Field studies were conducted in cooperation with the Bureau of Land Management at the BLM Evapotranspirometer Installation at Bernardo, New Mexico with Mobil-Leaf. The decrease in evapotranspiration from salt cedar observed in the field was less than that in the laboratory and current indications are that the resulting water savings was probably somewhat less than 30%. It is possible that the differences between laboratory in-field effect is due to a lack of uniformity and thoroughness of the spray covering.

8. Anderson, M., and Idso, S. B.

"Evaporative Rates of Floating and Emergent Aquatic Vegetation: Water Hyacinths, Water Ferns, Water Lilies and Cattails," *17th Conference on Agriculture and Forest Meteorology and 7th Conference on Biometeorology and Aerobiology*, May 21–24, Scottsdale, Arizona, American Meteorological Society, Boston, Massachusetts, 1985.

Quantitative *in vitro* experiments comparing the evaporative rates of small canopies of water hyacinth (*Eichornia crassipes*) and similar sized open water surfaces have all reported large vegetative transpiration rates. One specific experiment resulted in a plant/open-water loss ratio of 3.2 utilizing tubs with about 2 square feet (ft^2) of surface area. Other experiments found ratios of 3.7 and 5.3 for plants in relatively small containers. The experimental design of these studies was challenged as the small plant communities were apparently responding to the well known "oasis effect." The purpose of this study was to resolve the controversy and to quantify the effect of experimental designs having various sized vegetated and open-water bodies. Standard galvanized metal stock tanks possessing diameters of 0.4, 0.5, 1.1, and 2.3 meters (m) were recessed into the ground leaving only a few centimeters (cm) exposed above the surrounding bare soil on a plot at the U.S. Conservation Laboratory in Phoenix, Arizona. Larger ponds of diameters 3.4, 4.3, 5.4, and 11.4 meters (m) were formed by placing plastic sheets into and over 0.6-m high earth berm rings at the Arizona State University Research Park in Tempe, Arizona. Water use data was gathered for the following types of vegetation: water hyacinth, water lilies, water ferns, and cattails. Results are presented as graphs of various parameters versus the ratio of vegetation water use to open water evaporation. (Compiler's Summary)

9. Anderson, T. W.

"Evapotranspiration Losses from Flood-plain Areas in Central Arizona," *U.S. Geological Survey Open-File Report 76-864* (in cooperation with Arizona Water Commission), Tucson, Ariz., 1976, 91 pp.

The present (1975), near-future, long-term future, and potential evapotranspiration losses from flood-plain areas are estimated for most streams in central Arizona. It is assumed that the near-future and long-term future evapotranspiration losses will change as a result of a change in the surface-water flow regimen; although the surface-water flow regimen may change owing to any water-augmentation scheme, the most probable source of additional water will be from vegetation modification in the watershed. The stream channel from the point of introduction of additional water to the downstream user site is the area for which the present, near-future, long-term future, and potential evapotranspiration losses are estimated. The total stream length included in the study is 1,287 miles (mi) (2,071 kilometers (km)) and includes perennial and intermittent streams. The estimates of present evapotranspiration losses were determined by an integration technique based on areal mapping of vegetation types and densities and on relations between water use by different types of vegetation and depth to ground water. Several methods were used to check the results, including a base-flow method and a water-budget method. Near-future evapotranspiration losses were estimated using the integration method, and the increase in loss is attributed to shallower depths to water, it is assumed that long-term future losses will increase further owing to an increase in riparian vegetation density. Empirical methods were used to estimate the potential evapotranspiration losses.

Many of the streams included in the study are perennial; the near-future and long-term future increases in evapotranspiration losses are estimated to be negligible for the perennial streams. The streams for which large increases in evapotranspiration losses are predicted are generally in the west-central part of the State, where the environment is desert to semidesert.

The report gives a summary of the general hydrologic, vegetative, and geomorphic conditions for most streams in the study area. In addition, the present, near-future, long-term future, and potential evapotranspiration losses and the estimated increase in evapotranspiration losses are presented.

10. Avery, C. C., and Fritschen, L. J.

"Hydrologic and Energy budgets of Stocked and Non-stocked Douglas-Fir Sites as Calculated by Meteorological Methods," University of Washington, Seattle, Wash., Office of Water Resources, *Research Report No. A-0320WASH*, July 1969–July 1971, 1971.

A field study was made of the energy balances and the hydrologic balances of a 50-year old, 20-m Douglas fir stand and an adjacent clearcut during 1970 and 1971. The site, near Hatonville, Washington, was of low quality for Douglas fir having developed on a glacial outwash terrace, but with well-drained soils. The objectives of the study were to 1) obtain information about the effects of clearcutting on the hydrologic and energy balances of the forest and 2) determine the actual and potential evapotranspiration rates during selected periods for the two areas.

Actual evapotranspiration was determined with Bowen ratio approach of the energy balance and soil moisture extraction. Potential evapotranspiration was estimated using van Bavel's (1966) form of the combination model. Net radiation, wet and dry bulb temperature, wind speed, soil heat flux as well as precipitation, soil moisture, incoming solar radiation and albedo were measured or calculated.

Major results suggest greater water use in the clearing than at the forest site. The Bowen ratio approach appeared to yield valid results in the clearing but not always consistent results at the forest site. This was attributed to the air flow patterns set up by the leading edge of the forest and suggest that single site evaluations are questionable.

11. Babcock, H. M.

"The Phreatophyte Problem in Arizona," in *Proceedings of 12th Annual Arizona Watershed Symposium*, Phoenix, Ariz., 1968, pp. 34–36, illus.

Past phreatophyte research was summarized. Needed future research was discussed including standards for conducting phreatophyte inventories and means of determining the most effective water salvage measures. Three methods exist for salvaging water from phreatophytes: (1) take the water away from the plant, i.e., lower the water table; (2) substitute plants of higher beneficial use or lower the overall consumptive use; or (3) remove the plant from the water (eradication). To this date, the first two methods have been used extensively in Arizona. To effectively accomplish eradication, costs must be known as well as the quantity of evaporation remaining once the plants are eradicated. It was concluded that many questions about water used by phreatophytes can be answered by carefully observing existing projects. (Compiler's Summary)

12. Bailey, L. F.

"Some Water Relations of Three Western Grasses, I. The Transpiration Ratio," *American Journal of Botany*, Vol. 27, 1940, pp. 122–128.

The transpiration ratio has been determined for three grasses suitable for use in soil conservation projects in the semiarid grasslands of the United States. The grasses used were *Agropyron smithii*, *Agropyron ciliare* and *Bromus marginatus*. Plants were grown in large sealed metal cans, to which water was added frequently. The experiments were conducted under field conditions in an exposed site during 1937 and 1938.

The transpiration ratio–that is, the ratio between the amount of water transpired by the plant during its growth and the weight of dry matter produced–is expressed both on the basis of top growth and total plant growth. The figures based on total plants are about 50% lower than those based on tops alone. Since roots (and rhizomes) comprised about one-half of the total growth of these grasses, their transpiration ratios should be based on total growth, at least when evaluating them for soil conservation purposes in semiarid regions.

Agropyron smithii was most efficient in the use of water when total plants were considered. On the basis of tops alone it was least efficient. *Agropyron ciliare* had the lowest transpiration ratio on the basis of tops produced but compared less favorably with the other two species when total plants were considered. *Bromus marginatus* used water inefficiently under all conditions.

Although these grasses are less efficient in the use of water than grain crops such as wheat, their marked development of subterranean growth makes them superior plants for soil conservation. The three grasses used water more economically at 19% soil moisture than at 30% soil moisture. The transpiration ratio for each species was materially altered by growing the plants in two different soils. (Author's Summary)

13. Baker, J. N., and Hunt, O. J.

"Effects of Clipping Treatments and Clonal Differences in Water Requirements of Grasses," *Journal of Range Management*, Vol. 14, 1961, pp. 216–219.

The objective of this study was to determine the influence of clipping on the growth of individual grass tillers under drought stress. In the fall of 1958, three intermediate and two pubescent wheatgrass plants were selected from the source nursery located at the Wyoming Agricultural Experiment Station near Laramie. Half of each plant was brought into the greenhouse in September and the remainder in December. These plants were separated into individual tillers and planted in canisters after being rooted in sand. Half of the canisters were maintained at approximately field capacity and the other half were maintained just above the wilting point. The plants were clipped at two and four inches (in.) above the soil surface. Evaluation of the clones was made on the basis of tillering, dry-matter yield and water requirements.

Differences between the vernalized and nonvernalized plants in their reaction to total water use and dry-matter yield were observed. The results of the study indicate also that height of clipping affected the number of tillers produced, total herbage yield, and water used per gram of forage produced. There were significant clonal differences in the number of tillers produced and in the efficiency of water use. (Author's Summary)

14. Barrett, W. C., and Milligan, C. H.

"Consumptive Water Use and Requirements in the Colorado River Area of Utah," Agricultural Experiment Station, Utah State Agricultural College, *Specialty Report No. 8*, 1951, 28 pp.

Before the available water resources of a drainage basin in an arid or semiarid region can be satisfactorily ascertained, a proper evaluation must be made of the consumptive-use requirements for water in the separate parts of the basin. The purpose of this report is to present the results of investigations in two selected areas of the Colorado River basin in Utah. Two irrigated areas were chosen for making direct studies of consumptive water use–Ashley Creek valley near Vernal and Ferron Creek valley near Ferron, Utah. To provide data for the study, the following investigations were undertaken: (1) measurements of all inflow and outflow, including an estimate of any existing underground flows; (2) groundwater measurements to determine fluctuations in groundwater storage; (3) gathering of climatological data; (4) evapotranspiration tank studies of the principal crops and of native vegetation adaptable to tank investigations; (5) soil moisture depletion investigations of the major agricultural crops; and (6) mapping of land use. Consumptive use as determined by the integration and inflow-outflow methods was considered to be in reasonably good agreement. The appropriate consumptive use rates for types of vegetation in the Ashley and Feron Valleys are presented. The total consumptive use in these valleys was considerably more than the streamflow depletion caused by man's activities in the area. The native vegetation consumed most of the normal rainfall occurring on the valley floor plus some surface runoff and underground seepage from the surrounding hills. The maximum possible streamflow depletion chargeable to man's activities was growing season consumptive use on cropped lands, or other lands where vegetative growth has been materially changed, minus the effective summer precipitation. Reliable estimates of consumptive use were made from climatological data using the Blaney-Criddle method. However, it was suggested that consumptive use coefficients may need to be increased for eastern Utah conditions. The suggested coefficients are presented. (Compiler's Summary)

15. Beatley, J. C.

"Effects of Rainfall and Temperature on the Distribution and Behavior of *Larrea tridentata* (Creosote-bush) in the Mojave Desert of Nevada." *Ecology*, Vol. 55, 1974, pp. 245–261.

The effects of rainfall and temperature on the distribution and certain behavioral characteristics of *Larrea tridentata* (Creosote-bush) at and near its northern limits in the northern Mojave desert of southern Nevada, were investigated at 39 sites with *Larrea* and 20 sites without *Larrea* in eight drainage basins at elevations of 915–1,770 m over a 2,600 km^2 area of the Nevada test site. Data used were (1) rainfall records for 9 years (1963–71) for each site; (2) maximum and minimum air temperature records for each site, November 1962–February 1972; (3) percentage cover by all shrub species and by *Larrea*; (4) height and density data for *Larrea*; and (5) percentage of germinable seeds from 29 of the *Larrea* populations for three seasons (1963–65) in relation to the seasonal rainfall for each site.

Total percentage cover by all shrub species is highly correlated with mean annual rainfall, less well correlated with elevation. Percentage cover by *Larrea* follows two patterns of relationship with rainfall: (1) where mean rainfall is low to intermediate, the same pattern as total shrub cover in relation to rainfall, and (2) on sites of high mean rainfall, consistently low cover, a function of low density of *Larrea* on these sites. In general, in undisturbed communities, the taller the *Larrea* plants the fewer there are of them, but the relationship is not strictly linear. Using height as an index to plant volume, numbers of *Larrea* plants are highly correlated with total plant volume. Mean height is not strongly correlated with mean annual rainfall or temperature parameters, but is well correlated with the ratio of mean precipitation/mean temperature. Tall plants (> 1 meter (m)) occur in low density and on sites with high rainfall (mean 160–183 millimeters (mm)).

The prevailing low minimum air temperatures and their extremes in the lowlands of enclosed drainage basins are inferred to be the primary cause of the absence of *Larrea* in three discrete vegetation zones (*Atriplex confertifolia*, *Lycium pallidum*, and *L. shockleyi*) in Frenchman Flat, and over most of the basin floor of Yucca Flat, where the communities are *Atriplex* and *Grayia-Lycium andersonii*. The year-round low minima in the lowlands of these basins result from nocturnal cold air drainage phenomena and formation of a cold air layer of variable depth. Average extreme minima on these sites were mostly below 0° F; the extreme minimum was –18° F in one of the *Atriplex* communities of Frenchman Flat.

Larrea occurs over the bajadas of Frenchman Flat on sites above the lower layers of cold air. In Yucca Flat, at its northern limits, it is restricted to certain upper bajada sites and notably one site on the basin floor. Average extreme minimum air temperatures on all *Larrea* sites were above 1° F; the absolute minimum was –8° F. Upper altitudinal limits of *Larrea* apparently are not determined by minimum temperatures since minima (including the extremes) in *Coleogyne* vegetation, which replaces *Larrea* altitudinally on the slopes, are well within the range of those recorded on *Larrea* sites.

There is no pattern of relationship between maximum temperature and the distribution of *Larrea*, although the highest extreme maxima usually occur on non-*Larrea* sites in the lowlands of Frenchman Flat.

Mean annual rainfall on the *Larrea* sites ranged from 118 to 183 millimeters (mm). Altitudinal and latitudinal limits of *Larrea* coincide with a maximum mean rainfall of 183 mm. Mean annual rainfall of 160–183 mm appears to be critical to the behavior of *Larrea*. Germination trials support the inference of a deleterious effect of high rainfall on *Larrea* populations through time: there were high correlation coefficients (negative or positive, depending on the year) between the rainfall of the effective rainfall season and the percentage of germinable seeds; highest mean germination percentages (20%–60%) occurred with 80–150 mm of seasonal rain, and either lower or higher seasonal rainfall resulted in lower percentages of germinable seeds (0%–20%).

16. Belt, G. H.

"Spring Evapotranspiration from Low Sagebrush Range in Southern Idaho," *Research Project Technical Completion Report A-014-IDA*, July 1, 1968–June 30, 1969, University of Idaho Water Resources Research Institute, Moscow, Idaho, 1970, 44 pp.

Evapotranspiration was measured from low sagebrush covered rangeland at the Reynolds Creek Experimental Watershed, Reynolds, Idaho. The objectives of the study were twofold: To measure the magnitude of and the variation in evaporative flux rates for low sagebrush range; and to identify those parameters of the microclimate which were significant in causing daily and hourly variation in flux rates. Evapotranspiration (ET) from the low sagebrush range (38% crown cover), using the Bowen-ratio technique, indicates typical ET rates of 0.025–0.40 mm/hr. Losses during daylight hours ranged from 1.27–3.0 mm and represented 33–46% of the net radiation. Advection of sensible heat was negligible. Soil moisture during the May–June period ranged from 17–40% by volume. The instrumentation developed for Bowen-ratio energy balance measurements is also described.

17. Ben-Asher, J.

"Estimating Evapotranspiration from the Sonoita Creek Watershed Near Patagonia, Arizona," *Water Resources Research*, Vol. 17, No. 4, August, 1981, pp. 901–906.

In a study that was proposed to evaluate the water balance of the Sonoita Creek watershed near Tucson, Arizona, monthly evapotranspiration was defined by Morton's conceptual approach for large areas. The objective of this study was to test the model. The available climatological data were solar radiation, dew point temperature, mean monthly temperature, and humidity. The model was evaluated by testing the relationship between potential and actual evapotranspiration in Africa. Data for Africa were found to be in agreement with the concept of a complementary relationship. When applied to a small watershed such as Sonoita Creek, the model performance was good on an annual basis and in the hot seasons. In the cold seasons, however, an alternative approach was used. Error analysis indicated that a major source of error lies in the fact that the model neglects the effect of surface moisture content on net radiation. It assumes a single value of net radiation for both the Priestley-Taylor and Penman's formulae. However, the assumption of a well-watered surface, which is inherent in the first formula must be associated with net radiation which is higher than that associated with Penman's formula. As a result, a maximum error as large as 52% of the annual evapotranspiration may occur.

18. Benton, A. R., Jr., James, W. P., and Rouse, J. W., Jr.

"Evapotranspiration from Water Hyacinth (*Eichhornia crassipes* (Mart.) Solms) in Texas Reservoirs," *Water Resources Bulletin*, Vol. 14, No. 4, 1978, pp. 919–930. (Also refer to Discussion by S. B. Idso, *Water Resources Bulletin*, Vol. 15, No. 5, 1979, pp. 1466–1467.)

Water hyacinth, an attractive, floating aquatic plant, poses a substantial threat of unanticipated water loss from Texas reservoirs. A mature plant will lose about three times as much water through evapotranspiration as is lost from evaporation of an equivalent area of open water. The reservoirs of east and southeast Texas, which comprise the bulk of the state's existing and planned water storage capacity, seem likely to suffer a 20% average surface infestation of water hyacinth. A coverage that great will result in a yearly net loss of over 2,000,000 acre-ft of impounded water, based on present water development plans for the state. This would amount to nearly 20% of the anticipated yield from the reservoirs affected. An effective aquatic plant control program could head off the threat of this significant water loss.

19. Berndt, H. W.

"Precipitation and Streamflow of a Colorado Front Range Watershed," U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, *Station Paper 47*, Fort Collins, Colo., 1960, 14 pp.

Knowledge of the water-yielding characteristics of a variety of drainages is important in watershed management. This report presents information obtained during 1940–58 from the Missouri Gulch watershed on the Manitou Experimental Forest in Colorado. The purpose of the study was to gain information on water yield and its relation to precipitation for a drainage heading in the Colorado Front Range ponderosa pine type.

20. Bethell, D., Fereres, E., Buchner, R., and Mansfield, R.

"Irrigation Management for the Sierra Nevada Foothills of California," Cooperative Extension Service, University of California, El Dorado County, December, 1980. (Report prepared for U.S. Department of Interior.)

This publication culminates several years of crop irrigation research and five years experience with the El Dorado Irrigation Management Service (INS), and it is a general reference on foothill irrigation practice and development of irrigation management programs for farmers, consultants, irrigation districts, and government agencies. Major emphasis is on conducting a program similar to the El Dorado IMS and utilizing computer scheduling of irrigation for specific sites, using weather data and crop curves adjusted to reflect slope, elevation, and cover crop influences. The El Dorado IMS has become a reasonably accurate, economical and quickly delivered irrigation scheduling program for small-sized farms and irrigation units in an area of unusual variability in crop water requirements. The water budget potential of the irrigation management program will be better realized when it is adopted commercially and more public input is received.

21. Bittinger, M. W., and Stringham, G. E.

"A Study of Phreatophyte Growth in the Lower Arkansas River Valley of Colorado," Colorado Agricultural Experiment Station, Colorado State University, Fort Collins, Colo., 1963.

This study was part of a broader research investigation concerned with the interrelationships of surface and groundwater in the lower Arkansas River Valley of Colorado. The overall investigation, sponsored by the Colorado Department of Natural Resources, was conducted jointly by the U.S. Geological Survey and Colorado State University. This study was centered in a reach of the Arkansas River Valley between La Junta and Las Animas, Colorado. Preliminary analyses of hydrologic records from the study area revealed that an increasing amount of water had been consumptively used over the years and the consumption of water by phreatophytes represented an economically important portion of the water used. A field survey was conducted to determine aerial extent, species, and density of phreatophyte growth in the study area. The change in phreatophyte growth in the study area with time was determined using aerial photographs taken in 1936, 1947, and 1957. Annual consumptive use was estimated for the study reach based on rates previously published by Blaney and Criddle. Finally, the results were extended to the entire Arkansas River Valley between Pueblo and the Colorado-Kansas State line. (Compiler's Summary)

22. Black, T. A.

"Evapotranspiration from Douglas Fir Stands Exposed to Soil Water Deficits," *Water Resources Research*, Vol. 15, No. 1, 1979, pp. 164–170.

The rate of evapotranspiration from thinned and unthinned stands of Douglas fir was measured using energy and water balance methods. At high values of soil water storage in the root zone the evapotranspiration rate was approximately 80% of the equilibrium evaporation rate. Below a critical value of soil water storage the ratio of the evapotranspiration rate to the equilibrium evaporation rate (E/E_{eq}) tended to decrease linearly with decreasing soil water storage. The critical values of soil water storage in the root zone were 11.8 and 8.3 cm for the thinned and unthinned stand, respectively. Below these critical storage values, there was approximately 3.5 cm of water remaining in both root zones that was extractable by the trees. The relationship between E/E_{eq} and the fraction of extractable water in the root zone for both stands was very similar for sunny days. In this relationship, E/E_{eq} began to decrease when there was approximately 40% of the extractable water remaining in the root zones of both stands.

23. Blackburn, W. H., Knight, R. W., and Schuster, J. L.

"Salt Cedar Influence on Sedimentation in the Brazos River," *Journal of Soil Water Conservation*, Vol. 37, No. 5, 1982, pp. 298–301.

Saltcedar (*Tamarix* spp.) infestations along the Brazos River between Seymour, Texas, and the river's confluence with the Clear Fork occupied 57% of the original river channel by 1979. As saltcedar established on sandbars and channel edges, the plants stabilized the channel sediments causing deposition. By 1979, 3 m of sediment had been deposited in the saltcedar-infested channel, and the river channel's width had been reduced by 89.6 m. The presence of saltcedar and subsequent sediment deposition and channel closure in the Brazos River effectively reduced sedimentation of Possum Kingdom Lake. However, the saltcedar invasion resulted in higher flood stages for similar flow volumes, thus enlarging the area inundated by floodwaters.

24. Blaney, H. F.

"Consumptive Use of Ground Water by Phreatophytes and Hydrophytes," in General Assembly of Rome, International Union Geodesy and Geophysics, International Association Scientific Hydrologic Publication [Gentbrugge] 37, 1954, pp. 53–62, illus.

This paper presents and describes, with several tables and graphs, the results of studies and measurements of the use of groundwater by phreatophytes and hydrophytes in arid and semiarid areas of five Western States (Arizona, California, Colorado, New Mexico, and Texas) and again describes the method of determining rates of water consumption in areas where no measurements except climatological data are available. The method is expressed in the empirical formulae developed first by Blaney and Morin (1942).

25. Blaney, H. F.

"Consumptive Use and Water Waste by Phreatophytes," *Proceedings of American Society of Civil Engineers*, Journal of the Irrigation and Drainage Division, Vol. 87(IR3), 1961, pp. 37–46, illus.

Information given in this presentation was taken from earlier publications. The analysis extends the very limited information on use of water by tamarisk to predict savings of water caused by replacement of tamarisk by grass along portions of the Pecos River, New Mexico.

26. Blaney, H. F., and Hanson, E. G.

"Consumptive Use and Water Requirements in New Mexico," U.S. Department of Agriculture, Soil and Water Conservation Research Division and Department of Agricultural Engineering, New Mexico State University, *Technical Report 32*, 1965, 82 pp.

Many factors influence the amount of water that is consumed by plants. The more important natural influences are climate, water supply, soil, and topography. The climatic factors believed to have the greatest influence on consumptive use are precipitation, temperature, solar radiation, humidity, wind movement, and growing season. Irrigation practices also influence the amount of water consumed as do the kinds of crops grown, their stage of growth, plant species, and many other factors.

This report includes results of experimental studies in New Mexico, Arizona, and other western states. An empirical formula has been developed from these results and from data compiled in the Pecos River Joint Investigation of 1939–41 which show the relationship between temperature, length of growing season, monthly percent of annual daytime hours, and consumptive use of water. From this relationship, consumptive use of water by crops and natural vegetation can be readily estimated for any area where the basic climatological data are available. Irrigation requirements may be estimated from consumptive use.

Briefly, this procedure was developed by correlating measured consumptive-use data with monthly temperature, monthly percentages of annual daytime hours, quantity and occurrence of precipitation, and length of growing or irrigation season. The coefficients thus developed allow for the computation of consumptive use of each crop if only monthly temperature, latitude, and growing period of the crop are known, since monthly percentages of annual daytime hours are available for latitudes in New Mexico. Seasonal consumptive use can be computed from the Blaney-Criddle (B-C) formula $U = KF$; where U = consumptive use of water in inches, K = empirical seasonal use coefficient, and F = sum of monthly use factors (f) for the season. The monthly use factor (f) is the product of mean monthly temperature (t) and monthly (p) percent of annual daytime hours. The equation for monthly or short-period use is $u = kf$.

The seasonal coefficient for each crop appears to be approximately constant for most areas where irrigation is in practice. However, the coefficients do not appear to be constant for consecutive short periods of time throughout the growing season. For short periods the higher the temperature, the larger the coefficient (k) appears to be. However, temperature is not the only factor affecting consumptive-use relationships. Each crop has its own particular growth and water-use pattern. Thus, for short periods of time, use coefficients vary, largely depending upon temperature and stage of growth.

The net amount of irrigation water required to satisfy consumptive use during any period of time is determined by subtracting the effective precipitation and other available water from the total requirement for the period. This net requirement of irrigation water, divided by the irrigation efficiency, is the overall water requirement to satisfy the needs of the crop. If efficiency measurements are not available, they can be estimated by taking into account irrigation practices, soil characteristics, topography, skill of the irrigator, degree of land preparation, and availability and cost of water supplies. Irrigation efficiency may be measured in the field, but such measurements are expensive to make and–as an alternative approach–they are often estimated by making allowances for certain wastes such as ditch seepage, deep percolation, and surface runoff. The diversion requirement is the net consumptive irrigation requirement corrected for conveyance and application losses.

27. Blaney, H. F., and Muckle, D. C.

"Evaporation and Evapotranspiration Investigations in the San Francisco Bay Area," *Transactions of the American Geophysical Union*, Vol. 36, No. 5, 1955, pp. 813–820, illus.

During 1953 and 1954, studies were made to determine probable evaporation and evapotranspiration losses that would occur if barriers were constructed across the San Francisco Bay to exclude salt water. This would create freshwater pools to conserve water for irrigation, domestic, and industrial use. Available measurements of evaporation and consumptive use of water by vegetation were compiled and analyzed. New climatological stations were established in areas not covered by existing stations and measurements made on evaporation, temperature, humidity, wind movement, and precipitation. Evaporation and consumptive use data were correlated with climatological records, and estimates were made of annual and monthly rates of evaporation from lake surfaces and consumptive use by marsh vegetation for the 1921–52 period and for the five critical years, 1923, 1924, 1930, 1931, and 1951.

28. Blaney, H. F., Taylor, C. A., Nickle, H. G., and Young, A. A.

"Water Losses under Natural Conditions from Wet Areas in Southern California," California Department of Public Works, Division of Water Resources, *Bulletin No. 44*, 1933.

This report published by the California Department of Public Works contains a summary and the conclusions obtained from a cooperative study carried on by several agencies in southern California (California Department of Public Works 1933). Young (1933) compared use of water by various species of plants found in moist or wet areas. These were grown in tanks with the water table maintained at 1 ft, 2 ft, or 5 ft below the surface. Taylor and Nickle (1933) reported riparian water losses in Coldwater Canyon near San Bernardino, California. Blaney (1933) reported on the attempt to correlate evaporation data collected from various types of

evaporation pans. Troxell (1933) reported on studies made of the groundwater situation along the Santa Ana River.

29. Bleak, A. T., and Keller, W.

"Water Requirement, Yield, and Tolerance to Clipping of Some Cool-Season, Semiarid Range Grasses," *Crop Science,* Vol. 1, May–June, 1973, pp. 367–370.

A water requirement study was conducted for 689 days with 8 accessions of cool-season *Agropyrons* and a single accession of *Elymus junceus* grown in 3.8-liter cans in a greenhouse. Five plants of *A. desertorum* Nordan were cloned. Other accessions including *A. desertorum* Nordan, were grown from seed. All accessions were subjected to 11 successive harvests. *A. sibiricum* PI-314056 was most efficient in water use and also had the highest yields. Mortality of *A. inerme* was high beginning with the fifth harvest. One-fifth of the plants of *A. desertorum* Nordan and commerical *A. cristatum* were dead or nearly dead by the 11th harvest. Only *E. lunceus* Vinall and *A. sibiricum* PI-314056 had no mortality throughout the 11 harvests. A comparison of clones of Nordan with plants from seed indicated that 62% of the total variance was genetic. Differences in water requirement within the cloned Nordan suggest that it would respond to selection for efficiency of water use. The first harvest was not a good indicator of the mean yield or water requirement for the other 10 harvests.

30. Borrelli, J., Burman, R. D., and Davidson, S. C.

"Evapotranspiration from Heterogeneous Mountain Meadows," *Paper No. 81-2009,* Summer Meeting, American Society of Agricultural Engineers, Orlando, Florida, June 21–24, 1981, 18 pp.

The evapotranspiration rates of irrigated mountain meadow grasses were measured using nonweighing lysimeters during the 1979 and 1980 growing seasons. The lysimeters were located in a line across the Little Laramie River Valley near Laramie, Wyoming. The 1967 version of the Blaney-Criddle method for estimating evapotranspiration was calibrated using the lysimeter data (SCS 1967).

31. Bouwer, H.

"Predicting Reduction in Water Losses from Open Channels by Phreatophyte Control," *Water Resources Research,* Vol. 11, No. 1, February, 1975, pp. 96–101.

A procedure is presented for calculating seepage from a stream due to uptake of groundwater by vegetation or evaporation from soil in the floodplain. The calculation requires that the relation between evapotranspiration rate and water table depth be known. If these relations are available for a given floodplain before and after removal of phreatophytes, the reduction in seepage losses from the stream due to phreatophyte removal can be computed. To simplify the calculation process, the

curves relating evapotranspiration rate and water table depth, which are generally sigmoid, can be approximated by step functions of the same area. Potential water savings by phreatophyte control are calculated for step functions that are representative of deep-rooted vegetation, shallow-rooted vegetation, and bare soil. In addition to the depth from which groundwater can be evaporated before and after phreatophyte removal the water savings are affected by the vertical distance between the water level in the stream and the floodplain.

32. Bowie, J. E., and Kam, W.

"Use of Water by Riparian Vegetation, Cottonwood Wash, Arizona," *U.S. Geological Survey Water Supply Paper 1858*, 1968, 62 pp.

The change in water use as a result of the modification of riparian vegetation was measured in Cottonwood Wash, Mohave County, Arizona. A 4.1-mi length of the stream channel was selected and divided into a 2.6-mi upper reach and a 1.5-mi lower reach. Measurements of streamflow, groundwater levels, vegetation, and meteorological phenomena 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 computed average loss of water from the lower reach before modification was 80 acre-ft per growing season, a quantity which represented about 18% of the average flow entering the reach in the same period. The average loss after modification of the vegetation was 42 acre-ft per growing season, a quantity which represented about 12% of the average flow entering the reach in the same period.

33. Boyle Engineering Corporation

"Salinity Control and Irrigation System Analysis, Colorado River Indian Reservation," Yuma County, Arizona, August, 1976.

This is a report of the consultant's investigations of potential system improvement for accomplishing salinity control on the Colorado River Indian Reservation in Arizona. The evapotranspiration analysis involved the application of unit values derived in previous studies. The integration method was the primary technique for estimating basin-wide evapotranspiration. Nonirrigated vegetation considered in the analysis were saltcedar, arrowweed, and mesquite. The report concludes that rehabilitation of the existing irrigation system would be beneficial in reducing the salinity of the lower Colorado River. Accurate water measurement throughout the irrigation system was recommended together with increased use of irrigation management services and review of operational procedures. (Compiler's Summary)

34. Branson, F. A., Gifford, G. F., Renard, K. G., and Hadley, R. F.

Rangeland Hydrology, Society for Range Management, No. 1, Range Science Series, 2nd edition, Kendall/Hunt Publishing Company, Dubuque, Iowa, 1981.

35. Branson, F. A., Miller, R. F., and McQueen, I. S.

"Moisture Relationship in Twelve Northern Desert Shrub Communities near Grand Junction, Colorado," *Ecology*, Vol. 57, 1976, pp. 1104–1124.

Twelve northern desert shrub communities having the same macroclimate but differing habitats were studied. Arranged in order of decreasing production of live stems plus current growth, the communities were: (1) *Sarcobatus vermiculatus* (9,172 kilograms per hectare (kg/ha)); (2) *Grayia spinosa* (7,412 kg/ha); (3) *Artemisia tridentata* (5,474 kg/ha); (4) *Chrysothamnus nauseosus* (4,836 kg/ha); (5) *Atriplex confertifolia* (3,194 kg/ha); (6) *Eurotia lanata* (2,026 kg/ha); (7) *Hilaria jamesii-Atriplex confertifolia* (1,995 kg/ha); (8) *Atriplex corrugata* (1,949 kg/ha); (9) *Chrysothamnus greenii filifolius* (1,866 kg/ha); (10) *Atriplex nuttallii* (1,309 kg/ha); (11) *Elymus salinus* (865 kg/ha); and (12) *Tetradymia spinosa* (564 kg/ha).

The communities were relatively simple in terms of plant composition; the dominants in many of them contribute greater than 90% of the plant cover. Seasonal patterns of both internal-plant stresses and soil-moisture stresses were measured. Both sets of values increased from late May until early September when increases in rainfall caused both to decrease. Minimum internal-plant stresses were similar for all species but maximum values differed greatly. Maximum plant stress value ranged from 103 bars for *A. nuttallii* to only 40 bars for *C. nauseosus*. Internal-plant stresses were closely related to minimum soil-moisture stresses found within soil profiles at the time of sampling. The relationship was good for upland species but poor for species in moist habitats. Similar close relationships were found for internal-plant stress and quantities of moisture stored in soils. Correlation coefficients for internal-plant stress vs. wind and atmospheric stress were low and nonsignificant, but air temperature was significantly correlated with plant stress in several species. Evapotranspiration from the 12 communities ranged from 60 mm for the *C. greenii filifolius* habitat to greater than 130 mm for the *G. spinosa* habitat.

Evapotranspiration was significantly related to percent live cover (r = +.84 in.). Soil salinity at field-capacity values ranged from greater than 16 bars to less than 1 bar; only 5 of the 12 habitats had saline soils. The highest root mass (2,547 kg/ha) was in the *C. nauseosus nauseosus* soil–the lowest (569 kg/ha) in the *A. corrugata* soil. Efficiency of water use (plant growth per unit of water used) was lower for species occupying dry habitats than for those in moist habitats. Phenological observations showed that most species occupying moist habitats continued active growth for longer periods. A study of persistence of leaves showed 10% annual loss of leaves in *A. corrugata*. Ninety percent (90%) of leaves of this species were retained throughout the season whereas less than 20% of marked leaves were retained by *A. tridentata* and *A. nuttallii*.

36. Branson, F. A., Miller, R. F., and McQueen, I. S.

"Plant Communities and Associated Soil and Water Factors on Shale-Derived Soils in Northeastern Montana," *Ecology*, Vol. 51, 1970, pp. 391–407.

Sites on different strata of Bearpaw shale and on alluvium derived from the shale in a small basin in northeastern Montana supported strikingly different plant communities, including three Nuttall saltbush, three big sagebrush, two greasewood, one western wheatgrass, one blue gramma, one silver sagebrush, one foxtail, one buckwheat, and a community of mixed shrubs. Several soil factors were measured, but only total soil-moisture stress and soil-moisture volume gave rational ordinations of the communities studied. Total soil-moisture stress at the average root depth ranged from a high of 96 bars for a Nuttall saltbush community to only 19 bars for a mixed shrub community. The Nuttall saltbush community was found on soils having a high soluble salt content, high soluble sodium percentages, high total soil-moisture stress, and low infiltration rates. Soils at the big sagebrush site had low soluble salt content, relatively high soluble sodium, and intermediate total soil-moisture stress values. The wettest site, subject to spring flooding, was occupied by western wheatgrass. Quantities of water evapotranspired from each habitat (calculated as maximum soil moisture minus minimum plus increments added to soils by summer storms) when related to precipitation provided approximations of runoff from, or run-in moisture for, each habitat.

37. Brooks, K. N., and Thorud, D. B.

"Antitranspirant Effects on the Transpiration and Physiology of Tamarisk," *Water Resources Research*, Vol. 7, No. 3, 1971, pp. 499–510.

Five-stamen tamarisk, an important phreatophyte in the southwestern United States is difficult to eradicate for water salvage. There also is increasing opposition to its eradication because this species provides cover for wildlife and greenery in the environment. The application of nontoxic-antitranspirant sprays to reduce tamarisk transpiration may be an alternative to eradication. We tested several antitranspirants, including a combination of the monomethyl and monoglyceryl esters of n-decenylsuccinic acid (MDSA-GDSA), 8-hydroxyquinoline sulfate (8-HQS), and phenylmercuric acetate (PMA), on tamarisk in greenhouse and field environments. PMA was toxic at a concentration of 0.001 M and was therefore not considered in the evaluation described below. The effects of MDSA-GDSA and 8-HQS on transpiration, growth, net photosynthesis, dark respiration, relative stomatal apertures, chlorophyll and protein contents, and foliage temperature were evaluated. Transpiration rates of plants treated with MDSA-GDSA and 8-HQS were 25–35% less than those of control plants for 20 days in the greenhouse and for at least 5 days in the field. Growth was reduced for 2–3 weeks and net photosynthesis for less than

1 week. The other physiological factors were not changed substantially. Foliage temperatures increased 2–3° C for 3 days following treatment in the field. Further study for possible management application is suggested.

38. Brown, H. E., and Thompson, J. R.

"Summer Water Use by Aspen, Spruce, and Grassland," *Journal of Forestry*, Vol. 63, 1965, pp. 756–760.

Soil moisture was measured in spring and fall of 1955, 1957, and 1958 to determine relative amounts of water use on sites occupied by quaking aspen, Engelmann spruce, and mountain grassland during the summer growing season. Study plots were located on sites where the soil was deep enough to permit gravimetric sampling to a depth of 8 ft. Water use was considered as the difference between soil moisture in the spring and fall, adjusted for summer precipitation. Aspen plots averaged 19.2 in., spruce 14.9 in., and grassland 8.9 in. of water use yearly for the 3 years of record. Because the amount of spring soil moisture was significantly different among types, however, and because spring moisture was correlated with water use in aspen and spruce types, it was impossible to attribute differences in water use solely to the type of vegetation.

39. Buckhouse, J. C., and Coltharp, G. B.

"Soil Moisture Response to Several Levels of Foliage Removal on Two Utah Ranges," *Journal of Range Management*, Vol. 29, No. 4, 1976, pp. 313–315.

Range plant clipping studies were conducted at two elevations on Utah's Wasatch Plateau during 1966 and 1967. It was found that extreme clipping treatments (complete denudation) resulted in significantly less soil moisture withdrawal than the unclipped controls at the mid-elevation location. No significant differences were found among clipping treatments at the subalpine location, however.

40. Bureau of Reclamation

Evapotranspirometer Studies of Saltcedar near Bernardo, New Mexico, Albuquerque Development Office, Albuquerque, N. Mex., 1973 (1975 and 1979 update), 50 pp.

This report presents data obtained from 1962 through 1968 on consumptive use of water by saltcedar and evaporation from bare ground. Nine evapotranspirometers, sometimes referred to in this report as tanks, 12-ft deep, each having a surface area of 1,000 ft^2, were constructed of 1/16-in. butyl rubber. Three of these tanks were left bare to measure water loss by evaporation from bare ground; the other six tanks were planted to saltcedar.

The saltcedar consumptive use data indicate the following: (1) the rate of water use by saltcedar is not necessarily dependent on the depth to the water table; (2) consumptive use of water decreases as the plants mature; in this study, consumptive use when related to density became stabilized after about 3 years of growth; (3) there is a straight-line 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; and (5) consumptive use data for saltcedar in the Bernardo area are not similar to data obtained in other areas.

41. Bureau of Reclamation

Final Environmental Statement, Pecos River Basin Water Salvage Project, New Mexico-Texas, Southwest Regional Office, Amarillo, Tex., 1979.

The authorized Pecos River Basin Water Salvage Project will involve management of phreatophytes in the flood plain of the Pecos River and consists of the continuing maintenance control of saltcedar regrowth on 47,200 acres of previously cleared lands between Lake Sumner, New Mexico, and Pecos, Texas. Project purposes are to (1) prevent further decreases in the supply of water in the Pecos River Basin; (2) enhance the water supply for municipal, industrial, irrigation, and recreational uses; (3) provide protection for the farmlands in the basin from the hazards of floods; and (4) provide for the conservation of fish and wildlife. The program would reduce the consumptive use of water in the basin by saltcedar and other phreatophytes.

Through control of saltcedar regrowth, the project would reduce nonbeneficial consumptive use of water in the basin by saltcedar and conserve about 47,000 to 70,000 acre-ft of water annually. The program would aid in maintaining the present level of farming and agribusiness. Areas under maintenance would be subject to invasion of more desirable plant species of grasses, forbs, and shrubs. A mixed woody-open habitat will be maintained, thus continuing a diversity of habitat and a diversity of wildlife. Some wildlife habitat would be disturbed with minor losses expected to ground nesting or dwelling species. The maintenance activity will result in a short-term degradation of the esthetic environment during the presence of machinery. No significant changes in turbidities or sediment deposition rates would occur. Livestock grazing of existing cleared lands would be enhanced.

42. Bureau of Reclamation

“Lower Colorado River Water Salvage Phreatophyte Control, Arizona–California–Nevada,” *Reconnaissance Report*, Region 3, Boulder City, Nev., 1963.

Phreatophytes occupy large areas on the flood plains of the Lower Colorado River. The basic problems are the eradication of this nonbeneficial water-consuming vegetative growth, and the salvage of this water for beneficial use in the Lower Colorado River Basin.

This report presents an inventory of the extent of phreatophyte growth on the Lower Colorado River flood plain. Data obtained from this inventory, and from past studies and records, were used to estimate the nonbeneficial consumptive use of the existing phreatophytes and the potential water salvage that could be economically obtained by plant eradication and control. No specific locations were selected for the application of the salvaged water; neither was the effect of substituting beneficial vegetation evaluated.

Eradication and control of phreatophytes on the flood plain of the Lower Colorado River has economic justification. Continuing studies are warranted by the increasing water demands of an ever-growing population in the Southwestern States, and the annually decreasing water supply in the Colorado River as development continues in the Upper Colorado River Basin. This combination of increasing water demand and decreasing water supply is of great concern to the arid Southwest, and emphasizes the urgent need for water conservation measures, of which eradication of phreatophytes is only of many. (Compiler's Summary)

43. Bureau of Reclamation

"Prediction of Mineral Quality of Irrigation Return Flow, Vol. II. Vernal Field Study," *Environmental Protection Technology Series, EPA-600/2-77-179b*, U.S. Environmental
Protection Agency. Robert S. Kerr Environmental Research Laboratory, Ada, Okla., 1977.

This volume of the report details the field investigations conducted to develop and validate the "Simulation Model of Conjunctive Use and Water Quality for a River System or Basin" as given in Volume III of this report. The studies were conducted in Ashley Valley, near Vernal, Utah. The investigations included: the quantity and quality of ground water, irrigation water, and return flows; crop inventory and consumptive use; soil chemistry; and hydrological units to define nodes.

This report was submitted in fulfillment of *EPA-IAG-D4-0371* by the Bureau of Reclamation Engineering and Research Center, under the sponsorship of the Environmental Protection Agency.

44. Burman, R. D.

"Estimation of Mountain Meadow Water Requirements," *Symposium Proceedings, RJ141*, *Management of Intermountain Meadow*, June 1979, University of Wyoming Agricultural Experiment Station, Laramie, Wyoming, 1979, pp. 5–11.

Interest in estimating mountain meadow water requirements has accelerated greatly in the past few years because of competition for the water used in mountain meadow irrigation. More details on the water right transfers are presented at this symposium by Siemer and Burman. Mountain meadows represent a significant amount of the irrigated area in the United States. Lewis (1957) estimates that there are 5,540,000 hectares (ha) of mountain meadows in the 11 western states. This figure is about 12% of the total irrigated land in the United States. For the purposes of this paper, mountain meadows are defined as high altitude irrigated grasslands usually ranging from 1500 m to 3000 m in elevation above sea level. The grasses in these meadows are usually native and their composition depends upon long-term moisture and other management conditions (Siemer and Rumburg 1975). Rushes and sedges tend to dominate in very wet sites, and timothy, blue grasses, and other grasses appear in drier sites. Often weeds are significant. Irrigation water is applied in early spring as soon as spring snowmelt runoff occurs. Irrigation is often on a continuous basis until streamflow becomes low or water is withheld to dry up fields for hay harvest. Most mountain meadows have a rough surface topography. This is particularly true where the irrigated land contains numerous former oxbows of stream beds. In many respects the only consistent thing about mountain meadows is their inconsistency. (From Introduction)

45. Burman, R. D., and Pochop, L. O.; M. ASCE

“Maximum and Actual ET from Grasses and Grass-like Plants,” *Proceedings of Water Forum 86*, American Society of Civil Engineers Specialty Conference, Long Beach, CA, Aug. 4–6, 1986, pp. 831–838.

Two studies of mountain meadow water use were conducted along the Little Laramie River and in the Upper Green River Basin of Wyoming. Monthly and seasonal data from twelve non-weighing lysimeters are reported for 2- to 4-year periods. Water tables in the lysimeters were maintained at levels similar to the surrounding areas. During the latter portion of the growing season, water supplies often become limited and irrigation is infrequent or completely discontinued. Results show the variation in water use, from a relatively high rate in years when water supplies (thus, river flows) are high to low in years when water supplies are low and water tables are deep. A calibration of the Penman-Monteith model for the estimation of ET is given.

46. Burman, R. D., Rechard, P. A., and Munari, A. C.

“Evapotranspiration Estimates for Water Right Transfers,” *Proceedings, American Society of Civil Engineers Irrigation and Drainage Specialty Conference*, Irrigation and Drainage in an Age of Competition for Resources, Logan, Utah, 1975, pp. 173–195.

There is a large demand for water right transfers from wet meadows to urban, recreational, and industrial uses. Current practice is to allow the transfer of seasonal evapotranspiration less the effective rainfall. This study compared the various methods of estimating evapotranspiration with lysimeter measurements and streamflow depletion studies. Eighteen methods of computing evapotranspiration were compared at four locations. The Kohler, Nordenson, and Fox method of estimating lake evapotranspiration ranked highest and appeared to be a very desirable method of estimating evapotranspiration of mountain meadows. For monthly calculations, the Blaney-Criddle method with coefficients calibrated for mountain meadow conditions appeared to yield satisfactory estimates.

47. Busby, F. E., Jr., and Schuster, J. L.

"Wood Phreatophyte Infestation of the Middle Brazos River Flood Plain," *Journal of Range Management*, Vol. 23, 1971, pp. 285–287.

Sixty-four percent (64%) of the Brazos River flood plain upstream from Possum Kingdom Lake to the confluence of its Salt and Double Mountain forks is occupied by woody phreatophytes. Saltcedar dominated communities are found on 36% and mesquite on 17%. Saltcedar acreage increased significantly from 1940 to 1969, but mesquite did not. At 1969 densities, these two species used approximately 51,000 acre-ft of water annually along this expanse of the river.

48. Busby, F. E., Jr., and Schuster, J. L.

"Woody Phreatophytes Along the Brazos River and Selected Tributaries above Possum Kingdom Lake," *Report 168*, Texas Water Development Board, 1973, 41 pp.

The purpose of this study was to inventory the woody phreatophyte vegetation along the mainstream Brazos River upstream from Possum Kingdom Lake. The kinds, amounts, distribution, history of spread, and volume densities of the woody phreatophytes were studied along with their relation to flood plain location. Preliminary estimates were made of the water usage of the most extensive plant communities. This study was carried out by Texas Tech University under interagency contract with the Texas Water Development Board. (From Introduction)

49. Cable, D. R.

"Seasonal Use of Soil Water by Mature Velvet Mesquite," *Journal of Range Management*, Vol. 30, No. 1, January, 1977, pp. 4–11.

Mesquites used water consistently to a depth of 3 m and outward to 10 m beyond the crowns, but use at 15 m was limited mainly to drier periods when water supplies closer to the trees were depleted. With the start of spring growth, water was extracted more rapidly from the surface layers. As the season advanced, the water supply zone became increasingly thicker. Rates of extraction were highest immediately after recharge in early spring and early summer, and lowest in late fall. Differences in available water in the soil accounted for 72 to 88% of the variation in rates of extraction. The competitive effort of velvet mesquite on perennial grasses is most severe in the upper 37.5 cm of soil under and near the mesquite crowns, and gradually decreases with distance into adjacent openings. The competitive effect in the openings is much more severe in dry years than in wet years.

50. California State Department of Water Resources

"Vegetative Water Use in California, 1974," *Bulletin No. 113-3*, April, 1975 (Reprinted 1977).

As a leading agricultural producer, California consumes more water for irrigating crops than for any other purpose–virtually 85% of its total water use, in fact. This high level of use emphasizes the importance of being able to predict what total quantity of water is needed, as well as when and where it is needed. *Bulletin No. 113-3* is the third in a series of Department of Water Resources publications on the rate of water use by crops.

Based on field studies conducted from 1954 to 1972, the report expands the previously published body of basic vegetative water use data for California. It summarizes growing season evapotranspiration and evapotranspiration of applied water for principal crops grown in major agricultural regions of the State, tabulates evaporation and other climatic indexes and provides the data required to calculate irrigation efficiencies. For the first time in this series of reports, data on applied water are included.

The usefulness of the evapotranspiration measurements for a large number of irrigated crops was broadened by correlating measured values to local evaporation rates and then projecting the ratios derived to other areas of the State where only evaporation data were available.

51. Campbell, C. J.

"Periodic Mowings Suppress Tamarisk Growth, Increase Forage for Browsing," *U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station Research Note RM-76*, 1966, 4 pp., illus.

Tamarisk (*Tamarix pentandra* Pall.) was clipped (completely defoliated) and moved at 2-, 4-, 8-, and 24-week intervals throughout the growing season. Plant mortality increased with frequency of clipping. Plants were not killed by the one season of mowing, but dry foliage yields were similar to yields produced by clipping treatments. In central Arizona, mowings in May, July, and September are necessary to keep foliage succulent and within reach of browsing cattle. Evapotranspiration (determined by the evapotranspiration-tent method) decreased approximately 50% following mowing treatments.

52. Campbell, G. S., and Harris, G. A.

"Water Relations and Water Use Patterns for *Artemisia tridentata* Nutt. in Wet and Dry Years," *Ecology*, Vol. 58, 1977, pp. 652–659.

Plant H_2O relations and soil moisture depletion and recharge were followed in a stand of *Artemisia tridentata* near Washtucna, Washington, during 1973 and 1974. Precipitation during the 1972–73 recharge season was 14.5 cm, 11 cm below normal. The 1973–74 precipitation was 35.7 cm, or 10 cm above normal. The two years were therefore ideal for comparing plant behavior on wet vs. dry years.

Soil moisture was depleted to around –70 bars in 1973 and –60 bars in 1974 to depths of 2.5 m. Leaf H_2O potentials were –10 bars in the spring and decreased to –50 to –60 bars in the summer of 1973. In 1974, summer leaf H_2O potential was –30 bars. Osmotic potentials were around –20 bars in the spring of 1973 and throughout the spring and summer of 1974. In the summer of 1973 osmotic potentials dropped to –60 bars. Stomatal diffusive conductances of 0.5 cm/s (resistance of 2 s/cm) were common during the spring and summer of 1974 and the spring of 1973. Summer conductances in 1973 were .05 cm/s (resistance of 20 s/cm).

A simple model is proposed which predicts evaporation and transpiration from daily precipitation and potential evapotranspiration. Model parameters include soil hydraulic properties and maximum transpiration rate as a function of available soil moisture. The agreement between model prediction and measured values is within the uncertainties imposed by the input data. The model predicts 6.5 and 8.2 cm of evaporation for 1973 and 1974, respectively. In 1973 this was half of the total precipitation received. In 1974 it was only one fourth of the total.

53. Carman, R. L.

"Field Measurement of Evapotranspiration in Areas of Phreatophytes in Northern Nevada," *U.S. Geological Survey*, Carson City, Nev., 1986.

Evapotranspiration from bare soils and evapotranspiration (ET) from areas of phreatophytic vegetation are major sources of natural groundwater loss in the Great Basin region of Nevada and Utah. Many methods have been developed to try to quantify the amount of water used by phreatophytes and lost from bare soils. This study investigates several such methods, in particular the eddy correlation method, based on aerodynamics and turbulent transport, the Bowen ratio method, based on the energy balance, both of which measure actual ET under natural conditions, and the Penman method, a combination method, which measures potential ET.

Two sites were chosen for study, one in Smith Creek Valley near Austin, Nevada, and the other north of Soda Lake in the Carson Desert near Fallon, Nevada.

Phreatophytes at the Smith Creek Valley site consisted mainly of rabbitbrush. Estimated total evapotranspiration for the 1983 active growing period was 1.06 ft/year, compared to a calculated potential ET at the site of 6.57 ft/year. Phreatophytes at the Soda Lake site consisted predominantly of greasewood. Estimated total evapotranspiration for the 1983 active growing period was 0.94 ft/year compared to a calculated potential ET at the site of 5.84 ft/yr.

Statistical analysis of data collected indicated that the highest correlations occurred consistently between ET and solar radiation, suggesting the possibility of estimating ET from solar radiation data. The methods used, particularly the eddy correlation method, have proven to be viable means of measuring ET under natural conditions with a minimum number of measured parameters. They have proven to be highly sensitive, mobile, and versatile systems, and more research is warranted to develop their full potential.

54. Chalk, D. E.

"Predicting Impacts of a Proposed Irrigation Water Conservation Project on Wildlife Habitat," p. 305–309, in "The Mitigation Symposium: A National Workshop on Mitigating Losses of Fish and Wildlife Habitats," Fort Collins, Colorado, July 16–20, 1979, *General Technical Report RM-65*, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo., 1979.

Irrigation improvements on 84% of the treatable land in the Uintah Basin, Utah, could reduce water available to phreatophytes by 40%, resulting in the conversion of 19,800 acres of wetlands to upland habitat. Twenty-three percent (23%) of the water presently diverted for irrigation is consumed by phreatophytes. A 10.3-mg/l decrease in salinity will occur.

55. Chow, V. T. (Ed.)

Handbook of Applied Hydrology, McGraw-Hill, New York, p. 6–21, 6–22, and p. 24–8 through 24–21, 1964.

56. Christiansen, J. E., and Low, J. B.

"Water Requirements of Waterfowl Marshlands in Northern Utah," *Publication No. 69-12*, Utah Division of Fish and Game, Salt Lake City, Utah, 1970.

The use of water by the marshlands of northern Utah, as indicated by calculation of evapotranspiration from inflow-outflow data, varies from about 4 in. to 9 in. in June, decreasing to 3 in. in October for a 7-month total of about 41 in. These determinations were correlated with climatic data to determine the monthly coefficient K according to the Blaney-Criddle formula which was used to estimate consumptive use. Values of K for the Blaney-Criddle formula varied from 0.90 for

April to 1.20 for June, decreasing to 0.60 for October. For other formulas used to calculate radiation, pan evaporation, and additional climatic factors, varying monthly coefficients were found, including 0.98 for April, 1.15 for June, and 0.87 for October.

Conductance measurements at all waterfowl refuges near Great Salt Lake indicated that the water available varied in quality from excellent to poor (conductance values about 6 micro-mhos (mmhos)). Salt tolerance studies of important marsh plants showed that germination, growth, and seed and tuber production decreased as salinity increased; substantial reductions in growth were observed at substrate levels exceeding 12 mmhos. Fresh water produced the best growth in all plants with the exception of the sago pondweed tubers, which showed greatest growth in slightly saline conditions (3,000 parts per million (ppm)).

Relationships were developed for estimating monthly water requirements based on considerations of evapotranspiration, quality of water, and precipitation. From the relationship developed, water requirements can be estimated for marshlands under different climatic conditions. Suggestions given for water management practices on the marshlands include recommendations on both quality and quantity of water, and suggestions as to drainage, desirable water levels, and desirable plants for efficient marshland operation.

57. Cline, J. F., Uresk, D. W., and Rickard, W. H.

"Comparison of Soil Water Used by a Sagebrush-Bunchgrass and a Cheatgrass Community," *Journal of Range Management*, Vol. 30, No. 3, 1977, pp. 199–201.

Two contrasting plant communities occur on the Arid Lands Ecology (ALE) Reserve in south-central Washington, one dominated by a mixture of sagebrush and bluebunch wheatgrass and the other by a nearly pure stand of cheatgrass. At the beginning of the spring growing season in 1974, a year of above-average precipitation, both communities had about the same amount of soil water stored in the first 18 cm of the soil profile. During the growing season, the quantity of soil water used by the sagebrush-bunchgrass and cheatgrass communities was 15 and 8 cm, respectively. The difference in soil water used by the two communities is attributed to a deeper root system and a longer growing period by plants of the sagebrush-bunchgrass community.

58. Cline, R. G., Haupt, H. F., and Campbell, G. S.

"Potential Water Yield Response Following Clearcut Harvesting on North and South Slopes in Northern Idaho," *U.S. Department of Agriculture, Forest Service Research Paper INT-191*, Intermountain Forest and Range Experiment Station, Ogden, Utah, June, 1977.

The hydrologic response of small clearcuts on north and south slopes in northern Idaho was investigated. On the north slope, substantial gains (27 to 35 cm) in potential water yield per year resulted from (a) removal of transpiring surfaces associated with plant cover, (b) elimination of snow interception by a closed-canopied forest, and (c) gradual reoccupation of the soil mantle by invading herbaceous species. On the south slope, small to moderate gains (4 to 11 cm) in yield resulted from clearcutting, at least in 1973, the year studied. In earlier years, the gains probably would have been negligible. Site factors that compensated for clearcutting kept gains in yield small to moderate on the south slope. Initial forest losses from interception were light because of the open-canopied structure of the timber and windiness at treetop level. In the clearcut, water gains from reduced transpiration were more than used up within four years by invading shrub species. The south slope clearcut was subjected to other sources of water loss also. (Research Summary)

59. Cohen, P., and others

"Water Resources of the Humboldt River Valley near Winnemucca, Nevada," *U.S. Geological Survey Water-Supply Paper 1795*, U.S. Government Printing Office, Washington D.C., 1965.

This report, resulting from studies made by the U.S. Geological Survey as part of the interagency Humboldt River Research Project, describes the qualitative and quantitative relations among the components of the hydrologic system in the Winnemucca Reach of the Humboldt River valley. The area studied includes the segment of the Humboldt River valley between the Camus and Rose Creek gaging stations. It is almost entirely in Humboldt County in north-central Nevada, and is about 200 mi downstream from the headwaters of the Humboldt River.

Agriculture is the major economic activity in the area. Inasmuch as the valley lowlands receive an average of about 8 in. of precipitation per year and because the rate of evaporation from free-water surfaces is about six times the average annual precipitation, all crops in the area (largely forage crops) are irrigated. About 85% of the cultivated land is irrigated with Humboldt River water; the remainder is irrigated from about 20 irrigation wells.

The consolidated rocks of the uplifted fault-block mountains are largely barriers to the movement of groundwater and form groundwater and surface-water divides. Unconsolidated deposits of late Tertiary and Quaternary age underlie the valley lowlands to a maximum depth of about 5,000 ft. These deposits are in hydraulic continuity with the Humboldt River and store and transmit most of the economically recoverable groundwater. Included in the valley fill is a highly permeable sand and gravel deposit having a maximum thickness of about 90–100 ft; it underlies the flood plain and bordering terraces throughout most of the project area. This deposit is almost completely saturated and contains about 500,000 acre-ft of groundwater in storage.

The Humboldt River is the source of 90–95% of the surface-water inflow to the area. In water years 1949–62 the average annual streamflow at the Comus gaging station at the upstream margin of the area was 172,100 acre-ft; outflow at the Rose Creek gaging station averaged about 155,400 acre-ft. Accordingly, the measured loss of Humboldt River streamflow average nearly 17,000 acre-ft per year. Most of this water was transpired by phreatophytes and crops, evaporated from free-water surfaces, and evaporated from bare soil.

Inasmuch as practically no tributary streamflow normally discharges into the river in the Winnemucca reach and because pumpage is virtually negligible during the nonirrigation season, gains and losses of streamflow during most of the year reflect the close interrelation of the Humboldt River and the groundwater reservoir. An estimated average of about 14,000 acre-ft per year of groundwater underflow moves toward the Humboldt River from tributary areas. Much of this water discharges into the Humboldt River; however, some evaporates or is transpired before reaching the river.

More than 65% of the average annual flow of the river normally occurs in April, May, and June owing to the spring runoff. The stage of the river generally rises rapidly during these months causing water to move from the river to the groundwater reservoir. Furthermore, the period of high streamflow normally coincides with the irrigation season, and much of the excess irrigation water diverted from the river percolates downward to the zone of saturation.

The net measured loss of streamflow in April–June, which averaged about 24,000 acre-ft in water years 1949–62, was about 7,000 acre-ft more than the average annual loss. The estimated net average annual increase of groundwater in storage during these months in this period was on the order of 10,000 acre-ft. Following the spring runoff and the irrigation season, normally in July, some of the groundwater stored in the flood-plain deposits during the spring runoff begins to discharge to the river. In addition, groundwater inflow from tributary areas again begins to discharge into the river.

Experiments utilizing a neutron-scattering soil-moisture meter suggest that considerable water is stored in the zone of aeration in the shallow flood-plain deposits during the spring runoff. Most of this water eventually evaporates or is transpired by phreatophytes. Preliminary results of evapotranspiration experiments indicate that, of the plants studied, willow uses the most water, about 4 acre-ft per acre per year.

Sodium and bicarbonate commonly are the most abundant ions in the surface water and groundwater of the area. The dissolved solids content of most of the groundwater is less than 600 ppm, although locally it is more than 5,000 ppm. Almost all the water is moderate to very hard; otherwise, it is suitable for most uses.

In December 1961, nearly all the water in the Humboldt River between the Comus and Rose Creek gaging stations was seepage from the groundwater reservoir. The chemical quality of the river largely reflected the chemical quality of groundwater underflow from tributary areas.

An estimated average of 95,000 to 120,000 acre-ft per year of the total inflow to the lowlands of the area studied, including streamflow, groundwater inflow, and precipitation, was lost by evapotranspiration in water years 1949–62. Increased irrigation efficiency and the conjunctive use of groundwater and surface water would conserve such of this water. Intensive groundwater development, especially from the sand and gravel aquifer beneath the flood plain, however, will partly deplete the flow of the Humboldt River and may infringe upon downstream surface-water rights.

60. Collings, M. R., and Myrick, R. M.

"Effects of Juniper and Pinyon Eradication on Streamflow from Corduroy Creek Basin, Arizona," *U.S. Geological Survey Professional Paper 491-B*, 1966, 12 pp.

An investigation to determine the effect of juniper and pinyon removal and of controlled burning on runoff was made on the adjacent Carrizo Creek and Corduroy Creek basins, Fort Apache Indian Reservation, Arizona. The watersheds encompass areas of 237 and 213 square miles (mi^2), respectively. The study was begun in 1957 with five years of streamflow records already existing. Thirty-eight percent (38%) of Corduroy basin was modified; Carrizo basin was left undisturbed. There were seven years of premodification data (1952–1958) and five years of postmodification data (1959–1963). Comparisons were made on the runoff relations from adjacent basins and precipitation-runoff relations over each basin for water-year periods, summer storm periods, and winter storm periods. No statistically significant difference in runoff relations could be detected; however, a significant difference between precipitation-runoff relations was indicated for the winter storm period on both the modified basin and the control basin. A test of precipitation relations of the control versus the treated basin for the before- and after-modification periods indicated no detectable difference in precipitation between basins. A test of precipitation for the period before versus the period after modifications over each basin showed a statistically significant change in both basins; therefore, the change in the precipitation-runoff relations for the before- and after-modification periods was concluded to be the effect of a climatic change. The statistically significant change in the precipitation–runoff relations for the control basin was no different than would be expected by chance than the change in the precipitation-runoff relation for the modified basin. If a change does exist because of vegetation modification, the change is masked by the variance of the data.

Prior to this study the theory had been advanced that if undesirable species of vegetation were eradicated from a basin, such as the one studied in this investigation, runoff would be increased and measurable and additional discrete quantities of water would be made available for appropriation. From the results of this study, however, it cannot be demonstrated that the partial clearing of Corduroy Creek basin resulted in either an increase or a decrease in water yield.

61. Cooley, K. R., and Idso, S. B.

"A Comparison of Energy Balance Method's for Estimating Atmospheric Thermal Radiation," *Water Resources Research*, Vol. 7, No. 1, February, 1971, pp. 3945.

A radiation balance method and a modified radiation balance method were used to determine hourly and daily values of atmospheric thermal radiation on three clear and three cloudy days during February and March 1970 at Phoenix, Arizona. The radiation balance was used over surfaces of bare soil, Bermuda grass, and open water; whereas the modified radiation balance was used over the open water surface only. The modified radiation balance differed from the pure radiation balance method in that net radiation was calculated as the residual in the energy equation rather than measured.

The values of atmospheric thermal radiation thus obtained were compared to values obtained from measurements of incoming, all-wave radiation minus incoming solar radiation. From this analysis it appeared that the best alternative to the semi-direct measurement of atmospheric thermal radiation was the radiation balance over the bare soil surface. Results from this method were of sufficient accuracy, even on an hourly basis, for most research studies, and were even better on a daily basis. Radiation balances over grass and water surfaces were somewhat less satisfactory, but still better than the modification radiation balance method.

62. Cooley, K. R., Wight, J. R., and Robertson, D. C.

"Modeling Soil Water and Evapotranspiration on Rangelands," in DeCoursey, D. G. (ed.), *Proceedings of the Natural Resources Modeling Symposium*, Pingree Park, Colorado, Oct. 16–21, 1983, U.S. Department of Agriculture, Agricultural Research Service, April, 1985, pp. 270–273.

The soil profile plays a critical role in the water regime of semiarid rangelands. As much as 96% of the incoming precipitation on these rangelands may be returned to the atmosphere as ET after temporary storage in the soil profile (Branson et al. 1976). Available soil water seldom exists for more than a few months each year in the lower precipitation areas because plant transpiration and soil evaporation extract it so rapidly. Efforts to modify vegetation or water yield must be based on an understanding of the day-to-day variations in soil water status, evaporation, and transpiration to assure success. Mathematical models provide one means of assessing the many interactive parameters involved. This report summarizes some attempts to model soil water and evapotranspiration on semiarid rangelands in southwest Idaho. (Author Introduction.)

63. Corps of Engineers

"Gila River Channel improvements between Camelsback Reservoir Site and Salt River, Arizona (Upper End of Safford Valley between the Brown Canal Heading and the San Carlos Indian Reservation, Graham County, Arizona)," *EIS-AZ-73-0415-F*, Army Engineer District, Los Angeles, Calif., March, 1973.

This is the final environmental statement describing clearing work done along 54 mi of the Gila River. Work consisted of removing phreatophytes (mostly saltcedar) from 3050 acres. The environmental impacts are as follows: Developed areas in Safford Valley would be protected against floods up to 16,000 cfs and damages from larger floods would be reduced. Water previously lost by transpiration of phreatophytes would be salvaged. Loss of natural vegetation would reduce wildlife habitat. Alternatives ranged from no action to clearing various widths and configurations.

64. Cox, E. R., and Havens, J. S.

"An Appraisal of Potential Water Salvage in the McMillan Delta Area, Eddy County, New Mexico," *U.S. Geological Survey Water Supply Paper 2029-E*, 1974.

The Lake McMillan delta area is located between Artesia and Lake McMillan on the Pecos River in Eddy County, New Mexico. Alluvium, which is more than 200 ft thick in places, is the principal water-bearing formation and is part of the "shallow aquifer" of the Roswell basin.

Recharge to the shallow aquifer is by infiltration from the Pecos River, by irrigation water, by precipitation, and by groundwater that moves into the area. Discharge from the shallow aquifer is by wells, by transpiration from phreatophytes, and by evaporation from swampy areas.

Saltcedar growth in the area increased during the study period from about 13,700 acres in 1952 to about 17,100 acres in 1960, a 25% increase. Most of this increase was in the areal-density range of zero to 30%. The estimated average transpiration of phreatophytes in the Artesia to Lake McMillan reach is about 29,000 acre-ft of water per year from groundwater sources.

In the reach from Artesia to the Rio Penasco, where the regional water table is above the Pecos River, saltcedar eradication might salvage from 10,000 to 20,000 acre-ft of water per year for use downstream. From the Rio Penasco to Lake McMillan the river is parched above the water table; therefore, elimination of the saltcedar probably would not increase flow in the river, nor would drains be effective. Clearing in this reach, however, might increase the flow at Major Johnson Springs below Lake McMillan. Floodways through this reach would eliminate some evapotranspiration but might increase the amount of sediment deposited by floodwaters in Lake McMillan.

65. Criddle, W. D. (Chairman)

Stock Water Facilities Guide, Stock Pond Task Force, Hydrology Subcommittee, Pacific Southwest Inter-Agency Committee, 1962.

This report gives suggestions on the water requirements for stock water facilities and the intensity and maximum desirable spacing of the developments under various conditions of climate and topography in the Pacific Southwest. Hydrology and engineering design criteria for stock ponds and alternate methods of supplying the water needs are discussed. Finally, a brief section on water law and legal requirements of the various states located in the Pacific Southwest area is included. (Compiler's Summary)

66. Criddle, W. D., Bagley, J. M., Higginson, R. K., and Hendricks, D. W.

"Consumptive Use of Water by Native Vegetation and Irrigated Crops in the Virgin River Area of Utah," *Information Bulletin No. 14*, Logan, Utah, September, 1964.

In the summer of 1955, field work was initiated on a research project entitled, "Consumptive Use and Water Requirements of Crops and Natural Vegetation in the Virgin River Area of Utah." This study, conducted under cooperative agreement, was sponsored jointly by the Agricultural Research Service, USDA, the Utah Agricultural Experiment Station, the Utah State Engineer, and the Utah Water and Power Board. Until April of 1957, Mr. Wayne D. Criddle served as project leader. Mr. Jay M. Bagley was project leader for the remainder of the study until its conclusion in September 1957.

Results of this study were never previously published. However, they were used for part of the material contained in *Special Report No. 13* of the Utah Agricultural Experiment Station entitled "Water Supplies and Their Uses in Iron, Washington, and Kane Counties of Utah," and were used extensively in the presentation of Utah's case before the Special Master of the U.S. Supreme Court in the Lower Colorado River litigation.

The major objectives of the study were (1) to conduct tank and field experiments to determine seasonal consumptive use of water by native vegetation and agricultural crops during the growing season; (2) to determine the extent of land area being used for agriculture as well as that now occupied by water-loving plants, the amounts of water these areas are consuming and possibilities of salvaging uneconomic use; and (3) to study the climatic factors affecting consumptive use and how they correlate.

67. Croft, A. R., and Monninger, L. V.

"Evapotranspiration and Other Water Losses on Some Aspen Forest Types in Relation to Water Available for Stream Flow," *Transactions of the American Geophysical Union*, Vol. 34, No. 4, 1953, pp. 563–574.

This paper reports the effects of altering an aspen forest cover in Utah on evapotranspiration losses, overland flow, erosion, and mantle storage deficits during three successive growing seasons. These data, together with supplemental measures of winter precipitation and estimates of evaporation from snow, provided a basis for estimating amounts of water available for stream flow. Removal of aspen trees, leaving the herbaceous understory and litter undisturbed, reduced evapotranspiration losses and increased the amount of water available for stream flow by about 4 in. without seriously increasing overland flow or soil erosion during summer rains. Removal of the remaining herbaceous cover further reduced evapotranspiration losses and increased the amount of water available to streams by an additional 4 in. but resulted in an undesirable increase in summer rainfall runoff and soil loss.

68. Culler, R. C.

"The Gila River Phreatophyte Project," *Proceedings of the 9th Annual Arizona Watershed Symposium*, Tempe, Ariz., September, 1965, Tucson, Ariz., pp. 33–38.

Objectives of the project were: (1) to evaluate water conservation by phreatophyte control on a flood plain typical of many areas of existing and proposed applications; (2) to describe the hydrologic and ecological variables of the project area for the purpose of transposition of water conservation evaluations to other sites; and (3) to test and develop methods for evaluating hydrologic variables on a large area. The preclearing evaluation of evapotranspiration was to extend through 1966. The project area was then to be cleared and beneficial vegetation planted. Evaluation of evapotranspiration from the altered vegetation was to be continued through 1970. Although the water budget was the basic comparative method for the project, other methods were to be applied and tested. Geographic, hydrologic, geologic, groundwater, and vegetative features of the project were described. (Compiler's Summary)

69. Culler, R. C.

"Water Conservation by Removal of Phreatophytes," *Transactions of the American Geophysical Union*, Vol. 51, No. 10, 1970, pp. 684–689.

The comparative data presented in this report indicated that removal of phreatophytes from the Gila River flood plain in southeastern Arizona produced a significant reduction in evapotranspiration from the area cleared. The evapotranspiration data for bare ground during 1967 represented a temporary condition. Bare ground cannot be considered a permanent condition on the flood plain of a major river. It might be achieved by sterilizing the soil, but this would be undesirable because of the complete unproductivity of the area and because of the erosion potential. The long-term hydrologic effects of phreatophyte removal will depend on the successful establishment of vegetation having a low consumptive use of water. Continued maintenance will undoubtedly be required to resist invasion by such plants as saltcedar. (Author's Summary)

70. Culler, R. C., Hanson, R. L., and Jones, J. E.

"Relation of the Consumptive Use Coefficient to the Description of Vegetation," *Water Resources Research*, Vol. 12, No. 1, February, 1976, pp. 40–46.

Evapotranspiration from three reaches of the Gila River flood plain in Arizona was measured by the water budget during 1963–1971. Initially, the vegetation consisted of saltcedar and mesquite with densities of canopy ranging from 10 to 100%. The phreatophytes were removed from the study reaches in stages during 1967–1971. Perennial grass seed was applied but did not become established, and the postclearing vegetation was primarily annuals. Comparison of the evapotranspiration data from various reaches and comparison of data from before and after clearing required the application of an empirical equation. A consumptive use coefficient related to the description of vegetation was applied to an existing potential evapotranspiration equation based on macroclimatic observations, initially, the vegetation description consisted of plant identification and canopy dimensions obtained by use of black and white aerial photography and ground measurements. In 1967, remote sensing in the form of color infrared aerial photography became available and densitometric interpretation was used to develop a spectral signature as the vegetation descriptor.

71. Culler, R. C., Hanson, R. L., Myrick, R. M., Turner, R., and Kipple, F.

"Evapotranspiration Before and After Clearing Phreatophytes, Gila River Flood Plain, Graham County, Arizona," *U.S. Geological Survey Professional Paper 655-P*, 1982, 67 pp.

The conveyance of groundwater to or from a river channel and down its valley is an important hydraulic function of the alluvium underlying the river's flood plain. In the arid southwestern states, evapotranspiration from a flood plain can result in a significant reduction in the quantity of water conveyed to downstream users. A large part of this evapotranspiration is transpiration from deep-rooted plants, called phreatophytes, which obtain most of their water from the saturated zone and capillary fringe. Phreatophyte control, consisting of the removal of the phreatophytes and substitution of plants having a lower consumptive use and higher economic value, have been proposed for and applied to large areas of flood plain in an attempt to reduce the conveyance losses. The relatively high consumptive use by phreatophytes has been documented by numerous studies, but the actual reduction in evapotranspiration resulting from the application of phreatophyte control on the flood plain of a major river has never been measured.

The U.S. Geological Survey initiated the Gila River Phreatophyte Project in 1962 with the following objectives: (1) develop methods of analyzing the hydrology of a flood plain; (2) determine the evapotranspiration and the change in evapotranspiration resulting from the application of phreatophyte control on a flood plain typical of areas of existing or proposed application; (3) develop methods of extrapolating results to other areas; and (4) evaluate the reliability of the results. The project site consisted of 15 mi or 24 km of the Gila River flood plain in southeastern Arizona, subdivided into four contiguous reaches. The areas of the reaches ranged from 1,400 to 2,300 acres or 570 to 930 ha. In 1962, the vegetation consisted mainly of saltcedar and mesquite of variable heights and densities of cover. Removal of the phreatophytes was done in stages beginning in 1967 and completed in 1971. Postclearing attempts to establish grass were unsuccessful because of heavy grazing and adverse weather conditions, but annual plants did provide temporary cover when shallow soil moisture was available during the growing season.

Evapotranspiration was evaluated for each reach as the residual in a water-budget equation consisting of twelve components measuring all inflow and outflow of water through each reach, for budget periods of two or three weeks, during the study period 1963 through 1971. Evaluations were made for 414 budget periods. Measurement errors in the water budget are important because the accuracy of the evapotranspiration data is dependent on the quantity of water measured as inflow and outflow rather than on the magnitude of the evapotranspiration. The errors in each component and in the total budget were evaluated and the maximum potential evapotranspiration before and after clearing was computed. Acceptance criteria based on measurement errors and potential evapotranspiration were used to establish acceptable maximum and minimum evapotranspiration values and maximum errors in these values. Applying these tests to the water-budget evaluations provided 321 acceptable evapotranspiration values.

The accepted evapotranspiration data were fitted to four previously developed and widely used empirical evapotranspiration equations by use of an optimization program. Optimum fitting was achieved when the average difference between measured (accepted) and computed evapotranspiration for each accepted budget period was minimized. An analysis of variability between measured and computed values indicated a possible error in the annual values computed by empirical equations of 15% before clearing and 25% after clearing.

Annual evapotranspiration on the project averaged 43 in. or 1,090 mm before clearing, and ranged from 56 in. (1,420 mm) for dense stands of phreatophytes to 25 in. (630 mm) on areas of no phreatophytes. The removal of phreatophytes resulted in a reduction in evapotranspiration averaging 19 in. (480 mm) per year and ranged from 14 in. (360 mm). On reach 1 to 26 in. (660 mm) on reach 3 because of the difference in the density of phreatophytes. This reduction is temporary and would not apply after permanent replacement vegetation became established. A flood plain without phreatophytes is in an artificial condition, and the water requirements for maintaining this condition will depend on the land-management practices applied.

A logical replacement of phreatophytes would be a cover of forage grasses. For this reason the consumptive use of water for various grasses was computed with empirical equations using previously published parameters derived for optimum production of grasses under irrigation near Mesa, Arizona. The computations indicated a consumptive use greater than the evapotranspiration from the Gila River flood plain before removing the phreatophytes. Assuming that these grasses could be established, it can be postulated that the consumptive use would be less than under irrigation, production would be less than optimum, and some water would be salvaged. Data to confirm or disprove this postulation must await further studies.

72. Culler, R. C., Jones, J. E., and Turner, R. M.

"Quantitative Relationship between Reflectance and Transpiration of Phreatophytes–Gila River Test Site," *Fourth Annual Earth Resources Program Review*, National Aeronautics and Space Administration, Vol. 3, Section 83, 1972, pp. 1–9.

The dynamic characteristics of evapotranspiration require frequent and spatially complete observations of surface conditions to provide the data for quantitative estimates. The analysis described in this paper indicated that remote sensing could be used for this purpose. The accuracy of the estimates could be improved by greater radiometric fidelity. High geometric resolution was not mandatory because most hydrologic applications are made for large heterogeneous areas and gross measures would be adequate. Consistent IR-color or multiband photography with sensitive curves and step wedges to provide checks and controls would be desirable. Thermal sensing of surface temperatures would provide data for independent evaluations of ET as suggested by Wiegand and Bartholic (1970) or for refining the relationship between radiance in the visual and near infrared portion of the spectrum and ET. The remote sensing from ERTS-A covered the same range of the spectrum used in this analysis and will have the added advantage of greater radiometric fidelity. (Authors' Conclusion)

73. Culler, R. C., Leppanen, O. E., and Matalas, N. C.

"Objectives, Methods and Environment–Gila River Phreatophyte Project, Graham County, Arizona," *U.S. Geological Survey Professional Paper 655A*, 1970, 25 pp.

An inadequate water supply and an increasing demand for water have made conservation of water essential in the arid Southwest. One conservation method, which has been used in several places and which has been proposed for others, is replacement of phreatophytes by useful vegetation. Nonbeneficial plants infest areas of shallow groundwater, such as flood plains of major rivers. Tank studies have shown that phreatophytes use more water than beneficial grass in the same location. However, many hydrologic variables in nature are not duplicated in tank studies.

The most obvious need in phreatophyte-control research is evaluation of water conservation on a flood plain typical of many areas of existing and proposed application. Hydrologic and ecologic variables must be defined by the evaluation so that the data may be applied to other sites. The Gila River Phreatophyte Project was begun in 1962 by the U.S. Geological Survey in order to make this evaluation.

The project area is a 24-km (15-mi) reach of the Gila River flood plain in the San Carlos Indian Reservation which has been divided into three subreaches. About 2,400 ha (6,000 acres) are covered by phreatophytes, principally saltcedar and mesquite. Phreatophyte removal was started on the upper subreach in 1966; the middle and lower subreaches were undisturbed until 1967. The period of preclearing measurement of evapotranspiration extended from 1963 to 1966 for the upper subreach and from 1964 to 1967 for the other two subreaches. Postclearing measurement will extend to July 1972.

A water budget is being used to compute evapotranspiration as a residual. The water budget includes surface and subsurface inflow and outflow in the Gila River and its tributary inflow to the reach, precipitation on the flood plain, and changes in groundwater storage in the saturated and unsaturated zones of the study reach. The vegetation, chemical quality of water sedimentation, and climate also are being studied. The water budget will be the basic method of evaluation, but other methods will be applied and tested. All data are being collected for analysis by digital computer and will be subjected to rigorous statistical tests.

74. Cunningham, G. L., Fraser, J. G., Grieve, R. E., and Wolfe, H. G.

"A Comparison of Rates of Water Loss through Transpiration of Several Southern New Mexico Phreatophyte Species," *New Mexico Water Resources Research Institute Report No. 025*, 1973, 32 pp.

This report describes the development and use of a method of estimating transpirational water use by riparian plant communities. The method involves the development and use of mathematical models to predict transpiration rates on a leaf area basis from environmental data. These models were used in conjunction with leaf area estimates for a study stand to evaluate transpirational water use. The results indicate that differences exist among species. Species which are found in less disturbed stands tend to be much more conservative in their transpirational water use.

75. Davenport, D. C., Anderson, J. E., Gay, L. W., and others.

"Phreatophyte Evapotranspiration and Its Potential Reduction without Eradication," *Water Resources Bulletin*, Vol. 15, No. 5, October, 1979, pp. 1293–1299.

The continuous availability of groundwater to riparian phreatophytic vegetation results in large evapotranspiration (ET) losses in summer. Chemical or physical eradication of this vegetation can have undesirable environmental side effects. Spraying phreatophyte foliage with a nontoxic antitranspirant (AT) may reduce transpiration without eradication. Transpiration rate per unit leaf area was similar for several phreatophyte species, but ET per unit land area of phreatophytes depends more on stand density than species. The mean ET for saltcedar in June was 8.1 mm/day measured by Bowen ratio, compared with 7.9 mm by lysimeters. ATs and growth-retardants reduced transpiration by over 50% in laboratory tests where foliage was thoroughly sprayed. In the field AT sprayed by a backpack mistblower reduced ET by 20–35% initially and 10% after a month. No ET reduction occurred when AT was sprayed by helicopter on saltcedar, because excessive droplet size and heavy salt deposits on the foliage resulted in poor spray adherence. Wax-based AT was relatively nontoxic to fish and wildlife. Dissolved oxygen could be reduced for aquatic life, but further AT dilution in streams and ponds would minimize this. Helicopter spraying may affect bird nests and egg hatchability. Although ATs significantly reduce ET, their high cost and spraying difficulties preclude current use on phreatophytes. With improvement they may economically help to conserve water in riparian areas in future years.

76. Davenport, D. C., and Hagan, R. M.

"Reducing Phreatophyte Transpiration," In: "Hydrology and Water Resources in Arizona and the Southwest," *Proceedings of the 1977 meetings of the Arizona Section of the American Water Resources Association and the Hydrology Section of the Arizona Academy of Science*, Las Vegas, Nev., April 15–16, Vol. 7, 1977, pp. 141–146.

Transpiration rates (T) of riparian phreatophytes can be high. Antitranspirant (AT) sprays can curtail T without the ecological imbalance made by eradication. Saltcedar (*Tamarix* sp.) and cottonwood (*Populus* sp.) in 15-gallon drums enabled replicated trials on isolated plants or on canopies. T of isolated saltcedar plants could be 2 times that of plants in a fairly dense canopy. T for a unit ground area of saltcedar varied from 2.2 (sparse-stand) to 15.8 (dense-stand) mm/day in July at Davis. Extrapolation of experimental T data to field sites must, therefore, be made carefully. Wax-based ATs increased foliar diffusive resistance (R), and reduced T of saltcedar and cottonwood 32–38% initially and 10% after three weeks. R increased naturally in the afternoon when evaporative demand was high and if soil water was low. Nocturnal T of saltcedar was 10% of day T. AT effectiveness increased with a higher ratio of day, night hours, and with lower soil water stress. Therefore, AT will be most effective on long summer days in riparian areas where groundwater is available.

77. Davenport, D. C., Hagan, R. M., Gay, L. W., and others.

"Factors Influencing Usefulness of Antitranspirants Applied on Phreatophytes to Increase Water Supplies," *Contribution No. 176*, California Water Resources Center, University of California at Davis, October, 1978, 181 pp.

The continuous availability of groundwater to riparian phreatophytic vegetation results in large transpiration losses to the atmosphere, particularly during summer. Chemical or physical eradication of this vegetation can have undesirable side effects and therefore be environmentally and aesthetically unacceptable. Spraying phreatophyte foliage with an antitranspirant (AT) offers the potential for reducing transpiration losses with minimal impacts on the ecosystem. This research project investigated: (1) the magnitude of water lost through transpiration by phreatophytes; (2) plant and environmental factors that influence the water relations of the vegetation; (3) effectiveness of various ATs in the laboratory and in the field; and (4) effects of ATs on terrestrial and aquatic wildlife on riparian habitats.

Transpiration rates per unit leaf area, as well as diffusive resistance, are similar for several phreatophyte species. The transpiration rate of a saltcedar stand depends not only on plant and climatic factors, but also on stand density. Evapotranspiration from a given land area of phreatophytes, adequately supplied with water, will probably depend more on stand density than on species composition.

Estimates of stand transpiration from measurements of net-radiation exchange and gradients of temperature and humidity agreed closely with water loss measured from lysimeters at Bernardo, New Mexico. The mean Bowen ratio estimate for five days in June, 1977, was 8.1 mm/day, compared with 7.85 mm measured by the lysimeters. This agreement substantiates the usefulness of the mobile energy-budget method for estimating phreatophyte transpiration.

Two waxed-based ATs tested significantly reduced transpiration by phreatophytes in small-scale tests. Transpiration reductions of over 50% were observed in laboratory and field studies where foliage was thoroughly sprayed with a hand-sprayer. Field trials with AT sprayed by a backpack mistblower resulted in reductions of 20–35% initially and 10% after a month. No significant reduction in transpiration was achieved when the AT was sprayed by helicopter, probably because excessive droplet size and heavy salt deposits on the foliage resulted in poor adherence of the spray to the saltcedar. Thus, effectiveness of wax-based ATs appears to be determined primarily by the thoroughness of foliage coverage.

The wax-based ATs were relatively nontoxic to fish and wildlife. A high chemical oxygen demand of AT in laboratory tests suggests that dissolved oxygen could be reduced for aquatic life. That effect may be minimized in the field where

AT is further diluted in streams and ponds. AT application by helicopter could have an adverse effect on bird nests and eggs. In laboratory tests, which simulated spray coverage in field trials, the hatchability of chicken eggs was reduced when they were half covered with AT.

Although ATs do significantly reduce transpiration, an operational program for their application on phreatophytes cannot be recommended at this time because of the high cost of acceptable AT materials, the need to improve the efficiency of ATs and their application, and the need for more thorough investigation of the effects of wildlife in riparian areas. In future years, however, as demands increase for finite supplies of water, the information on water loss by phreatophytes and the concept of AT application to reduce that loss, presented in this report, may be useful to the development of a management alternative that is mutually acceptable to water, recreation, and wildlife interests.

78. Davenport, D. C., Martin, P. E., and Hagan, R. M.

"Aerial Spraying of Phreatophytes with Antitranspirant," *Water Resources Research*, Vol. 12, No. 5, 1976, pp. 991–996.

An antitranspirant (AT) can retard excessive groundwater consumption by phreatophytes without eradicating them. To determine whether aerial spraying (the only realistic application method for most sites) of a 6% (volume/volume) wax-based AT emulsion could provide adequate spray coverage and reduce transpiration, multiple passes were made with (1) a fixed wing plane on saltcedar, cottonwood, and willow, and (2) a helicopter on saltcedar. Spray coverage on the ground was 30–100% in the open (depending on the number of passes and wind drift) and 10–90% under the canopies (depending on vegetation density). Average coverage on tags ranged from 13% in the lower canopy to 75% in the upper (depending on species and application rate) after spraying by the fixed wing plane, and 47 to 98% after spraying by the helicopter. Coverage in the center of dense bushes was 0 to 20%, but transpiration is only minimal there. Scanning electron microscope photomicrographs showed considerable AT on foliage in the upper canopy and less amounts in the lower; the film was detected even 24 days after spraying. Aerially applied AT increased resistance to leaf water vapor diffusion by 150% during the first few days and by 80% thereafter. Transpiration of outer foliage of saltcedar was reduced 50% initially and 20% after two weeks without phytotoxicity.

79. Davenport, D. C., Martin, P. E., and Hagan, R. M.

"Evapotranspiration from Riparian Vegetation: Conserving Water by Reducing Saltcedar Transpiration," *Journal of Soil and Water Conservation*, Vol. 37, No. 4, 1982, pp. 237–239.

Spraying phreatophytic saltcedar (*Tamarix chinensis*, Lour.) with a nontoxic, wax-based antitranspirant can reduce evapotranspiration (ET) without eradicating the vegetation and eliminating its benefits for soil erosion control and wildlife habitat. In field studies, an antitranspirant sprayed with a backpack mistblower reduced saltcedar ET 20 to 35% initially and 10% after a month. No ET reduction occurred when the antitranspirant was sprayed by helicopter because the large droplet size resulted in poor foliar adherence. Although a properly applied antitranspirant clearly reduces the irrecoverable loss of pure water through transpiration, an operational program for antitranspirant spraying on phreatophytes cannot be recommended because of (1) the high cost; (2) the need to improve aerial application; and (3) the need to investigate more completely the effects of antitranspirants on wildlife. In the future, as water becomes more scarce and costly, antitranspirant spraying programs, with improvement, may become economical in preventing irrecoverable water losses.

80. Davenport, D. C., Martin, P. E., and Hagan, R. M.

"Evapotranspiration from Riparian Vegetation: Water Relations and Irrecoverable Losses for Saltcedar," *Journal of Soil and Water Conservation*, Vol. 37, No. 4, 1982, pp. 233–236.

Evapotranspiration (ET) from saltcedar (*Tamarix chinensis* Lour.) varies with weather factors as well as with stand density and water availability. In California, ET in July for a unit ground area of salt cedar in large drums varied from 2 mm per day in sparse stands, to 16 mm per day in dense stands; ET declined and diffusive resistance increased when saltcedar plants were subjected to stress brought on by low soil water availability and/or high evaporative demand. In a natural saltcedar stand in New Mexico, ET in June varied from 3 mm to 11 mm per day, depending upon weather and plant density. Extrapolation of experimental transpiration data to field sites must, therefore, be done carefully when assessing irrecoverable ET losses.

81. Davenport, D. C., Martin, P. E., Roberts, E. B., and Hagan, R. M.

"Conserving Water by Antitranspirant Treatment of Phreatophytes," *Water Resources Research*, Vol. 12, No. 5, 1976, pp. 985–990.

A wax-based antitranspirant (AT) was sprayed on three phreatophytes, saltcedar (*Tamarix* sp.), cottonwood (*Populus* sp.), and willow (*Salix* sp.), as an alternative to eradicating them to conserve water. Scanning electron micrographs gave information on the nature of the foliar surfaces and coverage by the AT wax. A 10% solution of AT (volume/volume) reduced the transpiration rates of container-grown phreatophytes by 35–75% one day after spraying and by 17–56% after four days. In gas exchange studies with saltcedar in the field, transpiration was reduced 40% by a light application of 6% AT and 70% by a heavy application. The AT also increased resistance to water vapor diffusion and the water potential of the sprayed leaves. On saltcedar, phytotoxicity occurred at high temperature and solar radiation only if spray applications were very heavy. The AT conserved water much more effectively when it was applied to the outer part of the canopy than when it was applied to the inner shaded foliage, where transpiration was already minimal. These data from sprays applied from the ground provided a basis for trials of AT application by aircraft.

82. Decker, J. P.

"A Brief Summary of the Influence of Phreatophytes on Water Yield in Arid Environments," in *Symposium on Water Yield in Relation to Environment in the Southwestern United States*, Sul Ross State College, Alpine, Texas, May 3, 1960, Southwest and Rocky Mountain Division of American Association for the Advancement of Science, 1960, pp. 64–69, illus.

After a brief summary of past research, the writer describes a new method for measuring evapotranspiration, based on an old technique: Confine a plant in a transparent vessel, ventilate at a known rate, measure absolute humidity of inflow and outflow, and multiply the humidity by the ventilation rate to compute the rate of water vapor production by the confined plant.

Field apparatus included frameless cylindrical tents, (10 by 10 ft) of transparent plastic film sealed to the ground with sandbags and inflated by ventilating blowers. Small sample air streams were withdrawn continuously from a tent inlet and outlet and were directed alternately into the gas analyzer to determine evapotranspiration rates.

During July and August 1958, evapotranspiration measurements were made on paired plats (one of closely grazed Bermuda grass sod, the other of sod overtopped by one or more tamarisk shrubs) on the Salt River, 20 mi east of Tempe, Arizona. Evapotranspiration increased linearly with the amount of tamarisk. Though the plot with the most tamarisk was only about one-third fully stocked, its evapotranspiration rate was about four times that of the adjacent grass plot.

The apparatus is far from ideal for the following reasons: (1) the analyzer worked well on a laboratory bench but often became troublesome in the field; (2) no practical means was devised for calibrating the complete apparatus directly against known primary standards, and thus, calibration depended on secondary standards; and (3) the effect of enclosure has not been completely evaluated. (Author's Text)

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

"Measuring Transpiration of Undisturbed Tamarisk Shrubs," *Plant Physiology*, Vol. 37, No. 3, 1962, pp. 393–397.

The tent method of measuring evapotranspiration from undisturbed plots of natural vegetation was used to compare the evapotranspiration rates of five-stamen tamarisk and Bermuda grass. Evapotranspiration of Bermuda grass-tamarisk plots increased linearly with the amount of tamarisk. A reduction of evapotranspiration could thus be expected to follow conversion of tamarisk stands to grass cover. The diurnal time-course of evapotranspiration followed generally the changes of light intensity and humidity deficit. On clear days, evapotranspiration for a midday period (10:00 am–2:30 pm) and for the night (8:30 pm–5:30 am) was 36% and 11%, respectively, of the daily total. (Author's Summary)

84. Duell, L. F. W., Jr.

"Evapotranspiration Rates from Rangeland Phreatophytes by the Eddy-Correlation Method in Owens Valley, California," 17th Conference on Agricultural and Forest Meteorology, Scottsdale, Ariz., May 21–24, 1985, *American Meteorological Society Bulletin*, Paper A&F3.2, 1985, pp. 44–47.

The U.S. Geological Survey, in cooperation with the city of Los Angeles and Inyo County, has undertaken a plant-survivability and groundwater study in Owens Valley, California.

This study involves measuring ET by the eddy-correlation and Bowen ratio/energy-budget methods, and calculating potential ET by the Penman method.

The eddy-correlation method described in this report can easily be used in similar areas where ET rates are desired. The results presented can aid users in their decision to select and monitor more than one site where ET rates may vary due to differing phreatophyte species and fluctuations in the shallow water levels. The data also present representative values that can be expected during growing seasons for similar areas. (Author's Introduction)

85. Duell, L. F. W., Jr., and Nork, D. M.

"Comparison of Three Micrometeorological Methods to Calculate Evapotranspiration in Owens Valley California," in *Riparian Ecosystems and Their Management: Reconciling Conflicting Uses*, First North American Riparian Conference, April 16–18, 1985, Tucson, Ariz. Forest Service General Technical Report RM-120, 1985, pp. 161–165.

Using the Bowen ratio/energy-budget, eddy-correlation, and Penman combination methods, 24-hour evapotranspiration values, in mm per day, were 6.1, 6.0, and 21.7 for a salt grass site in May 1984; 1.2, 2.0, and 12.3 for a greasewood site in June 1984; and 1.6, 2.2, and 10.4 for a rabbitbrush site in July 1984.

86. Dwyer, D. D., and Wolde-Yohannis, K.

"Germination, Emergence, Water Use, and Production of Russianthistle, (*Salsola kali* L.)," *Agronomy Journal*, Vol. 64, January–February, 1972.

Studies of Russianthistle (*Salsola kali* L.) have shown that it is a plant well suited to arid and semiarid regions. This study was conducted to learn some of the characteristics of the species related to germination and water use that allow it to succeed in these dry areas. Russianthistle seeds were planted in a sandy soil, and various amounts of simulated rainfall were added once. Emergence occurred in 14 hours when as little as 7.6 ml (0.3 in.), was applied. There was no significant difference in numbers of plants emerging and surviving to permanent wilting from 12.7 ml (0.5 in.) to 27.9 ml (1.1 in.) of simulated rainfall. Germination studies showed that Russianthistle seed germinated from 4° to 68° C with optimum germination from 7° to 35° C. Plants were grown for 90 days (to maturity) at four soil moisture levels–field capacity, 0.5, 0.2, and 0.1 available water–to determine water use and production. Shoot production was greatest at field capacity and least when soil was maintained at 0.1 available water. However, efficiency of water use was greatest at 0.1 available water, requiring only 98 g of water per dry-weight gram of shoot produced. Even under field capacity, Russianthistle used only 181 g of water per dry-weight gram of shoot and root produced.

87. Dylla, A. S., and Muckel, D. C.

"Evapotranspiration Studies on Native Meadow Grasses–Humboldt Basin, Winnemucca, Nevada," Agricultural Experiment Station, Max C. Fleischmann College of Agriculture, University of Nevada, Reno, and U.S. Dept. of Agriculture, Agricultural Research Service, Reno, Nev., *R9*, 1964, 29 pp., illus.

Three years (1961, 1962, and 1963) of measurements of evapotranspiration by native meadow grasses grown in lysimeters at the Winnemucca (Nev.) Experimental Station are presented. A discussion is included on the installation and operation of the lysimeters, also called evapotranspiration tanks. Bay yields were studied to compare effects of varied water content in the soil on production. (Author's Summary)

88. Dylla, A. S., Stuart, D. M., and Michener, D. W.

"Water Use Studies on Forage Grasses in Northern Nevada," Agricultural Experiment Station, Max C. Fleischmann College of Agriculture, University of Nevada, Reno, and U.S. Dept. of Agriculture, Agricultural Research Service, *T-10*, May, 1972.

Measurements were made of water used by three native meadow grasses (saltgrass, sedges, and bluejoint) growing in evapotranspiration tanks at Winnemucca in 1967, 1967, and 1969. In addition, water use measurements were made on two domestic forage species (tall wheatgrass and Alta fescue) in 1968 and 1969. Saltgrass and sedges were grown under the seasonal high water table (wet meadow) treatments; and bluejoint, tall wheatgrass, and Alta fescue were grown under seasonal high water table and surface irrigation treatments.

Linear correlations were calculated by species for 4-week and 1-week periods of measured water use to measured pan evaporation, net radiation, and calculated evapotranspiration by the combination model, Blaney-Criddle and Olivier methods. Evapotranspiration calculated by the combination model showed the highest correlation with measured ET; however, this method required the greatest number of meteorological measurements. The Olivier estimate of crop, water use, based primarily on pan evaporation amounts, shows better correlation with measured water use than pan evaporation alone. Where pan evaporation data are available, the Olivier method is simpler than most of the empirical equations for estimating seasonal crop water consumption. Sedges grown under wet meadow conditions in 1967, 1968, and 1969 used 27.3, 26.3, and 21.8 in. of water. In comparison, saltgrass used 22.4, 19.5 and 19.1 in. of water per season. Bluejoint used 25.0, 23.5 and 21.9 in. Under wet meadow conditions, tall wheatgrass used 27.8 and 23.6 in. of water in 1968 and 1969, and Alta fescue used 25.7 and 19.4 in.

Grown under surface-irrigated conditions, bluejoint used 34.6 and 32.1 in. of water in 1968 and 1969, as compared to 32.2 and 29.5 in. for tall wheatgrass and 29.9 and 26.4 for Alta fescue. Higher water-use efficiencies (pounds hay per acre-inch of water) were obtained by surface irrigations primarily because soil salinity in the root zone was kept below the 4 mmhos/cm (saturated soil extract) electrical conductivity level. Saltgrass, sedges, and bluejoint generally showed higher water-use efficiencies (pounds hay per acre-inch water) under high soil salinity levels than tall wheatgrass and Alta fescue.

Highest water-use efficiency attained was 171 pounds hay per acre-inch water by bluejoint and sedges in 1969. Lowest water-use efficiency was 86 pounds hay per acre-inch water for Alta fescue grown under seasonally high water table and high soil salinity conditions in 1969. (Authors' Summary)

89. Easter, S. J., and Sosebee, R. E.

"Influence of Soil-Water Potential on the Water Relationships of Honey Mesquite," *Journal of Range Management*, Vol. 28, No. 3, May, 1975, pp. 230–232.

Thermocouple psychrometry was used to measure soil and plant water potentials of honey mesquite growing under irrigated and nonirrigated field conditions. The trees growing on the irrigated area experienced more internal stress (average minimum water potential, –30.9 bars) than trees growing under nonirrigated conditions (average minimum water potential, –19.4 bars). The water potential in the trees and transpiration rates adhered to a very distinct daily pattern. Minimum water potential occurred about noon in the trees growing on both sites. During the growing season, the average transpiration rate of the trees on the irrigated area was 9.59×10^{-5} g cm^{-2} min^{-1}, while the average transpiration rate for those trees growing on the nonirrigated area was 7.15×10^{-5} g cm^{-2} min^{-1}. The trees growing under irrigation produced two times more foliage than the trees growing without irrigation. Consequently, the greatest amount of soil water depletion occurred under irrigation. The results of this study indicated the water loss via transpiration in honey mesquite growing in shallow soils or on upland sites (relatively dry situations) is not as great as the amount lost from trees growing on bottomland and on riparian sites.

90. Eckert, R. E., Jr., Bruner, A. D., and Klomp, G. J.

"Productivity of Tall Wheatgrass and Great Basin Wildrye under Irrigation on a Greasewood-Rabbitbrush Range Site," *Journal of Range Management*, Vol. 26, No. 4, July, 1973, pp. 286–288.

Nonbeneficial phreatophytes, greasewood and rubber rabbitbrush, in the Humboldt River Basin annually waste approximately 103,000 acre-ft of water that could be used beneficially if forage species were established. After brushbeating, tall wheatgrass and Great Basin wildrye were spring seeded and established by sprinkler irrigation. Irrigation was continued for three to five years to induce root penetration into a capillary fringe so that grasses would persist as beneficial phreatophytes. After irrigation ceased, productivity of 115 to 710 lb/acre indicated that roots had not reached the capillary fringe and that continued irrigation was necessary to maintain production. Soil physical characteristics restricted root growth, and productivity with limited water or without water was reduced by chemical properties of a saline-sodic soil. Highest production of tall wheatgrass (4000 to 6000 lb/acre) and Great Basin wildrye (2400 to 2600 lb/acre) was obtained three years after seeding with weekly irrigations of 1.25 in.

91. Eisenlohr, W. S., Jr.

"Hydrologic Investigations of Prairie Potholes in North Dakota, 1959–68," *U.S. Geological Survey Professional Paper 585-A*, U.S. Government Printing Office, Washington D.C., 1972.

A prairie pothole is a depression in the prairie, capable of storing water, that is the result of glacial processes. Years ago, there were many hundreds of thousands of prairie potholes in the North-Central United States, but large numbers of them have been drained for agricultural use. This report is limited to studies of prairie potholes in the eastern part of the glaciated northern Great Plains region in North Dakota–a rolling upland area covered with glacial drift, called the Coteau du Missouri. Potholes are wetlands that are the primary breeding area of migratory waterfowl in the United States. If production of waterfowl is to continue, suitable wetlands must be maintained, and even now wetlands created to offset those destroyed for agricultural use. The initial stage of the Garrison Diversion Unit calls for a normal annual diversion from Garrison Reservoir of 60,000 acre-ft of water for this purpose.

Many prairie potholes contain large amounts of emergent aquatic vegetation known as hydrophytes. Determining the loss of water by transpiration from emergent hydrophytes was one of the major objectives of the present study of the hydrology of prairie potholes. Other hydrologic factors were studied later, but the first part of the study was devoted almost exclusively to the determination of evaporation and transpiration losses at groups of potholes in Ward, Stutsman, and Dickey Counties. The mass-transfer method was used, and by determining the variation in the mass-transfer coefficient throughout a season, the losses by evaporation and transpiration were determined separately. Separate determinations were accomplished by relating the emergent height and the moisture content of the hydrophytes to the rate of transpiration, as determined by the mass-transfer coefficient.

Seasonal evaporation from the study potholes clear of vegetation was found to very nearly equal the generalized evaporation values published by the U.S. Weather Bureau. The effect of hydrophytes in potholes was twofold: Their presence reduced evaporation from the water surfaces; and, at the height of the growing season, their transpiration rate, added to the reduced evaporation rate, frequently was greater than the evaporation rate from potholes clear of the vegetation.

Net seepage outflow from potholes was generally very small–less than 0.01 ft per day per unit of water surface. This rate of seepage was not insignificant, however, because it often amounted to more than one-fourth of the total seasonal loss of water from a pothole.

The source of water supplying the evapotranspiration losses was primarily precipitation on the water surface of a pothole pond. Augmenting this supply was basin inflow–overland flow, flow in channels, and seepage inflow. Of these, overland flow, was estimated to have been the largest by far; direct observations were not possible. Basin inflow was very erratic; it depended on combinations of events, such as antecedent soil moisture and rainfall intensity, or depth of snow at time of melting and concurrent rainfall. The occurrences of these combinations were such that, for a given season (October–March or April–September), the total basin inflow generally showed little relation to total precipitation. The greatest inflows were associated with late snowmelt flowing over frozen ground.

Following the evapotranspiration study, the effects of groundwater movement were investigated. All the study potholes were located in areas of glacial till in order to reduce the effect of seepage in the mass-transfer computations. Accordingly, groundwater movement was not a major factor in the water budget of the study potholes; however, it could be, in potholes located in areas of outwash sands and gravels, and in potholes in glacial till with only temporary ponds. Also, the direction of groundwater movement has a controlling effect on the water quality of a pothole pond. Where there is not seepage outflow or overflow, there is no mechanism for the removal of dissolved solids brought to the pond by basin inflow. Such potholes are saline–some even more so than sea water. Conversely, potholes that receive no seepage inflow generally contain fresh water and are usually not permanent. All conditions between these two extremes were found.

The permanence of water in a pothole (the extent to which the water body is permanent) and its quality were found to have a direct and significant relation to the species of vegetation that grows under those conditions. In fact, the species of vegetation are excellent indicators of water quality and permanence, and the report contains a table listing the common species used as indicators and the conditions that they indicate.

Many other facets of the hydrology prairie potholes were investigated to ensure that no major factor was ignored, and the investigation results are described briefly.

92. Eisenlohr, W. S., Jr.

"Relation of Water Losses to Moisture Content of Hydrophytes in a Natural Pond," *Water Resources Research*, Vol. 5, No. 2, April, 1969, pp. 527–530.

Hydrophytes growing in natural ponds on the Coteau du Missouri in North Dakota have been studied. Previous studies in the same region showed how transpiration by hydrophytes could be separated from the total water loss from a natural pond, during the period that vegetation was growing in height, on the basis of a correlation between the height of vegetation and a mass-transfer coefficient. It is shown that a similar separation can be made during the period of declining activity of the vegetation. A significant correlation was found between the ratio of moisture content of vegetation to its oven-dry weight and the mass-transfer coefficient. Weekly photographs on Ektachrome Infrared Aero film helped to confirm some of the phenomena observed.

93. Eisenlohr, W. S., Jr.

"Water Loss From a Natural Pond through Transpiration by Hydrophytes," *Water Resources Research*, Vol. 2., No. 3, 1966, pp. 443–453.

The water loss to the air from a natural pond in which hydrophytes are growing consists of two parts, evaporation and transpiration. As both parts vary directly with the same meteorologic factors, the total loss, evapotranspiration, can be computed by means of a simplified mass transfer equation in which the only coefficient has been evaluated for that pond by means of a water budget. In addition to the variation with meteorologic factors, transpiration occurs at different rates throughout the growing season, depending on the stage of growth. Evaporation is affected by the amount of vegetation present. The mass transfer coefficient varies in accordance with these conditions. By assuming that the coefficient during the dormant season represents losses by evaporation alone, a basis is obtained for estimating the coefficient representing evaporation during the growing season. The computed

evapotranspiration minus the computed evaporation gives the water loss attributed to transpiration alone.

94. Evans, D. D., Sammis, T. W., and Cable, D. R.

“Actual Evapotranspiration Under Desert Conditions,” Chapter 9 in *Water in Desert Ecosystems*, Evans, D. D., and Thames, J. L., eds., US/IBP Synthesis Series 11, Dowden, Hutchinson & Ross, Inc., Stroudsburg, Penn., 1981.

95. Fletcher, H. C., and Elmendorf, H. B.

“Phreatophytes–A Serious Problem in the West,” *U.S. Dept. of Agriculture Yearbook*, 84th Congress, First Session, House Document No. 32, 1955, pp. 423–429.

Phreatophytes occupy about 15 million acres of land in the western states. These plants form a definite group but do not belong to any specific family. Their common characteristic is their heavy use of a scarce supply of water. As a general rule, the shallower the water table, the higher the rate of use. The depth to the water table controls the occurrence and growth of most species.

Few studies have directly demonstrated how much water could be saved from evapotranspiration loss by removal and replacement of phreatophytes. The actual amount of water saved for use elsewhere by removing the phreatophytic vegetation is still largely a matter of conjecture.

To recover the water, the vegetation must be removed or the water supply must be taken from it. Removal of the vegetation by mechanical means, burning, chemical sprays, or other methods generally is only temporary if other conditions are unchanged. Permanent control can be achieved only when the water supply is removed from the plants by lowering the water table, piping the water across the area, or cutting off the supply from above.

96. Freethey, G. W.

“Hydrologic Analysis of the Upper San Pedro Basin from the Mexico-United States International Boundary to Fairbank, Arizona,” *U.S. Geological Survey Open File Report 82-752*, Tucson, Ariz., 1982.

A definition of the hydrologic system of the upper San Pedro basin was obtained by developing a numerical groundwater model to evaluate a conceptual model of the system. The numerical model uses a three-dimensional, block-centered, finite difference scheme to simulate groundwater flow, stream-aquifer connection, and evapotranspiration. Information on hydraulic properties of the basin fill, recharge from bordering mountain ranges, discharge by evapotranspiration, and exchange of water between aquifer and stream was available from previous measurements or

estimates. The steady-state calibration procedure and subsequent transient simulations demonstrate that the conceptual model of the groundwater flow system can be reasonably simulated.

An analysis of model sensitivity to increases and decreases in certain hydraulic properties indicated a low sensitivity to aquifer anisotropy and a low to moderate sensitivity to stream leakance and evapotranspiration rate. An analysis to investigate the effects of using average values of recharge, hydraulic conductivity, and specific yield indicated that flow components and water-level response to stress could be simulated adequately; however, simulation of steady-state water-level conditions was sensitive to the hydraulic-conductivity distribution.

During equilibrium conditions, the basin received about 16,500 acre-ft per year recharge from runoff, underflow, and stream seepage. The same amount was discharged by evapotranspiration and seepage to streams. By 1978, withdrawal of groundwater for irrigation, industrial use, and public supply totaled about 10,500 acre-ft per year. The numerical model results indicated that about 5,600 acre-ft or 53% of the 1977 pumpage represented release of water from aquifer storage; the remainder is derived from adjustments in the evapotranspiration, discharge to and from the river, and underflow in and out of the basin.

97. Fritschen, L. J., and Doraiswamy, P.

"Dew: An Addition to the Hydrologic Balance of Douglas Fir," *Water Resources Research*, Vol. 9, No. 4, August, 1973, pp. 891–894.

The hydrologic balance of a 28-m Douglas fir tree in a weighing lysimeter was determined for two clear days in May 1972. The results indicated dew accumulations of 6.4 and 10.9 liters, which represent 15 and 20% of 42.5 and 55.2 liters of evaporation from the tree. Since the dew was recorded as a weight increase, its source has to be the atmosphere. In the Pacific Northwest, conditions are favorable for dew formation during most of the summer and fall. Thus dew formation could represent a large part of the hydrologic balance of fir forests.

98. Fritschen, L. J., Hsia, J., and Doraiswamy, P.

"Evapotranspiration of a Douglas Fir Determined with a Weighing Lysimeter," *Water Resources Research*, Vol. 13, No. 1, February, 1977, pp. 145–148.

The evapotranspiration (ET) of a 28-m Douglas fir in a weighing lysimeter located on the Cedar River watershed near Seattle, Washington, was determined during the summer and fall of 1972, 1973, and 1974. Average ET rates from the area of the crown projection were 1.8 mm d^{-1} (55.8 P d^{-1} or 14.7 gal d^{-1}) in 1972, 2.0 mm d^{-1} in 1973, and 2.5 mm d^{-1} in 1974. The range for monthly periods was 1.3–3.6 mm d^{-1}. During 1972, ET was 46% of precipitation plus irrigation (P + I), and evaporation of interception (i) was 36% of ET. Comparable values for 1973 were 51% and 37% and for 1974 were 69% and 24%. The lower ET/(P – 1) values in 1973 and 1974 were associated with soil moisture depletion studies and longer periods of clear skies. The relatively high i/ET percentages suggest the need for more interception studies. Problems such as irrigation, drainage, listing, wind, rainfall interception, and the translation of data to an area basis that are associated with large plants in lysimeters are discussed.

99. Fritschen, L. J., Simpson, J. R., and Smith, M. O.

"Eddy-Correlation Measurements of Evaporation from Bare Soil and of Evapotranspiration from Saltcedar Groves in the Pecos River Flood Plain, New Mexico," *Final Report to U.S. Geological Survey*, University of Washington, Seattle, Wash., January, 1980, 45 pp.

The U.S. Bureau of Reclamation has been clearing saltcedar and other phreatophytes from a 17,000-acre area in the flood plain of the Pecos River from Acme to Artesia, New Mexico, since 1967. It was originally anticipated, based upon a U.S. Geological Survey, Water Resources Division study, that about 28,000 acre-ft of water would be salvaged annually by such clearing. However, present USGS studies indicate that the gain in base flow in the reach has been relatively constant since 1964, suggesting that evapotranspiration salvage resulting from phreatophyte clearing is much less than originally anticipated. One hypothesis concerning this failure to accomplish the anticipated salvage rate is that the original estimates of water or usage by saltcedar in the Pecos River floodplain were too high, and/or estimates of evapotranspiration from bare soil and shallow-rooted replacement vegetation were too low. A study by the USGS of vertical flow in the unsaturated zone below the root zone is in progress at two sites.

Data from these studies will provide data on evaporation from ground water in bare areas or by areas covered by shallow-rooted replacement vegetation. The purpose of this study in collection with the above-stated problem is twofold. The first is to evaluate the use of a microprocessor-based system for the determination of evaporation by the eddy-correlation method in a preliminary pilot study over selected areas that have been root-plowed, leaving shallow rooted vegetation and areas still in saltcedar. Second, aided by the results of this study, make recommendations as to the feasibility, need, and approach for a longer study to determine evapotranspiration by micrometeorological methods. (Author's Introduction)

100. Fritschen, L. J., and Simpson, J. R.

"Evapotranspiration from Forests: Measurements and Modeling," in *Proceedings of the National Conference on Advances in Evapotranspiration*, December, 1985, Chicago, Ill., American Society of Agricultural Engineers Publication No. 14-85, St. Joseph, Mich., 1985, pp. 393–404.

Direct determination of evapotranspiration from forests is difficult due to the size and variability of the vegetation and the variability of the soil of the methods which have been used to determine evapotranspiration, e.g. soil water balance, lysimeters and the meteorological methods of eddy correlation, aerodynamic and the Bowen ratio energy balance, only the soil water balance (under special conditions), the eddy correlation and the Bowen ratio energy balance method are appropriate to forests. The eddy correlation has not been used operationally because of the instrumental difficulties. The Bowen ratio energy balance method relies on an assumption of unity for the ratio of the eddy diffusivities of heat and water vapor. A growing body of evidence suggests that this ratio may be larger than one over forests.

Models have been developed for forests which are detailed mechanistically. These models run on either hourly or daily input values. Results from the soil water balance and the BREB method have been used to develop and verify models of forest ET. These models must be considered conditional as a result of the discussion about the verification techniques.

Thus far the discussion of measurement and estimation of ET has been accomplished for specific sites. The sites usually are selected for uniformity of vegetation and soils and generally, are level. Little attention has been given to the extension of these models to nonuniform and mixed stands. Furthermore, extension of the measurements and models to sloping surfaces appears to require additional research. These detailed models require a large amount of input data concerning the vegetation and the soil. Therefore, extension of these detailed models to watershed areas would require considerable detailed information or assumptions. (Authors' Summary)

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

"Use of Water by Bottom-Land Vegetation in Lower Safford Valley, Arizona," *U.S. Geological Survey Water Supply Paper 1103*, 1950, 210 pp.

This monumental research effort on the ways of determining water loss from phreatophytes is probably the most complete study ever attempted on this problem. Many of the approaches were pioneering in character, and while they often did not prove to be practical, they represent a very thorough approach to methods of determining evapotranspiration losses from phreatophytes.

The study in lower Safford Valley, Graham County, Arizona, is an alluvial lowland plain, with some irrigated farmlands and a belt of natural vegetation in the bottom land along the river consisting of phreatophytes, principally saltcedar, baccaris, cottonwood, and mesquite. The annual use of water by the vegetation was investigated in 1943 and 1944 to supply the basic data for estimating the quantity of water that might be saved if such bottom-land vegetation were destroyed.

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 clear discussions of their applicability to river-reach studies of water losses.

Although the methods differed greatly, the figure for use of groundwater computed by each method was within 20% of the mean determined by averaging the results of all six methods.

Based on the results obtained by the six methods, the total use of water by vegetation during the 12-month period ending September 30, 1944, was 28,000 acre-ft in a total of 9,303 acres in the 46-mi reach of Gila River from Thatcher to Calva. Of the total water used, 23,000 acre-ft were derived from the groundwater reservoir and the remainder was derived from precipitation on the area. Of the 23,000 acre-ft, more than 75% was used by saltcedar.

A comparison by species for the study year shows that use of water by phreatophytes common to lower Safford Valley, computed for 100% volume density, was (in acre-feet per acre) saltcedar, 7.2; baccharis, 4.7; cottonwood, 6.0; mesquite, 3.3.

102. Gay, L. W.

"The Effects of Vegetation Conversion Upon Water Use by Riparian Plant Communities," *Research Project Technical Completion Report No. B-084-ARIZ,* School of Renewable Natural Resources, University of Arizona, Tucson, Arizona, to U.S. Dept. of Interior, January, 1964.

Evapotranspiration was measured at two points simultaneously over a dense stand of saltcedar on the lower Colorado River with a portable, computerized Bowen ratio system. Twenty-one days of good ET data were collected during two successive years on eight different expeditions within the April–November growing season. In addition, potential ET (PET) estimates were developed for four models (radiation, radiation and temperature, net radiation, and Penman combination) using climatological data from two weather stations at nearby Blythe, California.

ET from the saltcedar ranged up above 12 mm per day in midsummer. The March 23–November 11 growing season totals were estimated from these measurements to be 1677 mm, including 40 mm of evaporated precipitation, and annual totals were estimated to be 1727 mm. The climatological estimates of PET were converted to actual ET (AET) by a 4th-order calibrating function developed by regressing daily totals of Bowen ratio ET vs. PET. Seasonal totals of AET were in excellent agreement and averaged 1756 mm. There was little difference between years. The two approaches suggest that 1750 mm and 1800 mm are reasonable figures for growing season ET and for annual ET from well-developed saltcedar on the Lower Colorado. A simple radiation model appears suitable for estimating AET in this area if weather data are limited and direct ET measurements are lacking.

103. Gay, L. W.

"Energy Balance Estimates of Evapotranspiration," in *Water Studies in Oregon*, Seminar conducted by Water Resources Research Institute, Oregon State University, Corvallis, Ore., January, 1970. (Summary from *Bulletin 1234*).

This study looked first at the role of vegetation in the evapotranspiration process, and then illustrated the importance of this process in the establishment of a surface energy balance. Energy balance theory was briefly reviewed. Application of the theory was demonstrated by the field experiments carried out over two contrasting sites: a pumice desert and a lush wet meadow. Analysis of two similar days indicated that the wet meadow evaporated 5.1 mm (0.2 in.) for the period 0730–1930 PDT.

This was about six times the evaporation estimated over the pumice desert for the same period. The lack of water available for vaporization at the pumice site caused major differences in the resulting surface energy balances. The resulting microclimate effects are quite large in the zone where plant growth would take place near the surface. (Author Conclusions)

104. Gay, L. W.

"Energy Budget Measurements of Evaporation from Bare Ground and Evapotranspiration from Saltcedar Groves in the Pecos River Flood Plain, New Mexico," *Final Report to U.S. Geological Survey*, Denver, Colo., from University of Arizona, Tucson, Ariz., February, 1980, 18 pp.

A microprocessor-controlled Bowen ratio system was tested on the Pecos River floodplain near Roswell, New Mexico, in July 1979. The system generates real-time estimates of the energy budget components at half-hourly intervals, based upon measurements with a two-level psychrometer system. The psychrometers are periodically interchanged to eliminate biases between sensors. Two such psychrometer masts were deployed in the tests, and the closeness of the latent energy estimates provides an index of the system's precision.

The system was deployed initially over an area cleared of saltcedar, but covered with low, herbaceous vegetation (*Kochea scoparia*). At this site, data was collected for 26.5 daylight hours during a test run of about 2 1/2 days. The agreement between the two masts was judged to be excellent; the two estimates were within ±2% of the mean evaporation total of 7.76 mm over the period of the test. The daylight energy budget totals for the entire period were: net radiation, 40.2 MJ/M^2; soil heat storage, –3.7 MJ/m^2; convection, –19.0 MJ/m^2; and latent energy, –17.5 MJ/m^2. The mean Bowen ratio for the period was 0.92. ET from the Kochea cover was substantial (about 3 mm per day) at the time of these measurements.

The system was then deployed over a stand of young saltcedar of about 2-m height. The observations were terminated after a relatively few hours by an unusual and unexpected two-day rain.

105. Gay, L. W.

"Potential Evapotranspiration for Deserts," Chapter 8 in *Water in Desert Ecosystems*, Evans, D. D., and Thames, J. L., eds., Dowden, Hutchinson & Ross, Inc., Stroudsburg, Penn., 1981, pp. 172–192.

(Reference–No Abstract)

106. Gay, L. W.

"Water Use by Saltcedar in an Arid Environment," *Proceedings of Water Forum 86*, American Society of Civil Engineer's Specialty Conference, Long Beach, CA, Aug. 4–6, 1986, pp. 855–862.

Specialized instruments and measurement techniques developed at the University of Arizona facilitate precise estimation of evapotranspiration (ET) with the energy budget model. Use of the model is demonstrated in a study of ET from a dense stand of saltcedar (*Tamarix chinensis* Lour.) along the lower Colorado River. The measurements were carried out periodically with a portable, computerized Bowen ratio measurement system. Twenty-one days of good ET data were collected during two successive years on eight separate expeditions within the April to November growing season. Depth to water remained nearly constant at about 3.3 m during the study. Measured ET ranged from about 2 mm/day in the spring and fall up to 13 mm/day in midsummer. Water use at night was less than 0.6 mm/day. The ET totals for the growing season (233 days, March 23–November 11) were estimated as 1680 mm, including 42 mm of summer precipitation. Potential evapotranspiration (PET) estimates were developed from climatological data at nearby Blythe, California. PET estimates for the growing season ranged from 1160 mm with the Priestly Taylor net radiation model up to 2475 mm with the Penman model, with the Penman estimate being 113% greater than the smaller one. The PET estimates were converted to actual evapotranspiration (AET) with a calibration function that was developed by regressing daily totals of Bowen ratio ET against the corresponding daily totals of PET. The calibration function was then applied to each daily estimate of PET (n=233) to obtain growing season AET estimates that were within 1% of

1717 mm. The results demonstrate that excellent estimates of ET from well-watered vegetation can be obtained using climatological data if PET models are first calibrated against a relatively small set of Bowen ratio ET measurements.

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

"An Energy Budget Analysis of Water Use by Saltcedar," *Water Resources Research*, Vol. 15, No. 6, 1979, pp. 1589–1592.

Bowen ratio estimates of evapotranspiration (ET) over a stand of saltcedar (*Tamarix chinensis*) on the Rio Grande floodplain in central New Mexico provide (1) estimates of water use by saltcedar during hot, dry weather, (2) comparisons of ET measured at two different locations within the same stand, and (3) comparison of ET over natural stands with results obtained from four constant-level lysimeters. The mean ET for five consecutive days (June 14–18, 1977) was 8.2 mm d^{-1} by the Bowen ratio and 7.9 mm d^{-1} by the lysimeters. Vegetation on the lysimeters and at the Bowen ratio sites differed in density and vigor in a manner consistent with the evapotranspiration measurements. Given these differences, the agreement between methods is judged excellent.

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

"Water Use by Phreatophytes," *Proceedings, World Meteorological Organization Symposium on Forest Meteorology*, University of Ottawa, Ottawa, Ontario, Canada, August 21–25, 1978, World Meteorological Organization No. 527, Geneva, 1978.

The relatively infrequent watercourses in the semi-arid southwestern United States are lined with dense stands of phreatophytes. The high consumptive use rates of such water-loving vegetation are of particular concern in this water-short region, where evapotranspiration from wildlands competes with higher priority uses, such as irrigated agriculture and municipal water supplies.

This study reports the application of an energy budget analysis to an extensive stand of saltcedar during a period of extremely warm, dry weather. Replication of the energy budget measurements allow for a comparison of two simultaneous estimates of evapotranspiration. The energy budget measurements were conducted adjacent to a lysimeter installation so that comparisons could be made between the energy budget and the lysimetric measurement techniques.

Given the differences in conditions at the two Bowen ratio sites and on the four lysimeters, the agreement between the two techniques was judged to be excellent. The agreement adds confidence to the long-term (15 years) record obtained from the lysimeters at this site by the U.S. Bureau of Reclamation. The good agreement under the extreme conditions of measurement further substantiates the energy budget method for evaluating evapotranspiration on a short-term basis. From (Author Introduction and Summary)

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

"ET Measurements Over Riparian Saltcedar on the Colorado River," *Hydrology and Water Resources of Arizona and the Southwest*, Vol. 12, 1982, pp. 9–15.

Evapotranspiration (ET) 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 and 1981. The water table depth at the site near Blythe, California, was about 3 m during the two summers of measurement.

Daily ET totals ranged from 2.9 mm/day in early April up to 11.0 mm/day in late June, and dropped down 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 in length. The highest single day total measured by an individual system was 12.7 mm on June 28, 1981. The mid-summer ET rates from the saltcedar at this experimental site are substantial, and rank among the highest rates that have been reported elsewhere for irrigated cropland. The seasonal saltcedar water use of 1727 mm (including 90 mm of annual precipitation) is somewhat lower, however, than earlier, more speculative estimates for saltcedar that ranged up as high as 2100 mm per year.

110. Gee, G. W., and Kirkham, R. R.

"Arid Site Water Balance: Evapotranspiration Modeling and Measurements," *Report No. PNL-5177*, Battelle Memorial Institute, Pacific Northwest Laboratory, Richland, Washington, September, 1984, 38 pp.

The National Low Level Waste Management Program (NLLWMP) of the Department of Energy (DOE) established the Transport Assessment–Arid Task at Pacific Northwest Laboratory (PNL) in 1978. The primary focus of this task has been the assessment and development of modeling technology used to predict the transport of water and radionuclides through unsaturated sediment (i.e., unsaturated zone transport). Transport of materials through unsaturated soil is expected to be the dominant pathway for contaminant migration at most shallow land burial sites. To evaluate the magnitude of transport at an arid site, PNL conducted a field and modeling study to measure and predict water movement under vegetated and bare soil conditions.

We measured drainage in both bare and vegetated soil at a field location on the Department of Energy's Hanford site near Richland, Washington, during wet years (1983 and 1984). Both direct measurements of actual drainage and indirect measurements of changes in moisture profiles confirmed that water moves below the root zone and is lost to deep drainage during periods of low evapotranspiration. Measurements indicated that over 10 cm of drainage occurred during a one-year period from bare sandy soil and over 5 cm of drainage from a grass-covered field site. It should be noted that these drainage values were specific to this field site because of soil and plant characteristics. While this amount may be representative for some portion of the Hanford site, it cannot be considered as a reference for the entire site, as other site-specific characteristics could result in significantly greater or less drainage. Water balance at this field site was also estimated using UNSAT-ID, a computer model that describes transient unsaturated flow in soils. Plant evapotranspiration was simulated using a time-dependent transpiration function for cheatgrass (*Bromus tectorum*). The UNSAT-ID model simulations confirmed that coarse-textured soils could transmit water below plant root zones. Although the average annual rainfall at the Hanford site is 16 cm, the 1983 test year precipitation exceeded 28 cm with nearly three-fourths of the precipitation occurring during five winter months (January, February, March, November, December). The moisture content at all depths in the soil increased to maximum values and the monthly average potential evapotranspiration were lowest during these five months.

Moisture content profiles were measured at depth, with a down-well neutron probe, at biweekly intervals from January 1983 through June 1984, and these data were used to estimate drainage from the profile. Grass roots were not found below 1 m, hence, moisture changes below 1 m were assumed to be caused primarily by drainage. Upward capillary flow was considered negligible because the soil was a coarse sand and the water table was below 10 m. The large amount of drainage from this arid site is attributed to rainfall distribution pattern, shallow root zone, and soil drainage characteristics. These observations confirm earlier observations by Cline, Uresk and Rickard (1977) that drainage can occur below grass-covered areas at the Hanford site.

Simulations using the unsaturated flow model predicted about 5 cm of drainage from the grass site using daily climatic data, measured soil hydraulic properties, and estimated transpiration parameters for cheatgrass at the Hanford site. Improvements in the comparisons between measured and predicted drainage are anticipated with more direct measurements of grass cover transpiration. However, both measurements and model predictions support the conclusion that under conditions where above average rainfall occurs during periods of low potential evaporation and where soils are coarse, significant drainage can occur from the root zone at an arid site.

Waste management at arid sites in the western United States will require that special attention be paid to soil characteristics, precipitation distribution, and plant cover to adequately predict site-specific recharge rates. Infiltration barriers may be required at sites where recharge is found to be significant. The UNSAT-ID model appears to be a useful tool in assessing unsaturated-zone recharge at arid sites. (Authors' Summary)

111. Gifford, G. F.

"Approximate Annual Water Budgets of Two Chained Pinyon-Juniper sites," *Journal of Range Management*, Vol. 28, No. 1, 1975, pp. 70–74.

Approximate annual water budgets for various pinyon-juniper treatments (chaining-with-windrowing, chaining-with-debris-in-place, and natural woodland) have been compiled for a three-year period near Milford, Utah, and for a two-year period near Blanding, Utah. Results of the analysis indicate that most of the annual precipitation falling on each treatment is lost through evapotranspiration, with much of the balance being lost through interception. When runoff did occur, it was greatest from windrowed treatments and least from debris-in-place treatments.

112. Gifford, G. F., Humphries, W., and Jaynes, R. A.

"Preliminary Quantification of the Impacts of Aspen to Conifer Succession on Water Yield Within the Colorado River Basin (A Process Aggravating the Salt Problem)," *Report No. UWRL/H-83/01*, Utah State University, Utah Water Research Laboratory, Logan, Utah, 1983, 73 pp.

Quaking aspen cover 3.3 million hectares in the Upper Colorado River Basin, and these areas are gradually converting to conifer forest by the natural process of ecological succession. This change is being hastened by forest management practices that reduce fires, destroy pests, or otherwise prevent the natural processes that previously caused conifer areas to revert to the subclimax aspen. The hydrologic consequence has been forecast to cause a runoff reduction in the Colorado River as large as one million acre-ft annually, a major blow to water availability in the Lower Basin. Understanding and dealing with the problems requires quantitative comparison of the evapotranspiration rates of conifer aspen forests under a variety of conditions. For this comparison, heat pulse velocity techniques were developed for monitoring water movement in aspen (*Populus tremuloides*), subalpine fir (*Abies lasiocarpa*), and Englemann spruce (*Picea engelmannii*).

113. Gisser, M.

"Agricultural Demand for Water in the Pecos River Basin: An Addendum," *Water Resources Research*, Vol. 9, No. 5, 1973, pp. 1429–1432.

A study that deals with importing water to the Pecos River basin and using this water without artificial recharging (Gisser 1970) is compared with another study that deals with the problem of recharging imported water into the aquifer (Gisser and Mercado 1972). The sensitivity of the demand for water function to changes in salinity constraints is explored, and the possibility of reducing natural discharge of water by lowering the evaporation rate of saltcedars is investigated.

114. Glenn, E. P., and O'Leary, J. W.

"Productivity and Irrigation Requirements of Halophytes Grown with Seawater in the Sonoran Desert," *Journal of Arid Environments*, Vol. 9, 1983, pp. 81–91.

Native and exotic halophytes (genera *Atriplex*, *Salicornia*, *Distichlis*, *Cressa*, and *Batis*) were grown in field trials in Puerto Penasco, Sonora, Mexico using hypersaline (40%) seawater for irrigation. The most productive halophyte species yielded 1364–1794 g dry weight per square meter (DW/m^2) per annum. The minimum effective water rate was 18 m/year, using undiluted seawater and the flood method of application. Using 10% artificial seawater and the sprinkler method of application, *Salicornia bigelovii* yielded over 1000 g DW/m^2 with only 2.4 m of water. *Atriplex* plants were 12–17% protein but ash content was also high. The economic feasibility of seawater agriculture will depend on introducing desirable crop characteristics into halophytes and developing efficient, high frequency irrigation systems for seawater.

115. Grable, A. R., Hanks, R. J., Willhite, F. M., and Haise, H. R.

"Difference of fertilization and altitude on energy budget for native meadows," *Agronomy Journal*, Vol. 58, 1966, pp. 234–237.

Experiments were conducted for two years near Gunnison, Colorado, to evaluate the influence of N fertilizer and altitude on energy budgets of native wet meadows. Measurements included evapotranspiration from lysimeters (E_t), evaporation from Weather Bureau pans (E), net radiation (R_n), total short-wave radiation (R_s), soil heat flow (S), air and soil temperatures, wind velocity, precipitation, and forage yields.

During two periods of 1963, R_n, advected heat (A), and E_t were slightly but not significantly altered at one location by application of N fertilizer. S was 2% or less of R_n and A to lysimeters ranged from 6 to 11% of E_t when data from all plots were averaged.

Studies during the entire growing season of 1964 at altitudes of 2240, 2350, 2670, and 3080 m indicated that R_n, R_s, and E cannot be used to accurately predict E_t for high-altitude wet meadows. Although changes in R_n or R_s were generally accompanied by changes in E or E_t, the ratios of the values changed sharply during the season because of advected energy and crop harvest. During at least 1 or 2 weeks just before midseason harvest, S was negligible and sensible heat flux to the lysimeters (−A) was as much as 26% of E_t; after harvest, however, S was about 20% of E_t and sensible heat flux from the lysimeters (+A) was as much as 97% of E_t. E_t, E, and A (to lysimeters) during comparable periods generally decreased as altitude increased. The greatest photosynthetic efficiency obtained was about 2% of R_n; usually it was much less.

116. Graf, W. L.

"Tamarisk and River Channel Management," *Environmental Management*, Vol. 6, No. 4, 1982, pp. 283–296.

Tamarisk (*Tamarix chinensis*, Lour.) an artificially introduced tree, has become a most common species in many riparian vegetation communities along the rivers of the western United States. On the Salt and Gila rivers of central Arizona, the plant first appeared in the early 1890's, and by 1940 it grew in dense thickets that posed serious flood-control problems by substantially reducing the capacities of major channels. Since 1940 its distribution and density in central Arizona have fluctuated in response to combined natural processes and human management. Groundwater levels, channel waters, floods, irrigation return waters, sewage effluent, and sedimentation behind retention and diversion works are major control mechanisms on the growth of tamarisk; on a regional scale of analysis, groundwater levels are the most significant under present conditions.

117. Grosz, O. M.

"Evapotranspiration by Woody Phreatophytes," *Tenth Progress Report–Humboldt River Research Project*, Nevada Dept. of Conservation and Natural Resources–Division of Forestry, Carson City, Nev., in cooperation with Bureau of Reclamation and U.S. Geological Survey, 1969, pp. 2–5.

Studies of evapotranspirational water loss from woody phreatophytes grown in lysimeter tanks, located in the Humboldt River Research project study area near Winnemucca, Nevada, were continued as in previous years. The program has been in progress since 1959 and is a cooperative effort by the State of Nevada, U.S. Geological Survey and the U.S. Bureau of Reclamation. The purpose of this study has been to determine the seasonal water use by greasewood, rabbitbrush, willow and wildrose and evaporation of water from bare soil. During the 1968 growing season, water use by the four phreatophyte species was measured in nine lysimeter tanks, of which two each were planted with greasewood, willow and wildrose and three with rabbitbrush. Soil-moisture determinations were made in nine lysimeter tanks, in the Humboldt River flood plain near Winnemucca and in the study area. The soil-moisture determinations were made in early April, August and late October. (Author introduction)

1970, Progress report on studies of evapotranspiration by woody phreatophytes for 1969 growing season. *In:* Eleventh Progress report, Humboldt River Research Project, Nevada Department of Conservation and Natural Resources, p. 1–18. (Continuation of work outlined in 10th Progress Report)

1971, Progress report on studies of evapotranspiration by woody phreatophytes for the 1970 growing season. *In:* Twelfth Progress report, Humboldt River

Research Project, Nevada Department of Conservation and Natural Resources, p. 1–21. (Continuation of work outlined in 10th Progress Report)

1972, Progress report on studies of evapotranspiration by woody phreatophytes during the 1971 growing season. *In:* Thirteenth Progress Report, Humboldt River Research Project, Nevada Department of Conservation and Natural Resources, p. 1–22. (Continuation of work outlined in 10th Progress Report)

118. Gutknecht, P. J., Rice, W. A., Cole, C. R., and Freshley, M. D.

"Pasco Basin Hydrometeorological Study," *Report PNL-3855 (RHO-BWI-C-98)*, Battelle Memorial Institute, Pacific Northwest Laboratory, Richland, Wash., Prepared for Rockwell Hanford Operations, April, 1980, 31 pp.

Rockwell Hanford Operations (Rockwell) is conducting a research and assessment project under contract with the U.S. Department of Energy (DOE) to investigate the feasibility of deep geologic isolation of radioactive wastes within the Columbia River Basalt Group beneath the Hanford Site in Washington State. Project activities include an evaluation of groundwater dynamics within the Pasco Basin. A detailed recharge potential based on hydrologic budget analysis is required in this phase of the project. Previous groundwater recharge evaluations such as Rockwell's Columbia Plateau surface hydrology studies do not contain sufficient detail within the Pasco Basin as may be required for Rockwell's detailed mathematical groundwater models. The hydrometeorological data must also be updated. Hence, this report contains the updated, detailed precipitation and evapotranspiration distributions necessary in groundwater recharge calculations for the Pasco Basin. Data collection and interpolation methodology are also discussed in detail.

This project was jointly supported by funds from Rockwell's Basalt Waste Isolation project and Pacific Northwest Laboratory's (PNL) Assessment of Effectiveness of Geologic Isolation System (AEGIS) program, both of which are contracts under DOE. Close interaction was made with similar activities in the AEGIS program to take advantage of current groundwater modeling developments. The methodology for interpolating precipitation, potential evapotranspiration (PET), and actual evapotranspiration (AET) is the same in both projects. The Pasco Basin hydrometeorological study is done in greater detail by employing more precipitation stations in the Hanford area and choosing a 1-mi-node spacing as compared to the 3-mi spacing in the AEGIS program. (Author Introduction)

119. Haas, R. H., and Dodd, J. D.

"Water-Stress Pattern in Honey Mesquite," *Ecology*, Vol. 53, No. 4, 1972, pp. 674–680.

Water stress (LWP) was measured in honey mesquite, *Prosopis glandulosa* var. *glandulosa* (Torr.), trees by using the pressure-chamber method to detect negative hydrostatic pressure in the xylem of leaf petioles. The method was sufficiently sensitive to measure short-term changed of ±1 bar LWP throughout the diurnal period. Mean differences between sun-exposed and shaded leaves averaged 4.7 bars LWP on a clear day in May. Although the mean LWP for five trees ranged from 15.8 to 18.1 bars LWP, the interaction of exposure and tree was relatively minor in comparison with the large diurnal differences in LWP. Diurnal changes in LWP, often greater than 20 bars, were associated with changes in the evaporative potential of the atmosphere. Total daily water stress (ΣL) and net daily water stress ($\Sigma L - \Sigma L_0$) were calculated by integrating the area under a curve formed by the periodic measurements of LWP during the diurnal period. Net daily water stress was more sensitive to changes in environmental variables than other daily summaries. Throughout the range of available soil moisture there was a close relationship between net daily water stress and the integrated evaporative potential on a daily basis.

120. Hagan, R. M., and Davenport, D. C.

"Potential Usefulness of Antitranspirants for Solution of Some Water Supply, Plant Growth, and Environmental Problems," *Project Technical Completion Report*, California Water Resources Center, September, 1973, 60 pp.

Effects of film-forming antitranspirants on rates of transpiration and photosynthesis were evaluated by leaf chamber studies using dew-point hydrometer and infrared gas analyzer to monitor water vapor and carbon dioxide content of the air stream. Promising antitranspirant materials were evaluated as to foliar coverage with the aid of a scanning electron microscope, evaluated as to techniques of application, influence of stomatal conditions, plant-water potential, and transmission of photosynthetically active wave lengths of light. Various antitranspirants were also field tested for possible use in highway landscaping, extension of life of cut flowers, aid in survival of transplants and cuttings, and improvement in fruit quality. Possible use of antitranspirants in reducing water loss by phreatophytes, without destroying vegetation and ecological balance, were also considered.

121. Hall, T. L., and Taylor, J. H.

"Water and Land Resources in Eden Valley, Wyoming," *Environmental Resources Center*, Colorado State University, Fort Collins, Colo., 1973.

An inventory of existing information on land and water resources has been undertaken for Eden Valley, Wyoming. Much of the data came from existing reports of the United States Bureau of Reclamation regarding the Eden Valley Project. Also, some data were obtained from the University of Wyoming on irrigation efficiency studies conducted in Eden Valley.

As part of this study, land use data was collected for Eden Valley. The land use data was concerned with the crops and phreatophytes in the valley in order that the consumptive use requirements could be computed. Being able to compute evapotranspiration allowed water budgets to be prepared for the 1963–1969 water years. A summary of mean monthly and mean annual water budget is reported.

122. Hammatt, W. C.

"Determination of the Duty of Water by Analytical Experiment," *Transactions of American Society of Civil Engineers*, Paper No. 1428, Vol. 83, 1919–1920, pp. 200–276.

The purpose of this paper is to show the methods used in the determination of the quantity of water required for the growth of certain crops, where it was impracticable to measure it directly. This was done by analyses of the requirements and by the separate determination, by experiment, of the specific quantity required for the different parts which go to make up the whole use of water by the plant. The circumstances attending the investigation described herein were such as to open up a new field which is not covered to any great extent in available technical literature. The, writer hopes that the description of his work in this case will bring forth discussion from others who may have treated this matter along similar or different lines, as this may broaden the scope of the literature on this very important subject.

The term "duty of water" has no hard and fast definition, and is considered by various investigators as representing different things. Some consider it to be the average annual quantity, in acre-feet, applied by the farmers in a particular locality, or on a certain class of soil, to produce their crops. Others consider it as the minimum quantity which, if applied under certain conditions, will produce a crop. The writer considers it in these pages as the quantity which can be applied with the greatest efficiency, under given conditions, for the production of crops.

Many researches have been made in various States and. agricultural localities by the Office of Experiment Stations or by State agricultural colleges, professing to obtain the duty of water for the particular localities and under the particular conditions obtaining in the area covered by the investigations. Among the most complete of these are those of Don H. Bark, and the United States Department of Agriculture. These investigations attempted to fix the economical duty be dividing each tract into three parcels, applying different quantities of water to each, and observing the results. This was a step ahead of any work done heretofore, but did not produce results sufficiently comprehensive, due to the great differences in the quantity of water applied and to the lack of a complete analysis of the reasons for the results obtained.

The experiments to be described later were for the purpose of determining the duty of water for the propagation of certain wild grasses in Southeastern Oregon. They were confined to two localities, the valley of the Chewaucan River in Lake County, and the valley of the Silvies River in Harney County. In both localities, crops of wild or native grasses are raised for forage purposes, the raising of beef cattle being the main industry. Climatic conditions in these two regions are such that crops of greater value cannot be raised economically. Both regions are subject to long and severe winters, and, even in the summers, killing frosts frequently occur, no month of the year being free therefrom. Although some garden truck is raised for local use, and there are occasional patches of alfalfa and grain, the raising of any of these on a commercial basis is a hazardous undertaking. The raising of native wild grasses, however, inured to the existing climatic conditions, is very profitable, such grasses having good food value, and the cattle raised thereon being famous for their quality.

123. Hanson, C. L.

"Model for Predicting Evapotranspiration from Native Rangelands in the Northern Great Plains," *Transactions of the American Society of Agricultural Engineers*, Vol. 19, No. 3, 1976, pp. 471–477.

A model was developed to simulate daily evapotranspiration from native rangelands in the Northern Great Plains. The model was based on the premise that evapotranspiration consists of transpiration, and evaporation from the soil and water that had been intercepted by plants. The variables in the model consisted of daily evapotranspiration, potential evapotranspiration which was computed from an energy balance algorithm or from class A pan measurements, a plant coefficient which was based on leaf area index, a soil water coefficient which accounted for limited soil water, and direct evaporation. The model parameter values were computed from data obtained at Gillette, Wyoming, Newell and Cottonwood, South Dakota, and Sidney, Montana.

124. Hanson, R. L., and Dawdy, D. R.

"Accuracy of Evapotranspiration Rates Determined by the Water-Budget Method, Gila River Flood Plain, Southeastern Arizona," *U.S. Geological Survey Professional Paper 655-L*, U.S. Government Printing Office, Washington D.C., 1976, 35 pp.

Evapotranspiration by phreatophytes (primarily saltcedar) was determined by the water-budget method for 5,500 acres (2,230 ha) of the Gila River flood plain in southeastern Arizona. The water budget consists of 12 components including surface and subsurface flow through the study area, precipitation on the area, and soil-moisture changes in the unsaturated soil profile.

Nine years (1963–71) of hydrologic data were collected on four reaches within the area. These data provided over 400 measurements of evapotranspiration for two- or three-week periods. Midway through the study the vegetation was removed from the flood plain. The evapotranspiration measurements are therefore defined for both natural vegetative cover and essentially bare-ground conditions.

This report shows how each component of the water budget was evaluated, demonstrates the significance of each component in relation to the total evapotranspiration, and describes the methods used to evaluate the relative accuracy of each component.

The two most significant components of the water budget are, generally, the Gila River inflow and outflow. One of the least significant is tributary inflow, which occurred only 4% of the time during periods of low streamflow and is one of the more difficult components to measure. The groundwater flow components are the least variable in the water budget, fluctuating only in response to seasonal changes in the downvalley groundwater slope.

The total measurement error of each component consists primarily of a sampling error which is dependent on the number of observation points used to measure the component. This error is time variant, reflecting both the variability in repetitive measurements and the error due to missing data. Included in the total measurement error is a bias error which gives a constant overestimate or underestimate of the component. Only the groundwater flow components introduce a measurable bias error, but the direction of this error is unknown and its magnitude in relation to evapotranspiration is relatively insignificant.

The total measurement error in evapotranspiration is not related to the magnitude of evapotranspiration but rather to the total volume of water moving through the area. Thus, the minimum errors occur during the midsummer months of maximum evapotranspiration when streamflow is low and precipitation is negligible.

Evapotranspiration rates computed for Reach 1 indicate that phreatophyte clearing reduced summer rates by nearly 45%. The average computed measurement errors in summer evapotranspiration rates, before and after clearing, are +59% and +113%, respectively, and the average measurement error in the change in summer evapotranspiration as a result of clearing is nearly ±200%. These large computed measurement errors are shown to overestimate substantially the true measurement variable in evapotranspiration. The computed errors do give, however, a good indication of the relative significance of each evapotranspiration value and provide a means of selecting those values which should be used in computing average evapotranspiration rates. Furthermore, the results of this error analysis show that reliable estimates of summer evapotranspiration can be determined and that a significant difference in summer evapotranspiration could be detected as a result of clearing phreatophytes from the flood plain.

125. Hanson, R. L., Kipple, F. P., and Culler, R. C.

"Changing the Consumptive Use on the Gila River Flood Plain, Southeastern Arizona," American Society of Civil Engineers, Irrigation and Drainage Division, *Proceedings of Specialty Conference, Age of Changing Priorities for Land and Water*, Spokane, Wash., 1972, pp. 309–330.

The water budget method is used to evaluate water salvage by phreatophyte control on a 15-mi length of the Gila River flood plain in southeastern Arizona. The water-budget data obtained during this 9-year study (1962–1971) provide estimates of monthly evapotranspiration from the flood plain for two conditions: (1) a cover of phreatophytes consisting primarily of saltcedar with an areal density ranging between 39 and 80% canopy cover; and (2) no phreatophytes consisting primarily of bare ground. The water-budget data for Reach 1 (1,720 acres) of the four-reach (5,500 acres) study indicate a reduction in the average consumptive use from 50 in. per year before clearing (October 1962 to February 1967) to 20 in. per year after clearing (March 1967 to September 1971). The study also develops a relation of the general form of the Blaney-Criddle equation which includes a term for canopy cover. This relation can be used to evaluate evapotranspiration for other areas of similar phreatophyte cover and climatic conditions.

126. Harr, R. D.

"Potential for Augmenting Water Yield Through Forest Practices in Western Washington and Western Oregon," *Water Resources Bulletin*, Vol. 19, No. 3, June, 1983, pp. 383–393.

Western Washington and western Oregon comprise a water-rich region that has a very uneven annual distribution of both precipitation and streamflow. Highest demand for water coincides with lowest streamflow levels between July 1 and September 30 when less than 5% of annual water yield occurs. Increases in annual water yield in small, experimental watersheds in the region have ranged up to 600 mm after entire watersheds were logged and up to 300 mm in watersheds that were 25 to 30% logged. Most of the increase has occurred during the fall-winter rainy season, and yield increases have been largest during the wettest years. Estimated sustained increases in water yield from most large watersheds subject to sustained yield forest management are at best only 3–6% of unaugmented flows. Realistically, watersheds in this region will not be managed to produce more water. Water yield augmentation will continue to be only a small and variable by-product of logging. The utility of water yield augmentation is limited by its size and by its occurrence relative to the time of water demand. In some local areas, reduction of fog interception and drip or establishment of riparian phreatophytic hardwoods may reduce summer flows.

127. Harr, R. D., and Price, K. R.

"Evapotranspiration from a Greasewood-Cheatgrass Community," *Water Resources Research*, Vol. 8, No. 5, October, 1972, pp. 1199–1203.

Groundwater elevation, soil moisture, and precipitation were monitored to evaluate the components of water loss from two greasewood-cheatgrass (*Sarcobatus vermiculatus-aromus tectorum*) communities in south central Washington. Annual evapotranspiration was 21–25 cm, 18–31% of which was the transpiration of groundwater. The greatest loss from the system was the evapotranspiration of stored soil moisture, but this moisture was unavailable to greasewood. This study confirms that water use rates are a function of depth to water up to 2.3 m, but indicates a more complicated mechanism at depths of up to 13 m. Shrub height, canopy coverage, and total leaf surface are inversely related to depth to water, and the rate of water use is in turn directly related to these plant-associated features.

128. Harrison, A. T.

"Measurement of Actual Transpiration of Native Grass Stands as a Component of Nebraska Sandhills Groundwater Hydrology," *Project Completion Report A-066-NEB*, University of Nebraska, Lincoln, Nebr., June, 1983, 45 pp.

Objectives of this project were: (1) to quantify the role of native vegetation in site-specific evapotranspiration and to document consumptive use by native grass species on different sandhill soil types; and (2) to identify which vegetation/soil sites may act as important hydrologic water table recharge sites based on site-specific precipitation/transpiration/percolation dynamics. Data were collected on plant physiology and water stress relationships and consumptive use at three major topographic/soil/vegetation sites in Arthur County, Nebraska. Data on transpiration use by five dominant sandhill grass species were collected in addition to gravimetric soil moisture, bulk density and texture, all at four topographic sites at 40 to 140 cm intervals in the soil profile. Consumptive water use during a 90-day experimental period was estimated from soil moisture changes in the 140 cm profile assuming no growing season percolation occurred below 140 cm and correcting precipitation events for litter interception. Consumptive use values for the 90 days are surprisingly similar at 230 mm, 230 mm, and 213 mm for ridge, slope, and swale sites, respectively.

Total soil moisture withdrawal was least at the swale site (–31 mm) due to the shallow rooted western wheatgrass which dominates the site. Soil moisture withdrawal at the slope and ridge sites, dominated by deeply rooting warm season grasses, was –47 mm and –39 mm, respectively. During 1979, season end soil moisture profile deficits ranged from approximately 100 mm in the ridge profile to 250 mm in the swale site.

129. Harrison, A. T., Small, E., and Mooney, H. A.

"Drought Relationships and Distribution of Two Mediterranean-Climate California Plant Communities," *Ecology*, Vol. 52, No. 5, 1971, pp. 869–875.

The summer drought-deciduous coastal sage in Southern California near Los Angeles has a bimodal, coastal and interior, distribution at low elevations (sea level to 300 m), whereas the evergreen sclerophyllous chaparral is best developed at higher elevations. Winter rainfall is 300–350 mm at the low elevations and 500–600 mm at the higher elevations. Photosynthesis and transpiration in response to artificial drying were examined in field- collected leaves of species from the two vegetation types. The fully hydrated mesomorphic leaves of the coastal sage species has initially higher photosynthesis and transpiration rates which declined rapidly during the first 20–30 min of drying, presumably because of hydroactive stomatal closure. At zero net photosynthesis cuticular loss of water was high, nearly 25% of the maximum rate for these species. In the chaparral species photosynthesis and transpiration rates were one-fourth to one-third those of the coastal sage species. Decline of rates with drying time was not nearly as rapid. Net photosynthesis continued at 20–30% of maximum after 70–80 min with lower cuticular losses of water vapor. During cool spring periods with sufficient soil moisture, high transpiration and assimilation rates allow for rapid growth, flowering, and fruiting in plants of the coastal sage community. They are drought-evading by virtue of their summer deciduous habit and are better adapted to prolonged summer drought in areas of low rainfall. Chaparral species, at slightly higher altitudes with higher precipitation and with deeper and more extensive root systems and xeromorphic leaf characteristics, are less sensitive to conditions of high evaporative demand and can maintain net assimilation, although low at times, throughout the long summer drought period.

130. Hart, G. E., Schultz, J. D., and Coltharp, G. B.

"Controlling transpiration in aspen with phenylmercuric acetate." *Water Resources Research*, Vol. 5, No. 2, April, 1969, pp. 407–412.

A 0.001 M spray of phenylmercuric acetate was applied by helicopter to part of an aspen stand in northern Utah in June 1967. The natural fluttering action of the aspen leaves facilitated delivery of the spray to the stomate-bearing underside of the leaves. Nine days after treatment, stomate width on treated trees averaged 2.4 as compared with 4.0 measured on untreated trees. Heat pulse measurements indicated reduction in daylight sap velocity from 11 cm/hr to 6 cm/hr. Seasonal soil moisture depletion was not significantly affected, although the pattern of water usage was delayed for about 6 weeks on the treated area.

131. Hedlund, J. D.

"Water Conservation and Salvage," U.S. Department of Agriculture, Soil Conservation Service, *Interim Summary Report*, September, 1973, 26 pp.

As a part of its cooperative effort in the Western U.S. Water Plan, SCS is undertaking a study of water conservation and salvage potentials in the 11 Western States. Field data including potential for improving quality and efficiency are being collected at this time for a report later this year. This interim report, prepared from secondary sources, has been developed as an initial aid in preparing material for the final westwide report and for a perspective of the overall irrigation water use situation in the West. (Author Introduction)

132. Hibbert, A. R.

"Increases in Streamflow after Converting Chaparral to Grass," *Water Resources Research*, Vol. 7, No. 1, 1971, pp. 71–80, illus.

Water yield has increased substantially on two small chaparral watersheds in central Arizona following brush control and conversion to grass. Winter precipitation is the major source of water yield. Summer rains begin in July and normally account for about one-fourth of the annual precipitation but generally have little effect on streamflow. When annual precipitation is less than 16 in., increase in water yield resulting from treatment is likely to be less than 2 in. However, the efficiency of the conversion for producing extra water improves with rainfall, at least up to 34 in. At this amount of annual precipitation, the increase in flow may reach 12 in. or more, depending on seasonal distribution of the rain. (Author Abstract)

133. Hibbert, A. R.

"Potential for Augmenting Flow of the Colorado River by Vegetation Management," *Proceedings of 21st Arizona Watershed Symposium*, Report No. 10, Arizona Water Commission, Tucson, Ariz., 1977, pp. 16–21.

This paper summarizes a much more detailed paper entitled "Vegetation Management for Water Yield Improvement in the Colorado River Basin." Water supplies in the Colorado River Basin, while generally adequate for current needs, may not be sufficient to meet all the demands for water anticipated from rapid growth and energy development by the year 2000. One method under consideration for augmenting the water supply is management of vegetation and snow to reduce evapotranspiration. Potential increases in water yield were given for eleven cover types. This is compared to two previous evaluations. An overall assessment of basin water yield potential was made using these data. Costs, public acceptance, and other considerations were discussed. (Compiler's Summary)

134. Hibbert, A. R.

"Vegetation Management for Water Yield Improvement in the Colorado River Basin," U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo., July, 1979, 58 pp.

Water yield from forest and rangelands can be augmented by managing vegetation and snow to reduce evapotranspiration. Methods of managing vegetation include clearing, type conversion, patch cutting, and thinning. Snow can be trapped in forest openings and by snow fences in windswept treeless areas to reduce evaporation of windblown snow and concentrate snowmelt to enhance its delivery to streams. Some arbitrary augmentation goals were chosen to illustrate the potential for increasing water yield, and treatments were hypothesized to get these increases. Most of the water produced by vegetation management would be cheaper than imported water, and some of it from commercial forests would be in the price range of water produced by weather modification.

135. Hibbert, A. R., and Ingebo, P. A.

"Chapparal Treatment Effects on Streamflow," *Proceedings of 15th Annual Arizona Watershed Symposium,* Arizona Water Commission, Report No. 1, Phoenix, Ariz., September, 1971, pp. 25–34.

Cover type conversions on several small chaparral watersheds in Arizona over the past 10 years have produced substantial increases in water yield on favorable sites. Yield increases have averaged from more than 6 in. per year (five-fold increase in streamflow) on wet sites under dense brush to less than 1 in. on dry sites under open stands. On the wetter sites, treatment has created perennial flow from the small catchments that consistently were intermittent before conversion. There is some concern that the extra water will subsequently be lost to vegetation along downstream courses. However, because most of the water from treated chaparral is produced in the dormant season when water is already flowing in the channel system, we believe that 80% or more of the extra water will pass through to downstream storage. We assume that very little of the winter flow increase, which amounts to about 80% of the total increase from treatment, would be lost, but that a substantial part of the 20% coming in the summer might be lost to riparian plants. While some watersheds probably will prove exceptions to this rule, evidence strongly favors an optimistic outlook for retaining yield increases without eliminating downstream riparian vegetation.

136. Hidore, J.

"Regional Variation in Natural Water Consumption in the Conterminous United States," *Journal of Hydrology*, Vol. 4, 1966, pp. 79–90.

The amount of water which is consumed by natural uses varies greatly within the United States. Precipitation after reaching the ground is consumed by a variety of processes among which are evaporation, transpiration, and additions to groundwater supply. Since all of these factors vary from place to place, so will the total amount of water consumed by these processes. The area where the greatest amount of water is consumed is in southeastern United States in the Atlantic and Gulf Coastal Plains. Here natural water consumption reaches 40 to 50 in. per year. The water use reaches a maximum here as a result of abundant precipitation, high rates of evapotranspiration, and extremely permeable surface materials. Natural water use is least in the interior desert of southwestern United States due to limited precipitation. Natural water consumption measured as a percent of precipitation varies as well as the volume consumed. Over a large portion of western United States natural water consumption processes utilize over 90% of the precipitation. The percentage reaches low values of 40 to 50% in the mountains of the Pacific Northwest and in the New England Highlands.

137. Hill, R. W., Allen, L. N., Burman, R. D., and Brockway, C. E.

"Meadow ET in the Bear River Basin of Utah, Wyoming and Idaho," *Proceedings of Water Forum 86*, American Society of Civil Engineers Specialty Conference, Long Beach, Calif., Aug. 4–6, 1986, pp. 823–830.

Neither the SCS Blaney-Criddle or the Modified Penman ET equations can be used to predict irrigated meadow ET in the Upper Bear River Basin without calibration. A cooperative study involving Utah State University and the Universities of Idaho and Wyoming was begun in 1982 to assist the Bear River Commission in their statutory obligation of determining a duty of water under the Bear River compact. The study involved installing 7 non-weighing lysimeters in three states for the determination of meadow ET. At all study sites, climatic factors are measured by the use of Campbell Scientific CR21 automated weather stations. The study sites are located south of Evanston, Wyoming at an elevation of 7550 ft, near Randolph, Utah at an elevation of 6280 ft and near Bear Lake close to Montpelier, Idaho at an elevation of 5930 ft. The 1000-ft difference in elevation lead to marked differences in plant composition and other factors in the meadows. Most of the plants are grasses or grass like plants usually classified as sedges and rushes. In addition, many weeds and flowers also exist.

138. Hines, L. B.

"Quantification of Naturally-Occurring Evapotranspiration from Smith Creek Valley, Nevada: Application of Lysimeter and Hydraulic Conductivity Methods to a Semiarid Basin." Candidate for the U.S. Geological Survey Water-Supply Paper series, "Selected Papers in the Hydrologic Sciences," Carson City, Nev., 1984 (Manuscript in Review).

Naturally-occurring evapotranspiration from the groundwater reservoir in 1983 at Smith Creek Valley, Nevada, was estimated using foliage-volume, density-dependent rates which were based on earlier lysimeter measurements acquired near Winnemuca, Nevada. Naturally-occurring vegetation was grouped into five zones on the basis of foliage-volume density and plant-species composition. Evapotranspiration rates for three zones dominated by greasewood (*Sarcobatus*) ranged from 0.1 to 0.8 ft per year, whereas the rate for stands of pure rabbitbrush (*Chrysothamnus*) was 0.3 ft per year. A value of 0.5 ft per year used in previous work was applied to grass zones (*Distichlis* and *Elymus*). Discharge from the bare soil playa was estimated by discretizing vertical hydraulic head gradient into zones bounded by contours of 0.05 ft per ft and then by applying Darcy's Law. Evapotranspiration rates for bare soil ranged from less than 0.1 to 0.5 ft per year. Estimated annual evapotranspiration was 5,650 and 2,400 acre-ft for natural vegetation and bare soil, respectively (rounded to nearest 50 acre-ft) or a total groundwater discharge of approximately 8,050 acre-ft per year.

139. Hood, J. W., and Rush, F. E.

"Water-Resources Appraisal of the Snake Valley Area, Utah and Nevada," *Utah State Engineer Technical Publication No. 14*, prepared by U.S. Geological Survey in cooperation with Utah State Engineer and Nevada State Engineer, 1965, 43 pp.

The Snake Valley area is a north-trending narrow depression that extends about 135 mi along the central Nevada-Utah border. The area covers about 3,480 mi^2. Within the area, the principal groundwater reservoir is in the unconsolidated deposits of Quaternary and Tertiary age that underlie about 1.2 million acres. Carbonate rocks of Paleozoic age may form another reservoir system and locally may control the movement of groundwater.

Water in the Snake Valley area is derived mostly from precipitation in the surrounding mountains; however, about 4,000 acre-ft are estimated to enter the area as groundwater underflow from adjacent Spring Valley, Nevada. The Deep Creek and Snake Ranges produce most of the runoff and groundwater recharge. The estimated average annual runoff from the mountains above an altitude of 7,000 ft is 58,000 acre-ft. Of this amount, 38,000 acre-ft, is generated in Nevada. Much of the runoff percolates into the alluvium recharging the groundwater reservoir. The estimated average annual groundwater recharge is 105,000 acre-ft, including the inflow from Spring Valley of the recharge, 65,000 acre-ft is generated in Nevada.

Evapotranspiration of groundwater is estimated to be 80,000 acre-ft per year. The subsurface outflow northward to the Great Salt Lake Desert in the alluvium is estimated to be 10,000 acre-ft per year. The difference between the identified discharge and the recharge, about 15,000 acre-ft per year, may be the amount of the groundwater flow from the valley fill to the carbonate-rock reservoir. Discharge from wells in 1964 was about 7,000 acre-ft.

The recoverable groundwater stored in the uppermost 100 ft of saturated alluvium is estimated to be at least 12 million acre-ft. The preliminary estimate of the perennial yield of the Snake Valley area is about 80,000 acre-ft.

The chemical quality of all water samples from the alluvial area south of the Great Salt Lake Desert indicated that the groundwater is generally suitable for irrigating crops and for domestic use. Most samples had a low to moderate salinity and a low sodium hazard.

Present development of water in the Snake Valley area is limited mainly to use of creeks and springs in the Callao, Trout Creek, and Baker-Garrison-Big Spring Creek area. These supplies are supplemented by pumping from wells at Callao, Baker, and Garrison during dry years. Water from wells is used for irrigation at Eskdale and Partoun. Potential development of groundwater is large because little of the perennial yield, an estimated 80,000 acre-ft, is utilized (Summary).

140. Hood, J. W., and Waddell, K. M.

"Hydrologic Reconnaissance of Skull Valley, Tooele County, Utah," *Technical Publication No. 18,* State of Utah, Department of Natural Resources, 1968, 42 pp.

Skull Valley is a north-trending narrow depression that extends about 50 mi from the vicinity of Lookout Pass in T. 8 S., R. 7 W., northward to the southwestern shore of Great Salt Lake. The Skull Valley drainage basin includes about 880 mi^2. In the valley, the main groundwater reservoir is in unconsolidated rocks of late Tertiary and Quaternary age and underlies about 230,000 acres.

The source of all water in Skull Valley is precipitation which falls mainly on the Stansbury and Onaqui Mountains. The estimated potential long-term average annual runoff from the uplands is about 32,000 acre-ft of water, but only a small part of this amount flows out of the valley. The remainder becomes recharge or is lost by evapotranspiration within the valley.

The estimated average annual groundwater recharge and discharge is in the range of 30,000–50,000 acre-ft per year. Groundwater is discharged from Skull Valley by evapotranspiration, wells, surface outflow, and underflow from the mouth of the valley. of these, evapotranspiration accounts for 80–90% of the total groundwater discharge. In 1965, wells discharged only about 5,000 acre-ft of water.

The estimated perennial yield of groundwater in Skull Valley is 10,000 acre-ft or less. Water in excess of this amount would have to be drawn from storage. Recoverable water in storage in the upper 100 ft of the saturated unconsolidated rocks is estimated to be about 2.3 million acre-ft, but only about 1 million acre-ft of the groundwater is believed to be of a chemical quality suitable for irrigation and domestic use.

The chemical quality of water limits potential development of Skull Valley. The range of concentration of dissolved solids in the drainage basin is 98 to 17,200 ppm (parts per million). Most of the water from the area north of Iosepa and from parts of the valley south of Iosepa is saline. The freshest water is from streams and springs in the Stansbury Mountains. Water of good chemical quality underlies the alluvial apron that borders the area of greatest recharge—the Stansbury and Onaqui Mountains. Water of chemical quality suitable.for irrigation, with low to moderate sodium and salinity hazards, may underlie as much as 100,000 acres.

141. Horton, J. S.

"Evapotranspiration and Water Research as Related to Riparian and Phreatophyte Management," U.S. Department of Agriculture, Forest Service, *Miscellaneous Publication No. 1234*, 1973, 192 pp.

Determining actual or potential water losses from vegetation is difficult because of the complexity of the factors affecting evapotranspiration and the many problems involved in their measurement. Though many techniques for determining water losses from vegetation have been developed, the data obtained tend to be inconclusive and difficult to apply in wild-land management. The purpose of this abstract bibliography is to bring together published information that will help land managers and research workers to: (1) Evaluate relations of vegetation to water loss and (2) estimate the probable effect on water yield of manipulating vegetation. (from Author's Introduction)

142. Horton, J. S.

"Management Problems in Phreatophyte and Riparian Zones," *Journal of Soil and Water Conservation*, Vol. 27, No. 2, 1972, pp. 57–61.

At present there is a great need for basic research on water loss from vegetation and the ecology and life history of the plants involved. There is also a great need for resource managers and interested citizens to get together and decide what should be done to realize the greatest benefits from all resources in phreatophyte and riparian zones. Perhaps a resource classification aimed at optimum use of these lands could be developed. Natural values must not be sacrificed for immediate economic gains before sound management plans can be developed to use wisely the intrinsic resources of the lands. In some areas, immediate action is needed to preserve existing resources. (Author's Conclusions)

143. Horton, J. S.

Management of Moist-Site Vegetation for Water: Past History, Present Status and Future Needs, U.S. Department of Agriculture, Forest Service, San Francisco, California (Contract Report printed cooperatively with Bureau of Reclamation for Pacific Southwest Inter- Agency Committee), February, 1976, 41 pp.

This is a summary report on the state of the art of watershed management and water salvage techniques. It outlines:

a. The history of research leading to the buildup of knowledge in the field of land management as applied to water. The shift from considering forests and other vegetation as producers of water to the realization that they are users of water yield without causing floods or the destruction of other resources is covered.
b. The application of past research results and observations in the phreatophyte and riparian zones. The present knowledge about these types of vegetation and their management is discussed, including a listing of pertinent literature.
c. The pressing need for further research and evaluation of present conditions in natural vegetation management, emphasizing moist-site zones. (Compiler's Summary)

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

"Management of Phreatophyte and Riparian Vegetation for Maximum Multiple Use Values," U.S. Department of Agriculture, Forest Service, *Research Paper RM-117*, 1974, 23 pp.

Summarizes the status of our knowledge about environmental relations of vegetation along watercourses in the southwestern United States, and impacts of vegetation management to reduce evapotranspiration on other resource values. Reviews the literature on measurement and evaluation of water losses from moist-site vegetation, ecological relationships, other resource uses of phreatophyte and riparian areas, and control methods. Suggests approaches to management of moist-site areas by zones based primarily on water table depth, elevation, and tree species.

145. Horton, J. S., Robinson, T. W. and McDonald, H. R.

"Guide for Surveying Phreatophyte Vegetation," U.S. Department of Agriculture, Forest Service, *Handbook No. 266*, 1964, 37 pp.

This handbook presents a survey procedure based upon random samples that can be tested for statistical reliability. It is concerned principally with surveys designed to collect information that can be used as a basis for management of vegetation along

river or stream reaches. In most cases the primary purpose of this management will be to reduce uneconomic water losses (Author's Introduction).

146. Houk, I. E.

"Evaporation from Soils," *Transactions of American Society of Civil Engineers*, Vol. 94, 1930, pp. 982–985. (Letter) (No Abstract).

147. Houk, I. E.

Irrigation Engineering, Volume 1, Agricultural and Hydrological Phases, John Wiley and Sons, New York, 1951, pp. 310–313 (Reference Book–No Abstract).

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

"Determination of Water Use by Phreatophytes and Hydrophytes," Proceedings, American Society of Civil Engineers, *Journal of the Hydraulics Division*, Vol. 92 (HY2), March, 1966, pp. 63–81.

Evapotranspiration from arrowweed, saltbush, and cattail and evaporation from bare soil with depths of 2 to 4 ft of water were measured in evaporimeters of 100 to 1,000 ft^2 in area along the lower Colorado River. Preliminary results show uses of 5.0 to 9.0 ft of water per year for arrowweed, 2.5 to 4.0 ft per year for saltbush, approximately 8.5 ft per year for cattail, and 0.3 to 0.9 ft per year for bare soil. Related meteorological data are included (From Author Abstract).

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

"Operation of Evapotranspiration Tanks near Yuma, Arizona," in Investigation of the Water Resources of the Lower Colorado River Area, *Progress Report, Open-File Report No. 3*, U.S. Geological Survey, Water Resources Division, Branch of Ground Water, Yuma, Ariz., May, 1964, 13 pp.

The amount of water consumed by phreatophytes depends on many factors, some of which may be interrelated. Thus, the proper interpretation of water-use data derived from tank experiments requires that the conditions of the experiments be well defined. The purpose of this report is to present data obtained by operation of the tanks during 1963 and the first 3 months of 1964, and to review some of the factors that may have affected the results.

The transpiration tanks are in the Colorado River floodplain between Imperial Dam and Laguna Dam. They are in two areas about 3 mi apart, in environments typical of the species being studied. The nine tanks near Imperial Camp, California, about 1 mi south of Imperial Dam, contain saltbush, arrowweed, and bare soil (3 tanks each). Six tanks on the west side of Mittry Lake, about 1 mi northeast of

Laguna Dam, contain cattail (3 tanks), carrizo (2 tanks), and open water. (From Authors' Introduction).

150. Hughes, W. C.

"Economic Feasibility of Increasing Pecos Basin Water Supplies Through Reduction of Evaporation and Evapotranspiration," *WRRI Report No. 9*, New Mexico Water Resources Research Institute, New Mexico State University, 1970, 38 pp.

Each year a large portion of the southwestern water supply is lost through evaporation and plant transpiration. The growing threat of an insufficient water supply in the Southwest makes vegetation manipulation and evaporation suppression for reducing these losses increasingly attractive. These losses can be successfully reduced, but it has been difficult to estimate how much additional water could be produced by large-scale vegetation management and evaporation control, and whether such a program would be feasible.

A hydrologic model was developed for the Pecos River Basin in New Mexico to estimate the additional water that could be obtained by vegetation treatment in the forested headwater areas, by removing phreatophytes in the lower river valley, and by applying monolayer films on the major reservoirs in the Pecos Valley. The costs and benefits attributable to the increase in water supplies estimated by the hydrologic model were analyzed to determine the economic feasibility of such a program. Results of this analysis were as follows:

a. Removal of timber from the forested headwater region of the Pecos watershed would increase the water yield by about 15%, but was currently unfeasible because the recreational value of the forests far exceeded the value of the additional water.
b. The annual water gain of 70,000 acre-ft from the eradication of phreatophytes in the Pecos Valley justified the cost of their removal.
c. Suppression of evaporation during late summer and fall was feasible in the Pecos Valley and would yield approximately 4,000 acre-ft of water annually.

151. Hughes, W. C.

"Effects on Water Supply Due to Salt Cedar Removal," American Society of Civil Engineers, National Water Resources Engineering Meeting, January, 1971, Phoenix, Ariz., *Preprint 1290*, 30 pp.

The purpose of the investigation described in this article was to explore some of the facets of the interaction between salt cedar plants and their surrounding climate, and to attempt to detect under what conditions the removal of salt cedar plants might fail to yield a net increase in the water supply. The investigation involved the development of a model, based on an empirical mass transfer equation, which would simulate the water losses due to evapotranspiration with the plants in place and evaporation (primarily soil evaporation) 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. (From Author's Introduction)

152. Hughes, W. C.

"Estimation of Phreatophyte Water Use," American Society of Civil Engineers, Irrigation and Drainage Division Specialty Conference, Age of Changing Priorities for Land and Water, Spokane, Wash., 1972, pp. 191–203.

The objective of the study described in this paper was to develop a model, based on the modified Penman equation, for estimating total evapotranspiration losses from a flood plain inhabited by phreatophytes and estimating the effective water gain produced by the removal of the phreatophytes. The proposed model is discussed in the first section of this paper and the second section describes the application of the model to a reach of the Pecos River in New Mexico. In the second section the model is tested by comparing the computed evapotranspiration with the results of an inflow-outflow water balance study for the same reach. (From Author's Introduction).

153. Hughes, W. C.

"Simulation of Saltcedar Evapotranspiration," Proceedings, American Society of Civil Engineers, *Journal of Irrigation and Drainage Division*, Vol. 98 (IR4), December, 1972, pp. 533–542.

The objectives of this study were to determine the surface dependent variables representative of a stand of saltcedar, to relate the surface roughness, height and surface diffusion resistance so determined to physical and climatic parameters in order to generalize the variables, and finally to test the simulation model derived by combining these relationships with the modified Penman equation.

In addition to the results of the study, the article describes the data and its adjustment for variations in volume density, the procedure used to determine the surface dependent variables and their relationships with physical and climatic parameters, and the sensitivity of the modified Penman equation to variations in the surface dependent variables. A description of the modified Penman equation is included. (From Author's Introduction)

154. Idso, S. B.

"Relative Rates of Evaporative Water Losses from Open and Vegetation Covered Water Bodies," *Water Resources Bulletin*, Vol. 17, No. 1, February, 1981, pp. 46–48.

A review of literature pertaining to the relative rates of evaporation from vegetation covered and open-water bodies is presented. The review indicates that the only reliable experiments capable of correctly addressing this question are those conducted *in situ*. Experiments of this nature show the ratio of vegetation covered (swamp) evaporation to open water evaporation to generally be less than unity over extensive surfaces and to only approach unity for vegetation that is young and vigorous. Recent experimental evidence presented within a theoretical context, however, indicates that even in the latter situation the ratio may never reach unity. Consequently, over large lakes and reservoirs, the presence of vegetation may actually be a water conservation mechanism with the eradication of the vegetation leading to significantly increased evaporative water losses.

155. Johnston, R. S.

"Evapotranspiration from Bare, Herbaceous, and Aspen Plots: A Check on a Former Study," *Water Resources Research*, Vol. 6, No. 1, 1970, pp. 324–327.

Soil moisture depletion was measured and evapotranspiration estimated on high elevation plots with three cover conditions: bare, herbaceous, and aspen-herbaceous. Neutron moisture measurements were taken to a depth of 9 ft. The 4-year average annual evapotranspiration losses were 11.28, 15.27, and 21.00 in. from the bare, herbaceous, and aspen-herbaceous plots, respectively. Summer rainfall varied from 1.13 to 10.43 in. during this study. Soil moisture depletion to a depth of 6 ft and estimated evapotranspiration on these plots were reported by Croft and Monninger (1953). The results of this present study substantiate the earlier report concerning the comparative water savings to be realized by vegetative manipulation. They show that removing deep-rooted aspen can reduce the average evapotranspiration by about 6 in. per year from a 9-ft profile.

156. Johnston, R. S., Tew, R. K., and Doty, R. D.

"Soil Moisture Depletion and Estimated Evapotranspiration on Utah Mountain Watersheds," U.S. Department of Agriculture, Intermountain Forest and Range Experiment Station, *Research Paper INT-67*, Ogden, Utah, 1969, 13 pp, illus.

Soil moisture depletion was measured with a neutron moisture probe on 14 sites representing 10 vegetation types on mountain watersheds in Utah. A water balance equation was used to estimate evapotranspiration (ET). Both soil moisture depletion and ET varied considerably between sites and from year to year. Aspen (*Populus tremuloides*) sprouts utilized from 0.48 to 4.50 in. less water from 6 ft of soil than mature aspen; Gambel oak (*Ouercus gambelii*) sprouts utilized from 0.25 to 1.15 in. less water than mature oak. By converting aspen to grass, ET losses were reduced from 1.08 to 5.18 in. from the surface 6 ft of soil and up to 7.59 in. from a 9-ft soil depth.

157. Keller, W.

"Limits on Western Range Forage Production–Water or Man," *Journal of Range Management*, Vol. 24, No. 4, 1971, pp. 243–247.

Water is generally regarded as the limiting factor in forage production on arid rangeland. If 800 lb. is taken as the water requirement for a pound of range forage, 12 in. as the average precipitation, and 400 lb. as the average forage production/acre, only 12.5% of the precipitation, or 1.5 in., is used in producing the forage crop. If we estimate that in addition, ½ in. is lost to deep percolation, 1 in. to over-the-surface runoff, and 1 in. to undesirable vegetation, we account for 4 in. Thus, the remainder, two-thirds of the total precipitation, is lost by evaporation, without benefit to man. The importance of the resource lost by evaporation is discussed in relation to the potential productivity of arid lands.

158. Kipple, F. P.

"The Hydrologic History of the San Carlos Reservoir, Arizona, 1929-71 with Particular Reference to Evapotranspiration and Sedimentation," *U.S. Geological Survey Professional Paper 655-N*, U.S. Government Printing Office, Washington, 1977, 40 pp.

Reservoir data records were used in an investigation of evapotranspiration from the water-surface area. A water-budget analysis indicates that the evapotranspiration loss was 11.3% and the evaporation loss was 10.5% of the total outflow from the reservoir during 1931–71.

The water-budget computations were used to develop ratings relating lake stage to usable bank storage. The rating developed for the 1948–71 period indicates that usable bank storage is approximately 159,000 acre-ft (196 cubic kilometers (km^3)), or about 14% of total usable storage capacity, if the reservoir is filled to the spillway level of 2,511 ft (765 m).

A procedure was developed to simulate sediment deposition in the reservoir. The procedure was used to estimate the change in storage capacity between five reservoir capacity surveys made during the period 1914–66.

159. Kline, J. R., Reed, K. L., Waring, R. H., and Stewart, M. L.

"Field Measurement of Transpiration in Douglas Fir," *Journal of Applied Ecology*, Vol. 13, No. 1, 1976, pp. 273–283.

The objectives of this study were: (1) to measure the rate of water transport in Douglas fir in the field and (2) to extend the range of tracer measurements beyond previous limits and so to verify the generality of previous results.

Transpiration rates of Douglas fir trees (*Pseudotsugamenziesii*) were measured in the field, using tritiated water (HTO) as a tracer for water. Sites were located in the Cedar River Watershed near Seattle, Washington and in the Andrews Experimental Forest near Eugene, Oregon.

Transpiration rates ranged from 8 41 day^{-1} in a small tree to 530 1 day^{-1} in a large old-growth tree on the Oregon site.

A relationship between transpiration rate and sapwood cross-sectional area of trees was found which would permit extension of individual tree measurements to forest populations.

The HTO measurements, linked to current physical theories of evapotranspiration, permit the computation of actual daily transpiration rates for individual trees or areas of forest.

The method allows direct measurements of water loss from forests in situations where lysimeter installation would be impractical. (Author Summary)

160. Kruse, E. G., and Haise, H. R.

"Water Use by Native Grasses in High Altitude Colorado Meadows," *U.S. Department of Agriculture, Agricultural Research Service ARS-W-6*, February, 1974, 34 pp.

This paper reports measurements of evapotranspiration by meadow grasses, evaporation, and other climatological conditions in the South Park and Gunnison areas of Colorado during three summer seasons between 1968 and 1971. Several methods of estimating evapotranspiration from climate measurements under these conditions are derived and evaluated.

161. Larner, D. C., Marshall, R. M., Pfluger, A. E., and Burnitt, S. C.

"Woody Phreatophytes Along the Colorado River from Southeast Runnels County to the Headwaters in Borden County, Texas," *Report 182*, Texas Water Development Board, Austin, Tex., April, 1974, 19 pp.

The objectives of the survey were to determine the kinds, amounts, density, and distribution of the woody phreatophyte vegetation in the flood plain of the Colorado River from southeast Runnels County to the headwaters region in Borden County. (Author Summary)

162. Lauenroth, W. K., and Sims, P. L.

"Evapotranspiration from a Shortgrass Prairie Subjected to Water and Nitrogen Treatments," *Water Resources Research*, Vol. 12, No. 3, June, 1976, pp. 437–442.

Evapotranspiration was estimated by the water balance method for three water and nitrogen treatments and a control in a shortgrass prairie in northeastern Colorado in 1971, 1972, and 1973. Nitrogen was applied at a rate of 150 kg/ha to maintain soil mineral nitrogen levels greater than or equal to 50 kg/ha above control levels with and without supplemental water. The water treatment maintained soil water potential greater than –0.8 bar during the growing season and was applied with and without nitrogen. Evapotranspiration for the control and unwatered nitrogen treatments was not different and ranged from 118 to 226 mm over the three years. The three-year averages of evapotranspiration for the water and water plus nitrogen treatments were 505 and 578 mm, respectively. Evapotranspiration for the water plus nitrogen treatment agreed with potential evapotranspiration predicted by Penman's model.

163. Leaf, C. F.

"Watershed Management in the Central and Southern Rocky Mountains: A Summary of the Status of Our Knowledge by Vegetation Types," U.S. Department of Agriculture, *Forest Service Research Paper RM-142*, March, 1975, 28 pp.

This publication summarizes a series of comprehensive reports on watershed management in five major vegetation zones: (1) the coniferous forest subalpine zone; (2) the Front Range ponderosa pine zone; (3) the Black Hills ponderosa pine zone; (4) the alpine zone; and (5) the big sagebrush zone. What is known about the hydrology of these lands, what hydrological principles are important for multiresource management and what additional information is needed for each vegetation type are also discussed.

164. Leaf, C. F., and Alexander, R. R.

"Simulating Timber Yields and Hydrologic Impacts Resulting from Timber Harvest on Subalpine Watersheds," U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, *Research Paper RM-133*, February, 1975, 20 pp.

A dynamic simulation model which has been specifically designed to determine the hydrologic changes resulting from timber harvesting and corollary models which simulate timber yields are described. Emphasis is placed on the "planning unit" which is defined by environmental characteristics, including combinations of slope, aspect, elevation, and forest cover. The models are intended for use on subalpine watersheds where the primary source of streamflow is from melting snow. The hydrologic model simulates winter snow accumulation, the short- and long-wave radiation balance, snowpack condition, snowmelt, and subsequent runoff in time and space. The timber models simulate projected timber yields in response to changes in cultural treatments and/or variations in original stand and site conditions.

The models are capable of simulating a broad array of timber harvesting alternatives. Hydrologic changes and timber yields can be determined for intervals of time which can vary from a few years to the rotation age of subalpine forests (120 years and longer). In the hydrologic model, this is accomplished by means of time trend functions which compute changes in evapotranspiration, soil water, forest cover density, reflectivity, interception, and snow redistribution as the forest stands respond to management.

The models have been used to simulate the effects of forest and watershed management on several representative drainage basins in the Rocky Mountain region of the United States. Projected hydrologic changes and growth and yield subsequent to timber harvesting in lodgepole pine and spruce-fir are described in this report.

165. Leake, S. A.

"A Method for Estimating Ground-Water Return Flow to the Colorado River in the Parker Area, Arizona and California," *U.S. Geological Survey Water-Resources Investigations Report 84-4229*, September, 1984, Tucson, Ariz., 31 pp.

A method for estimating unmeasured groundwater return flow from water diverted for irrigation is needed to determine consumptive use of water from the lower Colorado River in the Parker area, Arizona and California. For use of the method, a part of Parker Valley is divided into two subareas. Groundwater under one of the subareas drains directly to the river as unmeasured groundwater return flow. Groundwater under the other subarea drains to drainage ditches and is a part of the measured surface-water return flow at the point of discharge to the river. The subareas were delineated using average annual water-table altitudes in a shallow aquifer that underlies Parker Valley. For the subarea under which groundwater drains directly to the river, groundwater return flow is estimated with a water budget. In the water budget, consumptive use is estimated on the basis of a consumptive-use value computed for irrigated land in the subarea under which groundwater drains to drainage ditches. Surface-water diversions are estimated on the basis of measured diversions to Parker Valley and irrigation requirements within the valley. Application of the method using data from 1981 resulted in an estimate of 15,400 acre-ft of groundwater return flow that discharges directly to the Colorado River.

166. Lee, C. H.

"The Determination of Safe Yields of Underground Reservoirs of the Closed Basin Type," *Transactions of the American Society of Civil Engineers*, Vol. 78, 1915, pp. 148–218, illus.

The objectives of this paper are to show the possibility and practicability of measuring the annual rate of recharge of underground reservoirs of the closed-basin type, and to indicate broadly the factors which determine safe yield from a basin by artificial development, such as Artesian flow or pumping.

The paper opens by pointing out the importance of the problem in California and the Southwest. Following this there is a description of the physical features of underground reservoirs and the general principles of inflow, outflow, and storage. The body of the paper presents detailed methods and results of extended measurements, by the Los Angeles Aqueduct Bureau and the United States Geological Survey, for the determination of the rate of annual recharge of the Independence Basin, in Owens Valley, California. The subjects of percolation from stream channels, relation of precipitation and altitude, soil evaporation combined with transpiration from grass, and ground-water fluctuations, were carefully studied in the field, and original data are presented. The paper closes with a discussion of the relation which the net safe yield from a basin bears to the rate of annual recharge.

The conclusions are as follows:

a. The "underground reservoirs" of California and the Southwest are water-tight rock basins, represented by the topographic valleys, which are filled with porous alluvial material in which the voids are saturated with water.

b. Inflow into these basins is by percolation from water on the surface of the alluvial filling, which source may occur as direct precipitation, stream flow, irrigation, or flooding. Natural ground-water loss occurs in the region of lowest depression of a basin, and consists of the breaking out of water at the surface in springs or seepages, evaporation from soil, transpiration, and underflow. Artificial development, by wells or other methods, reduces the natural ground-water loss. Considered as averages, the rates of recharge and ground-water loss are equal, unless the artificial drafts is excessive.

c. The rate of recharge in a region of small precipitation and high evaporation rate can be determined most accurately, and with least expenditure of time and money, by measuring the elements which make up the ground-water loss. Of the natural elements, the most important are soil evaporation and transpiration. The underflow is relatively small and often negligible.

d. The safe yield of artificially developed ground-water obtainable from an underground reservoir is less than indicated by the rate of recharge, the quantity depending on the extent to which soil evaporation and transpiration can be eliminated from the region of groundwater outlet.

167. Lee, C. H.

"An Intensive Study of the Water Resources of a Part of Owens Valley, California," *U.S. Geological Survey Water-Supply Paper 294*, 1912, 135 pp, illus.

Same data and conclusions as Lee, 1915 above.

168. Leppanen, O. E.

"Evapotranspiration from Rapidly Growing Young Saltcedar in the Gila River Valley of Arizona," *U.S. Geological Survey Open-File Report 81-485*, 1981, 26 pp.

Estimates of evapotranspiration by young saltcedar, based on energy budget measurements, were made in an unfilled portion of the San Carlos Reservoir in east-central Arizona. Forty-eight days of record were obtained before the site was inundated. The young saltcedar, which had grown from seed earlier in the season, had an average daily evapotranspiration of 5.8 mm of water during the period August 17, 1971, to October 3, 1971. Daily values ranged from 9.2 mm to a low of 0.23 mm which occurred during a stormy day.

169. Loeltz, O. J., and McDonald, C. C.

"Water Consumption in the Lower Colorado River Valley," *Proceedings of the American Society of Civil Engineers, Journal of Irrigation and Drainage Division*, Vol. 95, No. IR1, 1969, pp. 65–78.

The large flow of the Colorado River between Davis Dam and Imperial Dam limits the reliability with which the relatively small depletions can be determined from differences in measured streamflow. However, probability studies indicate only one chance in twenty that mean differences for 17-yr periods for the several reaches will deviate more than about 60,000 acre-ft from long-term means.

Although estimates of water consumption in some reaches computed by the inflow-outflow method differ from estimates of water consumption computed by the consumptive-use method by amounts greater than the aforementioned deviation. Such differences do not appear unreasonable in view of the many uncertainities as to the true values of the individual items of each method.

Therefore, it is concluded that the average annual water consumption in the lower Colorado River valley between Davis Dam and Imperial Dam during the period 1950–1966 was probably about 1,200,000 acre-ft, the average of the estimates obtained by the inflow-outflow and the consumptive-use methods. (From Author's Summary)

170. Lowry, O. J.

"Establishment, Operation, and Maintenance of Phreatophyte Control Projects," presented at *Symposium of the Phreatophyte Subcommittee at 66-3 Meeting of the Pacific Southwest Inter-Agency Committee*, Albuquerque, New Mex., 1966, pp. 26–36.

This paper outlines the history, status and need for phreatophyte projects. Past Bureau of Reclamation phreatophyte control projects are reviewed. Preliminary data for water use by saltcedar in the Bernardo, New Mexico evapotranspiration tanks are summarized. Various means of phreatophyte clearing and control are discussed and compared including mechanical measures and herbicides. (Compiler's Summary)

171. Luxmoore, R. J., Huff, D. D., McConathy, R. K., and Dinger, B. E.

"Some Measured and Simulated Plant Water Relations of Yellow-poplar," *Forest Science*, Vol. 24, No. 3, 1978, pp. 327–341.

Data from an experimental study of the water relations of yellow-poplar (*Liriodendron tulipifera* L.) on a silt loam soil were compared with simulation results from an hourly soil-plant water relations model. Simulated annual evapotranspiration was very similar for the two years studied even though rainfall and drainage through the root zone in the second year were higher by 28 cm. Water uptake from the B1 horizon supplied 83% of the simulated transpiration. Experimental values of leaf water potential matched or were somewhat higher than simulated values. The comparison suggested that deep roots may have an important influence on plant water potential. The model results approximated hourly stomatal dynamics on about half of the measurement occasions. Simulation results for five sunny days following rainfall showed that the vegetative surface conductance and water potential had midday minima that decreased during the drying period. Evapotranspiration decreased as water stress increased, and the simulated flux of water back into the root zone from deeper soil contributed 18% of the water evapotranspired in the 5-day period. The simulation forecasted that soil water potentials decreased below –5 bars on more occasions than were observed in periodic soil water measurements.

172. Mace, A. C., Jr.

"The Influence of Climatic, Hydrologic, and Soil Factors on Evapotranspiration Rates of Tamarisk (*Tamarix pentandra* Pall.)," Doctor of Philosophy Dissertation, Department of Watershed Management, University of Arizona, Tucson, Ariz., 1968, 104 pp.

In the arid southwestern United States, where water is a limiting factor in agricultural and industrial development, a sizeable portion of the annual precipitation may be lost through evapotranspiration. In Arizona such losses account for approximately 95% of the annual precipitation.

Tamarisk (*Tamarix pentandra* Pall.) is estimated to occupy over one million acres of the flood plains and streambanks in the southwest. Although reported to use a large quantity of water, accurate estimates of evapotranspiration are unknown. Evapotranspiration processes are complex and depend on many interrelationships of the soil-plant-atmosphere system. Although, water use by tamarisk has been intensively studied, evapotranspiration measurements under different climatic and hydrologic conditions are not available.

The evapotranspiration tent was selected to measure evapotranspiration rates of tamarisk under varying climatic and hydrologic conditions. Intensive investigations of the enclosure effect of the tent were performed. Modifications of the tent reduced serious enclosure effects of the original tent.

Evapotranspiration rates measured by the tent agreed favorably with rates computed by Penman’s equation. Evapotranspiration rates for an area where the water table depth was approximately 20 ft was greater than an area where the water table depth was 14 ft. This deviation, which may be attributed to salinity, led to a laboratory investigation of the effects of salinity on transpiration rates of tamarisk.

An intensive laboratory study was conducted to determine the effect of salinity on transpiration rates of tamarisk at different vapor pressure deficits. Results indicated that the effect of salinity is dependent on vapor pressure deficit. Transpiration rates were linearity related to vapor pressure deficits at low salinity levels, but a curvilinear relationship was obtained at high salinity levels.

An estimate of saturation deficit of the mesophyll cells was determined by extrapolation of transpiration and vapor pressure deficit relationships. These data indicate minimal increases in salt concentrations in the stomatal cavities as indicated by small increases in the mesophyll saturation deficits as the salinity of the root substrate was increased.

Root permeability tests were conducted on plants subjected to varying salinity and vapor pressure deficit levels. Results indicated a significant reduction only at the highest salinity and vapor pressure deficit levels.

173. McCully, W. G., and Haas, R. H.

“An Evapotranspiration Model for Great Plains Grasslands,” in seminar, Evapotranspiration in the Great Plains, March 23–25, 1970, Bushland, Texas, *Great Plains Agricultural Council Research Committee, Publication No. 50*, Agricultural Experiment Station, Kansas State University, Manhattan, 1970, pp. 55–65.

In summary, the grasslands of the Great Plains are an important agricultural resource of this area. The vegetative cover of perennial plants in itself is a great contrast with annual crops. The variable patterns of development within a mosaic of plant species place an immediate demand upon incident precipitation. This variability in vegetation is further confounded by the differential utilization of these forages by livestock in an ever-changing pattern of selection.

Previous work by range scientists and the complex nature of the problem suggests the water balance approach to ET for these grasslands. Ecological concepts of range science have been blended with ET principles to formulate a generalized mode.

Although many of the concepts of ET developed for annual crop plants can be used as a base, the study of ET in perennial grasslands offers a provocative challenge. (Authors' Summary)

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

"Studies of Consumptive Use of Water by Phreatophytes and Hydrophytes Near Yuma, Arizona," *U.S. Geological Survey Professional Paper 486-F*, 1968, 24 pp.

Studies of transpiration by several species of flood-plain vegetation and evaporation from water surfaces and bare soil were carried out near Yuma, Arizona, during the 6-year period 1961–66. Arrowweed (*Pluchea sericea*), fourwing salthush (*Atriplex canescens*), quailbrush (*Atriplex lentiformis*), and Bermuda grass (*Cynodon dactylon*) were grown under controlled conditions in large tanks, about 1,000 ft^2 in area, and cattail (*Typha latifolia*) was grown in tanks 100 ft^2 in area. Excavated pits were filled with soil after being lined with plastic membranes. Water was fed into the bottom of the tanks to maintain a constant water table (varying from 2.0 to 5.5 ft below the surface), simulating that of the natural area. As water levels were dropped by evapotranspiration, automatic meters kept the water level at the desired depth. The larger tanks were also used for studies of evaporation from bare soil. Evaporation from water surfaces was measured by two standard U.S. Weather Bureau class A pans and by a ground-level tank, which was 10 ft by 10 ft in area. Related meteorological observations were made near the sites of the experiments, and those of nearby meteorological stations at Yuma Proving Ground and Yuma, Arizona, were used.

Annual consumptive use of water by the several species increased with the volume of vegetation, but the consumptive use per unit volume decreased as the plants approached maturity. Depth to the water table strongly influenced evaporation from bare soil; for water-table depths of 2.0 to 4.0 ft, evaporation varied from 3 to 20 in. yearly. Water-table depths moderately influenced transpiration by the two species of *Atriplex* (average yearly water use, 38 to 44 in.), although the depth of the tanks did not permit the water table to be held at sufficient depth to create substantial moisture stress. The cattail lysimeters utilized a total of approximately 100 in. of water, or about 8.5 ft, per year. Arrowweed, with the water table at 5.5 ft, used 96 in. per year. Bermuda grass, with the water table at 3.5 ft, used 73 in. per year.

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

"Relative-Water Requirement of Arizona Range Plants," *Arizona Agricultural Experiment Station Technical Bulletin 80*, University of Arizona, Tucson, Ariz., 1939, pp. 167–246.

Water requirements of 28 species of Arizona range plants and five crop plants were determined under varying climatic conditions during the period 1931 to 1936. The experimental work was done at the Desert Grassland Station on the Santa Rita Experimental Range, located about 30 mi south of Tucson, Arizona.

The water requirement determinations for the crop plants were used in comparing climatic conditions at the Desert Grassland Station with those at Akron, Colorado, and elsewhere in the Great Plains area. The native species included six groups of plants: (1) perennial grasses of the desert grassland; (2) perennial grasses of plains grassland; (3) southern tall grasses; (4) winter annuals; (5) summer annuals; and (6) xerophytic trees and shrubs.

As a group, the 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 winter annuals were at least as efficient in the use of water as the perennial grasses during the same season. The summer annuals, as a group, had lower water requirements than the perennial grasses. The trees and shrubs had much higher water requirements than any other group.

176. McNaughton, K. G., and Black, T. A.

"A Study of Evapotranspiration from a Douglas Fir Forest Using the Energy Balance Approach," *Water Resources Research*, Vol. 9, No. 6, 1973, pp. 1579–1590.

Energy balance measurements of evapotranspiration from a young Douglas fir forest are reported for a period of 18 days in July 1970 when soil water was not limiting. Peak daily evapotranspiration rates characteristically occurred 2–3 hours after solar noon, and evapotranspiration showed a short-term independence from net radiation. This behavior is interpreted as being a consequence of the large forest roughness. Daily evapotranspiration and net radiation were, however, well correlated. Values of surface diffusion resistance calculated from Monteith's combination formula are presented. Daytime values showed significant day-to-day differences, and an attempt to define a potential evapotranspiration rate by assuming a constant daytime surface resistance was not successful. Comparison of evapotranspiration measurements with a potential evaporation formula for wet surfaces developed by Priestley and Taylor suggests that evaporation of intercepted water proceeds 20 percent more rapidly than evapotranspiration from the nonwetted canopy.

177. McQueen, I. S., and Miller, R. F.

"Soil-Moisture and Energy Relationships Associated with Riparian Vegetation Near San Carlos, Arizona," *U.S. Geological Survey Professional Paper 655-E*, 1972, 51 pp.

Measurements of soil-moisture content and stress made under and near selected species of riparian trees in Arizona supply additional knowledge about the mechanism of moisture movement and utilization. Solar radiation provides energy to move soil moisture both upward and downward from the upper part of a soil profile. Profiles of chemical analyses show higher concentrations of salts at the surfaces of unshaded sites than at the surfaces of shaded sites, which indicate that evaporation loss is greater at unshaded sites than at shaded sites. This relation is confirmed by moisture-stress profiles. Profiles of soil-moisture stress under saltcedar and willow trees show no evidence of soil-moisture depletion by the trees. At one site, soil moisture increased during the season of maximum plant growth, even though a dense stand of annual grasses was growing on the site. The tree roots may have supplied moisture to the soils to maintain the soil moisture in hydraulic equilibrium with the water table. Cottonwood and mesquite trees, however, deplete soil moisture even when groundwater is available.

178. Meinzer, O. E.

"Plants as Indicators of Ground Water," *U.S. Geological Survey Water Supply Paper 577*, 1927, 95 pp.

The most outstanding feature of the desert flora is its relation to the water table. one group of plants is distinguished by their ability to grow where they can send their roots down to the water table or to the capillary fringe above the water table and thus are able to obtain a secure source of supply. Such plants are called phreatophytes. This paper lists and describes the species of plants that habitually draw from ground water in contrast to plants that do not. It covers the relationship between plants that draw from ground water and other groups of plants, the value of plants as indicators of ground water conditions and the possible development of ground water plants having economic value. (Compiler's Summary)

179. Metzger, D. G., Loeltz, O. J., and Burdge, I.

"Geohydrology of the Parker-Blythe-Cibola Area, Arizona and California," *U.S. Geological Survey Professional Paper 486-G*, U.S. Government Printing Office, Washington, D.C., 1973.

This publication is a comprehensive study of the water resources of the area, including the paleohydrology of the lower Colorado River and the history of irrigation. An overall water budget was estimated for the Parker, the Palo Verde, and Cibola Valleys using (1) inflow-outflow and (2) consumptive use methods. In the latter, estimates were made for annual consumptive use by phreatophytic vegetation, irrigated crops and open water surfaces. (Compiler's Summary)

180. Metzger, D. G., and Loeltz, O. J.

"Geohydrology of the Needles Area Arizona, California and Nevada," *U.S. Geological Survey Professional Paper 486-J*, U.S. Government Printing Office, Washington, D.C., 1973, 46 pp.

This publication is a comprehensive study of the water resources of this area. A water budget was developed for the area and the difference between inflow minus outflow is compared to the consumptive use. Consumptive use of water by irrigated crops and by natural vegetation was estimated using the Blaney-Criddle method. (Compiler's Summary)

181. Meyboom, P.

"Three Observations on Streamflow Depletion by Phreatophytes," *Journal of Hydrology*, Vol. 2, No. 3, 1964, pp. 248–261.

Phreatophytes cause streamflow losses under natural and regulated flow-conditions, regardless whether the stream is influent or effluent. Indirect losses are said to occur whenever groundwater is intercepted by the vegetation before it reaches the stream. This type of depletion is common under conditions of natural drainage in valleys where the water table lies within 7 ft from the surface and where it has a gradient of more than 0.01. Direct losses from the river occur in a zone of induced infiltration, the width of which depends on the relation between the phreatophytic fluctuations and the transverse water table gradient in the valley. Direct losses can result also from bankstorage effects brought about by water releases from a reservoir. Extreme streamflow depletion takes place when the river dries up during the summer. This condition is characteristic for places where the consumptive use of the vegetation temporarily exceeds the combined supply of stream discharge and groundwater inflow.

182. Meyer, W. R., and Gordon, J. D.

"Water-Budget Studies of Lower Mesilla Valley and El Paso Valley, El Paso County, Texas," prepared by U. S. Department of the Interior, U.S. Geological Survey in cooperation with the City of El Paso and the Texas Water Development Board, June, 1973, 42 pp.

The total inflow of water to the lower Mesilla Valley in 1970 was 390,510 acre-ft. Of this amount, 41,300 acre-ft were consumptively used by crops and phreatophytes, and 4,700 acre-ft were lost by evaporation. Groundwater storage increased by 320 acre-ft, and 360,860 acre-ft left the valley as surface and groundwater outflow. Groundwater recharge was approximately 26,170 acre-ft.

183. Mower, R. W., and Feltis, R. D.

"Ground-Water Hydrology of the Sevier Desert, Utah," *U.S. Geological Survey Water-Supply Paper 1854*, 1968, 75 pp.

A cooperative hydrologic study was made of the Sevier Desert to determine amount and location of recharge, discharge, pumpage, water storage, and pumping effects on water levels. Most recharge to groundwater reservoirs results from water entering alluvial fans as percolation from streams, irrigation ditches, and irrigated fields. Leakage from the central Utah canal is a major source of recharge to the water-table aquifer. Most groundwater is suitable for domestic and stock uses. Water discharged by withdrawal from wells increased from 2,000 acre-ft in 1950 to 30,000 acre-ft in 1964 and water levels declined from 4 ft to 7 ft for the same period. In the 440,000 acres of the Sevier Desert that support phreatophytes, an estimated 135,000–175,000 acre-ft of groundwater is consumed by evapotranspiration. Consumptive waste of groundwater by vegetation of little or no value (principally saltcedar and pickleweed) is not great but will increase if saltcedar spreads into native meadow pastures, along canal and drain banks, and into surface reservoirs. About 120,000 acre-ft of water can be obtained from storage by lowering the artesian aquifer water level 20 ft. (Compiler's Summary)

184. Mower, R. W., Hood, J. W., Cushman, R. L., Borton, R. L., and Galloway, S. E.

"An Appraisal of Potential Ground-Water Salvage Along the Pecos River Between Acme and Artesia, New Mexico," *U.S. Geological Survey Water Supply Paper 1659*, 1964, 98 pp.

This paper reviews studies of water consumption by phreatophytes, such as saltcedar, saltgrass, sacaton, and mesquite. In addition, estimates were made of the amounts of water that might be salvaged by eradication of saltcedar. Four methods of quantitative determination of consumptive use were used: extrapolation of rates of water use from other areas, inflow-outflow method, pumping-well analogy method, and transpiration-well method. It was concluded that, if the saltcedar were eradicated, phreatophytic grasses encouraged to grow, and nonartesian water levels controlled, the use of water by evapotranspiration in the phreatophyte area would be about 45,000 acre-ft per year, as opposed to a potential 170,000 acre-ft if saltcedar growth continues uncontrolled. (Compiler's Summary)

185. Mower, R. W., and Nace, R. L.

"Water Consumption by Water-Loving Plants in the Malad Valley, Oneida County, Idaho," *U.S. Geological Survey Water-Supply Paper 1412*, U.S. Government Printing Office, Washington, D.C., 1957, 33 pp.

Nearly all available natural-flow surface water in the Malad Valley is appropriated for irrigation. Several small storage reservoirs on the Malad River and its tributaries add materially to the effective supply, and additional reservoir sites are available. The total surface-water supply, however, even with optimum development, would not be adequate for all irrigable lands in the valley. Several hundred flowing artesian wells and pumped nonartesian wells, and a few large springs, supply irrigation water for extensive tracts of land. Nevertheless, much of the irrigated land needs more water; also, additional dry lands could be irrigated if an adequate water supply were available. More efficient use of available water might be made by reducing low-value use by water-loving native vegetation. More profitable use of water could be achieved by eradication and control of low-value water-loving plants and substitution of vegetation having higher value.

In the southern part of the Malad Valley, water-loving plants occupy nearly 13,000 acres of land within an area of 25 mi^2. In general, except for alfalfa, the economic value of these plants is low to nil. If profitable crops could be substituted, the economy of the Malad Valley would be benefited appreciably.

Sixteen species of water-loving plants in the Malad Valley consume water in amounts estimated to range from about 2 to 7.5 acre-ft per acre per year, and the estimated arithmetical average consumptive use is about 4.2 acre-ft. The total quantity of water consumed by these plants in the southern part of the valley is about 37,000 acre-ft a year. Alfalfa, the only high-value water-loving plant that is grown in the valley, consumes nearly 5,000 acre-ft of this water. The residual 32,000 acre-ft of water which is consumed by low-value vegetation would be adequate, in suitable circumstances, to irrigate 10,000 to 15,000 acres of profitable crops having lower water requirements.

Samples of water from 40 sources in the southern part of the Malad Valley have been chemically analyzed. The amount of dissolved solids in samples analyzed ranges from 254 to 5,130 ppm and the average is 970 ppm. The percent sodium ranges from 7 to 82 and the average is about 40. The electrical conductivity ranges from 429 to 8,760 micro-mhos (mmhos) at 25° C, and the average is about 1,580.

The soil in the area occupied by the water-loving plants is generally poor in quality, ranging from moderately to excessively saline or alkaline. No records have been found of changes in soil quality since irrigation began, although the inhabitants report that the soil quality in some tracts has been improved by the leaching action of water applied for irrigation. Some of the land that is now occupied-by native vegetation reportedly once was barren and salt encrusted; this condition persists in some tracts.

186. Muckel, D. C.

"Phreatophytes–Water Use and Potential Water Savings," *American Society of Civil Engineers Proceedings, Journal of the Irrigation and Drainage Division*, Vol. 92(IR4), December, 1966, pp. 27–34.

Salvage of water consumed by phreatophytes of low economic value has long been considered, and increasing emphasis is being placed on this source of water in the arid and semiarid west. Evaluation of potential savings in water use requires that water use be estimated under present and modified conditions. Although the totals given for water use by phreatophytes are impressive and indicate that large quantities of water are being wasted, there is danger of oversimplification when it comes to salvaging the water and converting it to a beneficial use. Three means of salvage are mentioned: (1) removal or destruction of the phreatophytes by mechanical or chemical means, (2) lowering the water table or diverting the streamflow, and (3) substituting plants of high economic value.

187. Muckel, D. C., and Blaney, H. F.

"Utilization of the Waters of Lower San Luis Rey Valley, San Diego County, California," Division of Irrigation, Soil Conservation Service, Los Angeles, California, April, 1945.

The purpose of the study was to determine the water budget for the San Luis Rey watershed of southern California. A goal was to estimate the consumptive use for the various physical and political subdivisions. The integration method was used to accomplish the estimates while the overall watershed estimate was checked by the inflow-outflow water budget. In order to determine the water losses from areas covered with native vegetation, a tank containing willows, cottonwoods and grasses and another containing tules were monitored for water use during the period 1939–1943. (Compiler's Summary)

188. Mustonen, S. E., and McGuinness, J. L.

"Lysimeter and Watershed Evapotranspiration," *Water Resources Research*, Vol. 3, No. 4, 1967, pp. 989–996.

A statistical model was derived for permanent grass lysimeter evapotranspiration (ET_L), using lake evaporation, soil moisture, and precipitation as independent variables. Measured annual ET was substantially greater than ET derived from water budget estimates on small watersheds. Differences in the ET rate for permanent grass and grain crops were greatest at grain planting time when the ground was bare. ET_L fell to about one-half of normal when hay was cut and recovered to normal in about one month.

189. Naff, R. L., Baker, A. A., and Gross, G. W.

"Environmental Controls in Ground-Water Chemistry in New Mexico, Part I The Effects of Phreatophytes," *New Mexico Water Resources Research Institute, Report 052*, 1975, 102 pp.

The relationship between phreatophyte-induced evapotranspiration, water level fluctuations, and changes in groundwater quality were investigated with arrays of nested piezometers installed at two sites of the Rio Grande flood plain. Only data from one site (Hope Farms), spanning 490 days, were found suitable for analysis and interpretation.

Consumptive use was computed from continuous water level records. The best correlation was found between consumptive use and averaged maximum daily temperature, while a lack of direct recharge from precipitation at the site was indicated.

The absence of a dominant salinity stratification in either space or time was the salient feature of the specific-conductance data. A strong seasonal cyclic variation was observed in the difference between horizontally averaged conductivities from piezometers wet at 10 ft and 20 ft below the land surface. This cyclic variation showed a strong inverse correlation with water table fluctuations caused by evapotranspiration. This is in agreement with a salinity mechanism of temporary "deposition" of salts in and above the capillary fringe during the growing season, ascribed to the transpiring phreatophytes, and "dissolution" of these salts in the fall and early winter as the phreatic surface rises. The average horizontal water table gradient also showed a high inverse correlation with the specific conductance difference.

The chemical characteristics of the groundwater in this area appear to be determined by mining(?) of waters of different chemical composition. In general, the groundwater of this area has a calcium sulfate character. It is postulated that evapotranspiration causes fluctuations of the vertical hydraulic gradient which are responsible for the mixing and a weak diurnal cycle of specific groundwater conductance.

190. Nagel, H. G.

"Comparison of Evapotranspiration Rates in the Platte River in Nebraska: 1938 vs. 1978," Kearney State College, Kearney, Nebraska, Nebraska Water Resources Center, University of Nebraska, *Project Completion Report*, February, 1979, 36 pp.

A computational model was developed to estimate evapotranspiration (ET) in the Platte River ecosystem of central Nebraska. Data used in the model were mostly derived from the literature, although leaf temperature data were collected to estimate species transpiration coefficients. Preliminary estimates for ET are 35.5 in./year during the April to October growing season. Riparian forest accounted for 30% of the total ET, followed in order of importance by open water evaporation, forested islands, herbaceous riparian transpiration, sandbar evaporation and then herbaceous island vegetation, which accounted for only 10% of the total ET.

The Platte River has changed markedly during the last 40 years, with reduced flows and narrowed channel width. Much riparian forest has grown up in that time, and vegetated islands occupy a greater percentage of the remaining channel than previously. A comparison of ET rates between the 1930’s and 1970’s was attempted, using the computational model developed. Total ET rates in the 1930's were about the same as today (37.3 in./year), but proportion by habitat differed greatly, with open-water evaporation probably accounting for about half the total ET then.

191. Nagel, H. G., and Dart, M. S.

“Platte River Evapotranspiration: A Historical Perspective in Central Nebraska,” *Transactions of the Nebraska Academy of Sciences*, VIII, 1980, pp. 55–76.

A computational model was developed to estimate evapotranspiration (ET) in the Platte River ecosystem of central Nebraska. Data used in the model was mostly derived from the literature, although leaf temperature data were collected to estimate species transpiration coefficients.

Preliminary estimates for ET are 35.5 in. per year during the April-to-October growing season. Riparian forest accounted for 30% of the total ET, followed in order of importance by open-water evaporation, forested islands, herbaceous riparian-transpiration, sandbar evaporation, and then herbaceous island vegetation, which accounted for only 10% of the total ET.

The Platte River has changed markedly during the last 40 years, with reduced flows and narrowed channel width. Much riparian forest has grown up in that time and vegetated islands occupy a greater percentage of the remaining channel than previously. A comparison of ET rates between the 1930’s and 1970’s was attempted, using the computational model developed. Total ET rates in the 1930’s were about the same as today (37.3 in. per year) but proportion by habitat differed greatly, with open-water evaporation probably accounting for about one-half the total ET then.

The total loss due to evapotranspiration between Kingsley Dam and Duncan, Nebraska, from Platte River ecosystems (except for wet meadow and cropland) was estimated to be 379,000 acre-ft per year.

192. National Park Service

Proposed Natural and Cultural Resources Management Plan and Draft Environmental Statemen–Death Valley National Monument, Nevada/ California, U.S. Department of the Interior, National Park Service, Death Valley National Monument, Denver Service Center, Denver, Colorado, 1981, 234 pp.

This proposed natural and cultural resources management plan and draft environmental impact statement (DEIS) discusses the alternatives and the proposed action for natural and cultural resources management at Death Valley National Monument, Inyo and San Bernardino Counties, California, and Nye and Esmeralda Counties, Nevada. The plan proposes to restore natural ecosystems by removing exotic plants and animals, rehabilitating water sources, and revegetating disturbed areas. Proposals for cultural resources include archeological studies and surveys, historic research, and preservation of historic structures.

As a result of the proposed plan, approximately 174,000 acres of disturbed desert land will be restored by removing domestic livestock, feral burros, and exotic plants, and by reclaiming and revegetating natural areas. The available water supply will be increased for wildlife, and water quality will be improved. Construction activities, such as fencing and installation of watering devices, will disturb a maximum of 152 acres of land. Opportunities for visitors to view natural landscapes and to visit historic remains will be increased; however, some visitors may object to the removal of exotic animals and plants.

A no-action alternative, which would alter the existing resource management programs only slightly, was considered. Other alternatives considered were methods of achieving environmental restoration and total removal of feral burros, methods of achieving partial restoration with retention of some feral burros, methods that might achieve either partial or total removal of burros, and fencing as a method of excluding burros from the monument. (Author Summary)

193. Neff, E. L., and Wight, J. R.

"Soil-Vegetation-Hydrology Studies, Volume I. Research Results, Summary, Discussion, and Recommendations," U.S. Department of Agriculture, Agricultural Research Service, *Agricultural Research Results, Western Series, No. 28,* ARR-W-28, January, 1983, 55 pp.

This publication contains results of Agricultural Research Service (ARS)–Bureau of Land Management (BLM) cooperative research conducted in southeastern Montana from 1968 to 1981. It is presented in two volumes and an appendix.

It contains project history and background; summary research results; recommendations for field application of contour furrowing; recommendations for disposition of research facilities; and a bibliography of pertinent range research publications written by dentists at the Northern Plains Soil and Water Research Center, Sidney, Mont. (Authors' Introduction)

194. Nevada Department of Conservation and Natural Resources
and U.S. Department of Agriculture

"Basinwide Report on Humboldt River Basin, Nevada," *Report Number Twelve*, Economic Research Service-Forest Service-Soil Conservation Service, Max C. Fleischmann College of Agriculture, University of Nevada, Reno, Nevada, November, 1966.

The State of Nevada recognized the need for a systematic survey of water and related land resource conditions and problems in the Humboldt River Basin. It was felt that such a survey would develop information for the coordination of programs and projects in the basin. Results of this Nevada-USDA Cooperative Survey are published in reports written on 11 segments of the Humboldt Basin called sub-basins. This report, Basinwide Report, number twelve in the series, contains information as to what might be accomplished by feasible Public Law 566 projects and other Department of Agriculture land and water activities in solving the Basin's resource management problems. (From Authors' Introduction)

195. Nicolson, J. A., Thorud, D. B., and Sucoff, E. I.

"The Interception-transpiration Relationship of White Spruce and White Pine," *Journal of Soil and Water Conservation,* Vol. 23, No. 5, 1968, pp. 181–184.

Reported herein is a study of the interception-transpiration relationship of two widely distributed northern conifers-white spruce (*Picea glauca*, Moench) and eastern white pine (*Pinus strobus,* L.).

Intercepted water reduced transpiration and conserved soil-moisture. The amount saved partially depended on weather conditions. The mean saving in relation to the total amount of intercepted water applied was 13 percent for white spruce and 12 percent for white pine.

Grouping periods according to the number of wettings required during a 3 ½-hour period showed that the percentage of water saved in white pine decreased as the number of wettings increased. White spruce failed to show any trend.

In a second classification using atmometer evaporation, the percentage of water saved in white pine again decreased as evaporational stress increased. White spruce again failed to show any trend. However, within subgroups in this classification, the percentage of water saved in white spruce tended to decrease as wind speed increased.

Water savings in white pine appeared to be greatest during calm, humid, low radiation environments. Savings in white spruce tended to be higher in environments favoring moderate transpiration. However, within the range of environments encountered in this study, the difference in the average amount of soil moisture conserved between the two species was insignificant. (Authors' Introduction and Summary)

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

"Diurnal and Seasonal Water Relations of the Desert Phreatophyte *Prosopis Glandulosa* (Honey Mesquite) in the Sonoran Desert of California," *Ecology*, Vol. 64, No. 6, 1983, pp. 1381–1393.

Diurnal and seasonal water relations were monitored in a population of *Prosopis glandulosa* var. *torreyana* in the Sonoran Desert of southern California. *Prosopis glandulosa* at this research site acquired its water from a groundwater source 4–6 m deep. Measurements of diurnal and seasonal cycles of aboveground environmental conditions, soil moisture, and soil water potential (to 6-m depth) were taken to ascertain environmental water availability and water stress. Leaf water potential, leaf conductance, leaf transpiration, relative saturation deficit of leaves, osmotic potential, and turgor potential were measured to evaluate plant adaptations to environmental water stress. Soil water potential was low (–4.0 to –5.0 MPa) in surface soil in relation to deep soil (–0.2 MPa). This difference was due to high surface soil salinity and low surface water content. The climatic conditions at the research site produced extreme water stress conditions in summer months when temperatures reached 50° C, vapor pressure deficit (VPD) reached 8 kPa, and surface soil water potential was below –4.5 MPa. Although considerable plant water stress developed in these trees (midday leaf water potential –4.8 MPa), osmotic adjustment occurred and turgor was maintained on a diurnal and seasonal cycle. *Prosopis glandulosa* has adapted to avoid water stress by utilizing deep ground water, but this phreatophyte has also evolved physiological adaptation, such as osmotic adjustment and seasonally changing stomatal sensitivity to VPD, which result in greater tolerance of water stress.

197. Nnyamah, J. U., and Black, T. A.

"Rates and Patterns of Water Uptake in a Douglas-Fir Forest," *Journal, Soil Science Society of America*, Vol. 41, 1977, pp. 972–979.

The forest water balance was studied in a thinned (840 stems/ha) and an unthinned (1,840 stems/ha) Douglas-fir forest [*Pseudotsuga menziesii* (*Mirb*.) Franco] during two consecutive summers. Soil water content was measured with the neutron meter. Soil water potential was measured with tensiometers and dew-point hygrometers over a range of 0 to –15 bars. These data were used to compute water extraction rates and patterns for the root zone over a four-week drying period. The results showed a gradual downward shift of the zone of maximum root water uptake as the soil dried. The fully developed root system of Douglas fir showed less hydrotropic response than the developing root systems of annuals reported in the literature. There was good correlation between water uptake rate and rooting density. During the drying period, water flux into the bottom of the root zone, estimated by the use of Darcy's law, increased from 8 to 15% of the evapotranspiration at the thinned site and from 2 to 8% at the unthinned site. Soil profile water depletion corrected for flux out of or into the bottom of the root zone agreed well with evapotranspiration computed from micrometeorological energy-balance data. Water withdrawal from trunk storage accounted for only 2% of the total evapotranspiration over the four-week drying period.

198. Olmsted, F. H., and McDonald, C. C.

"Hydrologic Studies of the Lower Colorado River Region," *Water Resources Bulletin*, Vol. 3, No. 1, March, 1967, pp. 45–58.

In 1960 Geological Survey began a comprehensive study of the hydrology of the lower reaches of the main Colorado River Valley from Davis Dam to the International Boundary. Although final results of the study were not available when this study was completed, objectives, scope, methods used, and some preliminary results are described. The general objective was the definition of the hydrologic regimen of the main Colorado River Valley and certain adjacent areas where Colorado River water is used, principally the Imperial Valley and Salton Sea area. The study places greatest emphasis on appraisal of groundwater resources in or adjacent to the main river valley; location, extent, and hydraulic characteristics of the aquifers; relationship between aquifers and the river, irrigated lands, and other sources of recharge; regional movement of the groundwater; and probable effects of pumping in generalized areas. The report includes an appraisal of the probable water supply to the area and a discussion of consumptive users by crops, native vegetation, and evaporation.

199. Otis, C. H.

"The Transpiration of Emersed Water Plants: Its Measurement and Relationships," *The Botanical Gazette*, Vol. LVIII, No. 6, December, 1914, pp. 457–494.

The evaporation taking place from free water surfaces has been the subject of much experimentation during the past century, and the laws governing this phenomenon have been quite definitely stated. The matter of transpiration of plants, a special kind of water evaporation, has also been the subject of a great deal of theoretical and experimental investigation, and we know the quantity of water transpired by certain plants in various situations and some of the factors which influence it. But, although the subject is of great importance in regions of small rainfall and scant water supply, especially where immense irrigation and water supply projects are involved, practically no investigation of any importance has been conducted to determine the effect of emersed water plants on the evaporation from a water surface.

It has been a matter of common belief that emersed water plants transpire large amounts of water, although there seems to be little evidence in support of such belief. Fanning says, “Marshy margins of ponds are profligate dispensers of vapor to the atmosphere, usually exceeding in this respect the water surfaces themselves.” Such statements as this, unsupported by experimental evidence, are of only passing interest, yet they constitute all of the scanty literature on the subject.

The investigation was undertaken to secure experimental data leading to a better knowledge of the quantity of water transpired by emersed water plants, its relationships, and some of the factors which influence it. (Author Introduction)

200. Owen-Joyce, S. J.

“A Method for Estimating Groundwater Return Flow to the Colorado River in the Palo Verde-Cibola Area, California and Arizona,” *U.S. Geological Survey Water-Resources Investigations Report 84-4236*, Tucson, Arizona, September, 1984.

Groundwater return flow to the Colorado River was estimated as the residual in water budgets for the areas that drain in the subsurface to the river in Palo Verde and Cibola Valleys–California and Arizona. Two groundwater drainage areas in each valley were delineated using average annual water-table altitudes in the shallow alluvial aquifer that underlies Palo Verde and Cibola Valleys. Surface-water diversions from and returns to the Colorado were measured. Consumptive use was estimated using a water budget for the area drained by drainage ditches in Palo Verde Valley and was adjusted for the unequal distribution of vegetation types on either side of the groundwater divide. Cibola Valley had no drainage ditches in 1981, and consumptive use was estimated using vegetation types, empirically determined consumptive use, and acreages. Vegetation data were obtained from crop records, crop mapping, and Landsat satellite imagery. A one-year period was used because river-surface altitudes, groundwater heads, and irrigation-water deliveries follow a one-year cycle and changes in groundwater storage are probably negligible at the end of the one-year period. Estimates of groundwater return flow using data from 1981 were 23,900 acre-ft from Palo Verde Valley and 5,200 acre-ft from Cibola Valley.

201. Parshall, R. L.

“Laboratory Measurement of Evapotranspiration Losses,” *Journal of Forestry*, Vol. 35, No. 11, 1937, pp. 1033–1040, illus.

The evapotranspiration losses of several common plants were investigated by growing them in soil tanks with shallow depths of soil and high water tables. The studies covered the growing seasons of 1929, 1930, 1931, and 1932 and were

conducted under a cooperative agreement between the Bureau of Agricultural Engineering, U.S. Department of Agriculture, and the Colorado Agricultural Experiment Station at Fort Collins, Colorado.
The results of the investigation are not conclusive as to the actual use of water by plants when growing in a natural environment. The results obtained were reasonably consistent but do not represent enough observations on any one crop to establish definite relations. It is probable that the evapotranspiration loss under actual field conditions would be less than that reported.

202. Parton, W. J., Lauenroth, W. K., and Smith, F. M.

"Water Loss from a Shortgrass Steppe," *Agricultural Meteorology*, Vol. 24, No. 2, 1981, pp. 97–109.

Daily and hourly water loss from a shortgrass steppe in northeastern Colorado was determined for four years (1972–1975) with a weighing lysimeter. Daily potential evapotranspiration rates were also calculated, and canopy resistance was evaluated on an hourly basis for selected days. The results show that on a monthly basis water loss was generally equal to the water input, while actual water loss was substantially lower than the potential evapotranspiration rate. The daily water loss data show that water loss is approximately equal to the potential evapotranspiration rate immediately after large precipitation events, then decreases very rapidly for four days after the event. The precipitation data show that large events (> 15 mm day^{-1}) contribute most of the annual total precipitation, with most of the annual water loss from the system occurring during the period (2–4 days) immediately following the large precipitation events. The hourly water loss data show that when the soil was wet, water loss was maintained at the maximum rate; however, as the soil dried out, the water loss rate fell below the potential rate during the middle of the day, with the rate falling below the potential rate at early morning hours with drier soils. The canopy resistance is fairly low (2–5 s cm^{-1}) when the soil is wet and does not change throughout the daytime; however, as the soil dries, the resistance increases throughout the day with the greatest increase observed on the driest soils.

203. Patric, J. H.

"A Forester Looks at Lysimeters," *Journal of Forestry*, Vol. 59, 1961, pp. 889–893.

Despite their usefulness in agriculture, lysimeters have found little use in forestry. One reason is that plants grown in lysimeters tend to be smaller than those grown nearby under more natural conditions because root systems cannot expand normally. This paper reports studies which indicate that lysimeters can aid forestry research if application of the data is treated with due caution.

Comparisons of the crowns of Coulter pine trees growing in the lysimeters on the San Dimas Experimental Forest, in California, with those growing in the surrounding area show a much reduced growth for the former. The conclusion is inescapable that lysimeters are a poor place for raising trees. Is there, then, a place for lysimeters in forestry research? Undoubtedly there is, but data from their use must be treated with great caution. Results derived growing trees in lysimeters will necessarily be based upon plants smaller and less vigorous than those expected to survive under natural competition.

The use of lysimeters may, however, adequately fulfill certain functions in forestry research. Probably no better way is known to determine or compare rates of water use by plants, including relatively small trees.

204. Patric, J. H.

"The San Dimas Large Lysimeters," *Journal of Soil Water Conservation*, Vol. 16, No. 1, 1961, pp. 13–17, illus.

Twenty-six lysimeters installed in 1937 on the San Dimas Experimental Forest, in California, compare water losses and yields under several plants native to the chaparral-covered mountains of southern California. Local, uniformly mixed soil was placed in concrete tanks, 10.5 ft by 21 ft by 6 ft deep, each drained by a parallel top and bottom slope of 5 percent. Surface runoff and seepage are measured for each unit. Soil moisture is measured at uniform depths in several lysimeters with Colman electrical resistance units. A climatic station is on the site.

The research program was developed in three stages: (1) the soil settlement period, (2) the grass cover period, and (3) the long-term native species test period, which began in 1946.

Soil settlement under a protective excelsior cover was completed by 1940. A 6-year calibration period followed, when 25 of the lysimeters were seeded to grass. The soil in one unit was left bare and has remained bare since 1940.

In 1946 the grass cover was replaced in 23 lysimeters by four chaparral species and Coulter pine. Two lysimeters contained grasses. During tests made in the period 1952–56, the significant results indicated that water yield was entirely surface runoff, except for a small amount of seepage under grass cover. Woody plants used all available moisture, while 10 in. of moisture remained under bare and grass-covered soils. During the winter and spring, pine and grass dried the soil faster than scrub oak. During a season of high rainfall (48.4 in.), evapotranspiration losses were computed as follows: bare soil, 8.7 in.; grass, 16.0 in.; pine, 25.1 in.; chamise (*Adenostoma*), 25.5 in.; and scrub oak, 24.8 in.; buckwheat 24.3 in.; and ceanothiis, 23.6 in.

205. Patt, R. O.

"Las Vegas Valley Water Budget: Relationship of Distribution, Consumptive Use and Recharge to Shallow Ground Water," Desert Research Institute, Las Vegas, Nevada, U.S. Environmental Protection Agency, Ada, Oklahoma, 1978, 69 pp.

Estimates of quantity and geographic distribution of recharge to the shallow groundwater zone from water use return flows in Las Vegas Valley were made for the years 1973, 1965, 1958, 1950, and 1943 as part of a broader study on the impact of water and land use on groundwater quality. Considered components of water use in Las Vegas Valley include the following: supply from surface and groundwater; agriculture using potable water; agriculture using sewage effluent; residential lawn watering; lawn watering of parks, schools, cemeteries, hotels, motels; golf courses using potable water; golf courses using sewage effluent water; septic tank recharge; evaporative coolers; system losses; industrial use; power plant cooling; swimming pool use; consumptive use by phreatophytes; in-valley recharge from precipitation, and "unaccounted for water." Consumptive use of plants was calculated through use of the Blaney-Criddle method as 3.47 ft per year and recharge was assumed to be the difference between applied water and calculated consumptive use. Data developed during this study indicates consumptive use as determined by this method could be low by 1.5 to 2 ft per year, and thus the following estimates of recharge to the groundwater system are considered maximum, in acre-feet: 1973–39,000; 1965–27,600; 1958–26,650; 1950–13,000; and 1943–21,000.

206. Paylore, P. (ed.)

"Phreatophytes, A Bibliography," *WRSIC 74-201*, USDI, OWRR Water Resources Scientific Information Center, Washington, D.C., 1974, 277 pp.

(No Abstract–This is a Bibliography)

207. Perkins, R. J.

"Natural Vegetation Consumptive Use, A Component of Alluvial Valley Hydrologic Balance," *Paper No. PNW 81-214*, presented at 1981 Pacific Northwest Regional Meeting, American Society of Agricultural Engineers and Canadian Society of Agricultural Engineering, September, 1981, 15 pp.

Stripmining regulations require definition of the hydrologic balance of alluvial valley floors. A major component of this balance is the evapotranspiration of natural vegetation. Coefficients for use in the SCS TR-21 modified Blaney-Criddle method were developed for tules and cattails, willows, cottonwoods, rushes and sedges, and saltgrass.

208. Petersen, M. R., and Hill, R. W.

"Evapotranspiration of Small Conifers," American Society of Civil Engineers, *Journal of Irrigation and Drainage Engineering*, Vol. 111, No. 4, December, 1985, pp. 341–350.

Three lysimeters were established containing different sized Scotch pines (*P. sylvestris*), and the consumptive water use of each tree was monitored during the 1982 and 1983 growing seasons near Logan, Utah. Weather data including maximum, mean, and minimum daily temperatures, solar radiation, and daily precipitation were collected. Consumptive use data of the first season were of limited use due to the transplanting stress experienced by the trees. The results of the second season were consistent with the usual water use of irrigated crops. Mean monthly crop coefficients were calculated based on the modified Blaney-Criddle and the Jensen-Haise methods, assuming water was extracted from only the crown projection area of the tree. A seasonal Blaney-Criddle crop coefficient was estimated to be 1.22. The growing season was long, and the crop coefficient (Blaney-Criddle) during the winter at this site may be as high as 0.85. An equation was developed to find the composite crop coefficient for conifer tree farms relating tree size, tree spacing, and type of ground cover.

209. Philipp, K. R., and Gallagher, J. L.

"Evapotranspiration from Two Potential Halophytic Crop Species," Proceedings of the National Conference on Advances in Evapotranspiration, American Society of Agricultural Engineers, *Publication No. 14-85*, December 16–17, Chicago, Illinois, 1985, pp. 259–261.

Research in geographic areas currently considered marginal for agriculture due to saline conditions has led to experimentation with halophytes as crop plants (Somers 1979, Somers 1982 and Gallagher in press). The relationship of crop dry weight (DW) to crop evapotranspiration (ET_c) has been well established in predicting crop yield (Hanks 1983) and may be discussed in terms of water use efficiency (WUE) (Sinclair et al. 1983). The ratio of ET_c to reference crop evapotranspiration (ET_o) is equally well established in predicting the water use of different crops (Doorenbos and Pruitt 1977).

Additionally, crop production is determined by the effects of salinity. Increasing salinity generally reduces production or yield for a given crop due to the additional energy costs of salinity tolerance (Osmond et al. 1980). The development of halophytes as potential crops requires knowledge of ET_c, ET_c/ET_o, and WUE for their efficient cultivation. This knowledge must include the effects of variation in salinity, since salinity conditions may vary for each agricultural area. These terms may, therefore, be used in investigating how salinity may affect the crop water requirements of halophytes.

210. Pochop, L. O., Burman, R. D., Borrelli, J., and Crump, T.

"Water Requirements of Mountain Meadow Vegetation," *Proceedings* of Specialty Conference, Irrigation and Drainage Division, American Society of Civil Engineers, San Antonio, Texas, July 17–19, 1985, pp. 437–443.

Measurements to define agricultural water consumption have been taken in the Green River Basin of Wyoming throughout the summers of 1983 and 1984. The weekly measurements included water use from 14 lysimeters consisting of eight with mountain meadow vegetation, three with alfalfa and three with alta fescue as a reference crop. In addition, pan evaporation was taken at three of the lysimeter sites. Water use for both alfalfa and mountain meadows exceeded or was near pan evaporation at all sites having pan data. Seasonal consumptive use and water use efficiencies are given for sites throughout the Basin.

211. Pochop, L. O., Smith, F. M., and Smith, R. E.

"Evapotranspiration Estimates for the Pawnee Grasslands," Proceedings of the National Conference on Advances in Evapotranspiration, *American Society of Agricultural Engineers Publication No. 14-85*, December 16–17, Chicago, Illinois, 1985, pp. 262–267.

Ritchie's method for estimating evaporation for crops with incomplete cover has been applied to the Pawnee Grasslands site. Application of the method required definition of the soil depths affecting the soil and plant evaporation components. Because of the relatively dry conditions at the Pawnee site, these depths were not as great as in Ritchie's original application.

Ritchie originally used the Priestley-Taylor equation to predict maximum possible ET. Since the Priestley-Taylor equation may not be as well suited to predicting. ET in arid and windy regions as other equations, substitution of the Penman equation for the Priestley-Taylor equation was tested. The change in equations greatly affected the plant evaporation component, but total ET estimates were improved much less.

Since the model separates plant and soil evaporation, calibration of the method could be performed most effectively if measurements of the individual components were taken. (Author Summary)

212. Pratt, D. C., Dubbe, D. R., and Garver, E. G.

"Energy from Biomass Production in Minnesota–Part 1, Wetland Biomass Production," *Final Report* from Department of Botany, University of Minnesota, submitted to Minnesota Department of Energy and Economic Development and Legislative Commission on Minnesota Resources, Contract No. 22100/02479/01, St. Paul, Minnesota, August, 1985, 35 pp.

Wetland plants, such as cattail (*Typha* spp.), common reed (*Phragmites australis*), and rushes (*Scirpus* spp.), are one type of bio-energy crop under consideration in Minnesota because of their high productivity, chemical composition, and the fact that they are well adapted to a substantial portion of the state's 8.6 million acres of wet marginal lands. Evaluation of the commercial potential of wetland plants as an energy crop depends on an understanding of the tradeoffs between productivity and production costs. Research conducted by the Wetland Biomass Production Project at the University of Minnesota has sought to provide the information base that will be required to develop a bio-energy production system that maximizes output while minimizing inputs, resulting in a renewable energy resource that is economically competitive. This report is organized in a manner that focuses on key steps and issues involved in commercial production, including species selection, establishment methods, and stand management practices. An appendix is provided which presents an alternative viewpoint to a Minnesota Department of Energy and Economic Development report on the economics of bio-energy production. (From Authors' Summary)

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

"Water Disposition in a Stream Channel with Riparian Vegetation," *Soil Science Society of America Proceedings*, Vol. 31, No. 2, 1967, pp. 263–269.

Water losses along stream channels in the semiarid southwestern United States are of utmost importance in relation to water disposition and water yields from a watershed. This paper describes an analysis used for estimating water disposition along a reach of a natural stream channel with riparian vegetation and impermeable bedrock at a shallow depth. Results for one annual cycle are presented which indicate the quantity of water removed from the stream channel reach by various processes.

Methods adapted for the particular set of conditions were used in measuring subsurface water flow and water storage in the channel alluvium. Subsurface water flow was calculated from Darcy's equation. Water storage in the channel alluvium was estimated from water content, water-table elevation, specific yield, and volume of alluvium measurements.
Four distinct water use periods were apparent within a yearly cycle, each expressed by a separate water balance equation. Water losses by evapotranspiration were estimated from these equations. For example, 9 mm of water were estimated to be lost per day by transpiration of the riparian vegetation 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.

214. Rand, P. J.

"Woody Phreatophyte Communities of the Republican River Valley in Nebraska," Department of Botany, University of Nebraska, Lincoln, Nebraska, *Final Report*, *Research Contract No. 14-06-700-6647* to Department of Interior, Bureau of Reclamation, June, 1973.

The woody phreatophyte communities of the Republican River valley were studied in the field by means of 33 transacts located at 4–8 mile intervals along the 285 miles of its course in Nebraska. Four principal community types were identified of which two comprise more than three-quarters of the woody vegetation. Three of the four are dominated by cottonwood, while in the fourth hardwood species such as boxelder, slippery elm, mulberry, and green ash have importance values exceeding those of cottonwood.

The four community types represent stages in the natural riparian succession of Midwestern rivers. In Type I stands the early pioneer species, cottonwood and peachleaf willow, are dominant, while in Type II, the intermediate stage, and Type III, the mature stage, cottonwoods and willows are being replaced in importance by a variety of hardwood species. In Type IV communities the transition has been completed.

Measurement of plant communities depicted on recent aerial photographs of the river valley reveals that about 40% of the floodplain is wooded and that the total acreage of woody phreatophyte communities approaches 50,000 acres.

Thirteen species of trees were found in the transects and three others were seen in stands along the river. Of these, cottonwood is the most important. It averages over 100 trees per acre throughout the valley, contributes a third or more of the canopy coverage in all stands, and has an average basal area of 40.79 ft^2 per acre. The 612 cottonwoods measured through the valley had an average height of 42.5 ft, and average d.b.h. of 7.6 in., and an average crown depth of 24.0 ft. There is a pronounced difference in the size of the cottonwoods from west to east, those on the western end being smaller than those on the eastern, and there is a decline in the I.V. of cottonwood from west to east.

Peachleaf willow is the next most important tree in the phreatophyte stands and shares dominance to the west with cottonwood. Secondary species of importance are boxelder, mulberry, green ash, and slippery elm, but their I.V.'s are only one-tenth as large as those of cottonwood.

Succession in the woody phreatophyte communities follows that of other Midwestern rivers. Sandbar willow, peachleaf willow, and cottonwood are the pioneer species which become zoned on the sandbars very early in their development. Sandbar willow grows next to the water; cottonwood and peachleaf willow occur together farther back on the flood plain. Due to differences in tolerances and growth rates, cottonwood develops at the expense of peachleaf willow and rapidly forms even-aged stands. Unable to reproduce in their own shade, the cottonwoods are replaced by mixed hardwood species which come in under the cottonwood canopy and, given freedom from disturbance, eventually become dominant and persist for long periods.

Humans have used the Republican River and the plants in its valley for at least the last 2,000 years, but their influence during this time seems to have been less important than shifting climatic regimes and periods of flooding and drought. What current manipulations will do to phreatophyte communities remains to be seen.

215. Rantz, S. E.

"A Suggested Method for Estimating Evapotranspiration by Native Phreatophytes," in Geological Survey Research, *U.S. Geological Survey Professional Paper 600-D*, 1968, pp. D10–D12.

A graph and table have been developed for selecting values of the coefficient K to be used in the Blaney-Criddle formula for estimating evapotranspiration by native phreatophytes. Values of K are dependent on the species of phreatophyte, the density of growth, and the depth to water table.

216. Rawls, W. J., Zuzel, J. F., and Schumaker, G. A.

"Soil Moisture Trends on Sagebrush Rangelands," *Journal of Soil and Water Conservation*, Vol. 28, No. 6, November–December, 1973, pp. 270–272.

In 1966 and 1967 three networks of soil moisture access tubes were established on Idaho's Reynolds Mountain Watershed, a mountainous area near Boise with elevations from 3,600 to 7,200 ft. These networks represent a range of soils, elevations, and precipitation zones. Biweekly monitoring with a neutron soil moisture probe allowed us to derive an average annual soil moisture curve for the top 3 ft of soil in each area. These curves showed that maximum soil moisture accumulation occurred in late February at the low elevations and in late May at the high elevations. Minimum soil moisture occurred in July and August. Maximum soil moisture accumulation varied from 8 to 18 in. of water. The depletion rate between minimum and maximum soil moisture was approximately linear with a total depletion of 2.5 to 4 in. of water.

217. Reed, J. L., and Dwyer, D. D.

"Blue Grama Response to Nitrogen and Clipping Under Two Soil Moisture Levels," Journal of Range Management, Vol. 24, 1971, pp. 47–51.

Effects of N-fertilization and clipping on production and water use of blue grama were evaluated under two soil moisture levels, field capacity and one-fifth available water. Nitrogen increased shoot production 77 percent on unclipped plants. Clipping decreased shoot production 287 percent below the control averaged across N levels. Soil moisture levels produced no differences in yields. Root weights were decreased an average of 253 percent below the control by clipping. No differences were observed in total water-used between fertilized and unfertilized plants but clipping reduced water used by 95 percent. Unclipped plants fertilized with 80 lb N/acre used more water than unfertilized unclipped plants. The amount of water required to produce a unit of a shoot was reduced 37 percent when fertilized. Clipping lowered this water requirement an average of 98 percent. Nitrogen greatly increased seed stalk numbers and the increase in shoot production due to fertilization came primarily from increased numbers of seed stalks.

218. Rich, L. R.

"Forest and Range Vegetation," *Transactions of the American Society of Civil Engineers*, Vol. 117, 1952, pp. 974–990, illus.

Consumptive use of water by forest and range vegetation depends primarily on climatic and watershed conditions and on water availability. There are few areas in the West in which unlimited water is available for full potential consumptive use. The ability of plants to grow and use water is greatest in summer and least in winter. Actual water use is dependent on growing conditions when moisture is available. The availability of moisture depends on the distribution of precipitation and the moisture held in the soil for use during period of drought.

Water use in the semidesert grassland zone was 92 percent of the precipitation for perennial grasses and 98 percent for winter annuals; it was 89 percent of the precipitation lost from bare soil by evaporation. Consumptive use of water in the chaparral zone was 81 percent of the precipitation for grasses and 84 percent for shrubs; it was 78 percent of the precipitation lost from bare soil by evaporation. The use on watersheds in the mixed grassland-chaparral zone ranged from 90 percent to 95 percent of the precipitation on four adjacent watersheds, depending on soil type and depth of soil. Water use on forested watersheds has varied from 77 percent to 90 percent of the rainfall, depending on depth of soil and slope.

A method that appears suited to determining consumptive use of water by forest and range vegetation consumptive use of water by rforest and range vegetation is to divide the water year into four periods—(1) soil moisture recharge, (2) water surplus, (3) soil moisture utilization, and (4) water deficit—and to consider each period separately. Vegetation or evaporation from bare soil can always use more water than falls as precipitation during the summer period in the Southwest, and consumptive use is dependent on total precipitation less the small amount of surface runoff that results from summer thunderstorms.

219. Rich, L. R., and Thompson, J. R.

"Watershed Management in Arizona's Mixed Conifer Forests: The Status of Our Knowledge," U.S. Department of Agriculture, *Forest Service Research Paper RM-130*, 1974, 15 pp.

Watershed management research in Arizona dates from the formal establishment of the Sierra Ancha experimental watersheds on the Tonto National Forest in 1932. Although water yield has often received primary emphasis, forage, timber, and other resources have always been considered as important and integral parts of the total watershed ecosystem. This paper summarizes the results of water yield studies that apply to Arizona's mixed conifer vegetation association, and hopefully provides a foundation from which alternative forest management practices can be more easily evaluated. (Author Introduction)

220. Richardson, C. W., Burnett, E., and Bovey, R. W.

"Hydrologic Effects of Brush Control on Texas Rangelands," *Transactions of the American Society of Agricultural Engineers*, 1979, pp. 315–319.

Noneconomic brushy vegetation infests millions of acres of rangeland in the southwestern United States. This investigation was conducted to determine the hydrologic effects of controlling the brush chemically or mechanically. In the Blackland Prairie of Texas, two small watersheds infested with honey mesquite were selected for this study. The mesquite on one watershed was killed with chemicals. Killing the mesquite reduced evapotranspiration about 8 cm per year and increased surface runoff about 10 percent. In the Edwards Plateau of Texas, two watersheds infested with brush were used to determine the hydrologic effects of mechanical methods of brush control. Root plowing to remove the brush on one watershed reduced surface runoff about 20 percent.

221. Rickard, W. H.

"Seasonal Soil Moisture Patterns in Adjacent Greasewood and Sagebrush Stands," *Ecology*, Vol. 48, No. 6, 1967, pp. 1034–1038.

Soil moisture measurements were made over a 2-year period in adjacent greasewood (*Sarcobatus vermiculatus*) and sagebrush (*Artemisia tridentata*) stands in the desert steppe region of southeastern Washington. Soil moisture accumulated during fall and winter. The greater accumulation of moisture in the upper 4 cm of the greasewood stand appeared to be the result of decreased evaporation losses and the lack of transpiration from shrub species which are leafless during winter and early spring. The more luxuriant growth of cheatgrass in the greasewood stand was related to winter and spring retention of soil moisture.

222. Riekerk, H.

"Lysimetric Measurement of Pine Evapotranspiration for Water Balances," Proceedings of the National Conference on Advances in Evapotranspiration, *American Society of Agricultural Engineers, Publication No. 14-85*, December 16–17, Chicago, Illinois, 1985, pp. 276–281.

The information showed slash pine Et to be controlled mainly by atmospheric demand. Too dry or too wet soil moisture conditions modified this control by reducing Et. Maximum Et of 0.7–1.1 cm/day occurred in early June with the onset of hot and wet summer weather and averaged 12.6 cm/mo for the April–September growing season and 5.5 cm/mo for the dormant season. Evapotranspiration of the growing season matched potential Et, but dormant season measurements of the Et/Etp crop factor were 25% lower on the average.

The monthly crop factors were used to estimate the Et term of monthly water balances of watersheds most similar to the lysimeter. The residual groundwater plus soil moisture storage term contained large errors but indicated significantly higher leakage rates from the watersheds than estimated previously. (Author Summary)

223. Riekerk, H.

"Pine Tree Evapotranspiration," *Publication No. 62*, Florida Water Resources Research Center, Research Project Technical Completion Report, U.S. Department of Interior, Office of Water Research and Technology Project Number A-039-FLA, March, 1982, 36 pp.

Evapotranspiration data of a young slash pine tree (*Pinus elliottii*) is presented. The information was obtained with a weighing lysimeter placed in the poorly-drained soil of a flatwoods site. The installation had a sensitivity of about 0.5 mm water.

Average seasonal evapotranspiration was 2.4 mm/day for the autumn months, 1.2 mm/day for the winter, and 5.7 mm/day for the spring months. Equipment failures due to high humidity and lightning damage prevented reliable measurement of evapotranspiration for the summer.

Potential evaporation was calculated with the Penman equation using data from a nearby weather station. Total potential evaporation was 1440 mm for the year of measurement.

The seasonal ratios of measured evapotranspiration to calculated potential evapotranspiration were 0.92 for the autumn months, 0.44 for the winter months, and 0.89 for the spring months.

Measurements will be continued for several years until root restriction begins to have an effect.

224. Ritchie, J. T., Rhoades, E. D., and Richardson, C. W.

"Calculating Evaporation from Native Grassland Watersheds," *Transactions, American Society of Agricultural Engineers*, 1976, pp. 1098–1103.

Evaporation from soil and plant surfaces in many natural grassland sites will often be less than potential evaporation because of sparse vegetation or soil water deficits in the rootzone. A computer model developed for calculating daily evaporation from row crop surfaces with partial cover was modified for use on native grasslands. Daily evaporation is computed by adding independently calculated soil evaporation and transpiration. Potential evaporation is calculated from commonly available atmospheric information. Soil evaporation rate is related to soil hydraulic properties, mulch cover, and potential evaporation rate. Transpiration rate is related to potential evaporation through the green leaf area index and the soil water status of the rootzone. Daily evaporation was calculated for three small native grassland watersheds where runoff, rainfall, and soil water content were measured. Seasonal changes in soil water content were calculated based on drainage rates computed from the amount of infiltration in excess of the upper limit of extractable soil water and calculated evaporation rates. Calculated changes were usually within ±5 cm of measured soil water during a one-year period.

Water may be transported from soil to the atmosphere directly as evaporation from soil as a transpiration through plants. In many native grassland sites, actual evaporation rate (soil evaporation and transpiration) will depend on atmospheric, soil, and plant interactions.

A model that describes how these factors combine to determine evaporation from crop plants has been described by Ritchie (1972) and Richardson and Ritchie (1973). Evaluations of evaporation from grasslands by Garwood and Williams (1967), Aase and Wight (1972), Nkemdirim and Yamashita (1972), and Nkemdirim and Haley (1973) indicate that evaporation response to atmospheric demands and soil water deficits on many grassland species is similar to that of many crop species. In this paper we report a modification of the cropland model for calculating evaporation from native grasslands and identify specific soil, plant, and atmospheric information needed for calculating grassland evapotranspiration.

225. Robinson, T. W.

"The Effect of Desert Vegetation on the Water Supply of Arid Regions," in *International Conference on Water for Peace,* Washington, D.C., May 23–31, 1967, U.S. Government Printing Office, Vol. 3, 1968, pp. 622–633.

Xerophytes and phreatophytes are compared in this report, and some phreatophytes and their uses are listed. The typical water requirements of various phreatophytes are listed and the resultant draft on the groundwater is discussed.

226. Robinson, T. W.

"Evapotranspiration by Woody Phreatophytes in the Humboldt River Valley near Winnemucca, Nevada," *U.S. Geological Survey Professional Paper 491-D*, 1970, 41 pp.

This report presents the results of cooperative studies of evapotranspiration by phreatophytes in the Winnemucca reach of the Humboldt River Valley. Water that is wasted by evapotranspiration from areas of low beneficial phreatophytes is one of the largest unknowns in the water budget of the reach. In order to obtain information with which to evaluate the consumptive waste, studies of the water use of four wood phreatophytes–greasewood, rabbitbrush, willow, and wildrose–were undertaken in evapotranspiration tanks at the Winnemucca test site.

Twelve tanks ranging in size from 30 ft^2 and 10.5 ft deep to 10 ft^2 and 7 ft deep were constructed. Seedlings of greasewood were planted in two tanks and of rabbit-brush in three tanks: cuttings of willow were planted in three tanks and of wildrose in three tanks. The twelfth tank was left bare. The tanks were constructed in place by lining excavated pits with watertight plastic membranes, providing a water distribution system on the bottom, and backfilling with the excavated material. The tanks were operated during the growing season April 1 to October 20 from 1961 to 1967, inclusive.

Evapotranspiration, expressed on an areal basis as depth over a unit area, gives no indication of growth conditions for which the information was obtained and may result in serious error when transposed to areas of dissimilar growth conditions. Some of the difficulties and uncertainties of the areal method may be avoided by expressing evapotranspiration on a volume-of-foliage basis, as a quantity of water per unit of foliage volume. The method presumes that transpiration by a species is proportional to the total transpiring leaf area and, so, proportional to the foliage volume. In the results of the studies, evapotranspiration is expressed in both quantities. The annual use of water ranged rather widely over the study period as the plants responded to the effect of plant damage, boron toxicity, depth to the water level, and warmth and length of the growing seasons.

227. Robinson, T. W.

"Introduction, Spread and Areal Extent of Saltcedar (*Tamarix*) in the Western United States," *U.S. Geological Survey Professional Paper 491-A*, 1965, 12 pp.

Saltcedar, the name generally applied to two exotic deciduous species of the genus *Tamarix*, was introduced into this country more than 100 years ago and has, in the last 30 years, become very much of a nuisance plant in the arid and semiarid regions of the western states. The species are highly water-consuming, salt-tolerant, naturalizing shrubs that have escaped from cultivation and spread rapidly from one stream valley to another.

Saltcedar occurs in 15 of the 17 western states. Areas infested range from less than 1,000 acres each in Idaho, Montana, Nebraska, and South Dakota, to about 450,000 acres in Texas. Its dense growth along stream channels presents a barrier to flood flows, and thereby increases flood hazards and sediment deposition. The time of awareness of the plant by residents of the region was generally in the 1920's.

The total area of saltcedar growth has increased from an estimated 10,000 acres in 1920 to more than 900,000 acres in 1920 to more than 900,000 acres in 1961. It is possible that by 1970 saltcedar will be growing on 1 1/3 million acres. Not only is the growth increasing in areal extent but also in density of growth. The consumptive waste of groundwater by the plant is estimated as 40 to 50 thousand acre-ft in 1920, 3.5 million acre-ft in 1961, and possibly 5.0 million acre-ft by 1970.

228. Robinson, T. W.

"Phreatophyte Research in Western United States, October 1958 to March 1959," *U.S. Geological Survey Circular 413,* 1959, 14 pp.

This report states that there are three categories of active research projects on phreatophytes in the western states: hydrologic and ecologic, eradication and control, and salvage. It covers only projects that were currently in progress or for which plans were firmly developed during the period October 1958 to March 1959.

229. Robinson, T. W.

"Phreatophyte Research in the Western States, March 1959 to July 1964," *U.S. Geological Survey Circular 495*, 1964, 31 pp.

Between March 1959 and July 1964, 48 research projects on phreatophytes were reported as active in the arid and semiarid regions of the western United States. This circular is a revision of *U.S. Geological Survey Circular 413* (Robinson 1959).

230. Robinson, T. W.

"Phreatophytes," *U.S. Geological Survey Water Supply Paper 1423,* 1958, 84 pp.

In the arid and semiarid regions of the western United States, phreatophytes with their low economic value and high rate of consumptive use of water, pose a serious problem. It is estimated that phreatophytes (excluding such beneficial species as alfalfa) cover about 16 million acres in the 17 western states and discharge as much as 25 million acre-ft of water into the atmosphere annually. Although little has been done so far to prevent this waste, much of the water undoubtedly can be salvaged by converting consumptive waste to consumptive use. There are two basic methods: reducing consumptive waste by diverting water from the plants to other uses and increasing the efficiency of water use by substituting beneficial for nonbeneficial plant species. These methods, to be successful, require an understanding of the factors that affect the occurrence and amount of water used by phreatophytes and of climate, depth to and quality of groundwater, and soil.

More than 70 plant species have been classified as phreatophytes; this report lists information concerning them. The available information about the phreatophytic characteristics of most of the species is meager, but for eight (pickleweed, rabbitbrush, saltgrass, alfalfa, cottonwood, willow, greasewood, and saltcedar) there are sufficient data to warrant separate discussions. The annual use of water by phreatophytes ranges from a few tenths of an acre-ft per acre to more than 7 acre-ft per acre.

In the Southwest, saltcedar, an exotic plant that develops a jungle-like growth, has invaded and choked the normal overflow channels of streams so as to produce a flood hazard that must be reckoned with. In addition, the ponding effect of the dense growth results in above-normal sediment deposition in the area of growth and reduced deposition downstream, as was observed at the McMillan Reservoir on the Pecos River in New Mexico.

231. Robinson, T. W.

"Phreatophytes and Their Relation to Water in Western United States," *Transactions, American Geophysical Union*, Vol. 33, No. 1, 1952, pp. 57–61.

Phreatophytes cover about 15 million acres in the 17 western states and may waste as much as 20 to 25 million acre-ft of water into the atmosphere annually. Many variable factors affect the growth of the plants and their use of water, but knowledge of them is limited. The water used by these plants probably represents the largest source of reclaimable water in the arid western United States. Obviously, it is not possible to salvage all the water wasted, but the potentialities and the rewards of success are sufficient to warrant thorough investigation and study of the problem of groundwater salvage.

One way of reducing waste would be to destroy the vegetation. Destroying some species of vegetation, however, is not a simple task. Saltcedar is particularly difficult to destroy, and attempts to kill the cover by burning, mechanical removal, or use of herbicides have not been completely successful.

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

Lowering the water table in the area of evapotranspiration discharge, either by pumping or by drainage, is another method of reducing waste. To be successful, however, the drainage should be rapid so that plants will die from lack of water; otherwise, the plant roots will keep pace with the declining water table and keep the plant alive until conditions are again stable.

The efficiency of use of groundwater may be increased by substituting, in the area of discharge, plants having higher economic value. Forage crops, particularly alfalfa and grasses, seem best adapted for this purpose. (From Author's Summary)

232. Robinson, T. W., and Johnson, A. I.

"Selected Bibliography on Evaporation and Transpiration," *U.S. Geological Survey Water-Supply Paper 1539-R*, 1961, 25 pp.

This publication presents selected references from the United States from the early 1800's into 1958.

233. Robinson, T. W., and Donaldson, D.

"Pontacyl Brilliant Pink as Tracer Dye in the Movement of Water in Phreatophytes," *Water Resources Research*, Vol. 3, No. 1, 1967, pp. 203–211.

In connection with evapotranspiration studies, pontacyl brilliant pink (a fluorescent dye) was used to trace the movement of water in two species of woody phreatophytes, willow and wildrose. The dye was introduced into water surrounding the plant roots on August 4, 1964. Thereafter, leaf samples were collected periodically until the end of the growing season in October. Fluorometric measurements showed the presence of the dye in the leaves. Dye was also found in samples of roots and stems and in transpired water collected in plastic bags. Dye concentration was greatest in the upper part of the stems. As a tracer, the dye offers a rapid method for studying the source, movement, and disposal of water used by phreatophytes. The method is rapid and inexpensive, and the laboratory determination is not difficult. The fluorometric determinations were made with a GK Turner fluorometer Model 111, which has a sensitivity of 1 ppb.

234. Rowe, P. B., and Reimann, L. F.

"Water Use by Brush, Grass and Grass-Forb Vegetation," *Journal of Forestry*, Vol. 59, No. 3, 1961, pp. 175–181.

A plot study on the San Dimas Experimental Forest, in the San Gabriel Mountains of southern California, indicated wide differences in seasonal and annual evapotranspiration from deep soil beneath grass and brush covers. Evaluations and comparisons were made during years of high (40.5 in.), moderate (24.9 in.) and low (15.5 in.) rainfall. One set of plots was left in its natural vegetation of dense oak-brush cover. The other set was cleared of brush and sown to Italian ryegrass (*Lolium multiflorum*). The grass cover was maintained for 2 years by killing all brush sprouts with 2.4.5-T. The fourth year a heavy stand of summer-growing forbs was allowed to develop. In the years without weed growth, evapotranspiration was 15.5 in. (evapotranspiration with brush was 23.4 in.). In the fourth year the grass-forb evapotranspiration was 17.0 in.; the evapotranspiration from brush was 18.0 in. The results indicated that the brush plots transpired 8 in. more than the grass plots during the years of high and moderate rainfall. In a year of low rainfall, the transpiration of the brush plot was only 3 in. more than that of the grass.

235. Sammis, T. W.

"Water Disposition in Ephemeral Stream Channels," *Hydrology and Water Resources in Arizona and the Southwest*, Proceedings, Association and the Hydrology Section, Arizona Academy of Science, May 5–6, Prescott, Ariz., Vol. 2, 1972, pp. 473–491.

The general objective of the study was to develop an infiltration equation for estimating transmission losses during a flow event in an ephemeral stream channel near Tucson. Involved in the study was the investigation of the effect of soil texture and water content on the infiltration function, and a method for determining soil moisture disposition after a flow event. (From Author Introduction)

236. Sammis, T. W., and Gay, L. W.

"Evapotranspiration from an Arid Zone Plant Community," *Journal of Arid Environments*, Vol. 2, No. 4, December, 1979, pp. 313–321.

The one-year water loss from a weighing lysimeter containing a large creosotebush (*Larrea tridentata* (DC) Cav.) was 259 mm at a Sonoran desert site near Tucson, Arizona. The loss from an adjacent stand of creosotebush totaled 242 mm, and that from bare soil plots was 231 mm. The three loss estimates were in good agreement with measured annual precipitation of 234 m. Transpiration made up only 7 percent of the loss from the lysimeter according to a simplified diffusion model.

There was no deep drainage or runoff, so the remaining losses were by evaporation from the soil surface.

237. Scholl, D. G.

"Soil Moisture Flux and Evapotranspiration Determined from Soil Hydraulic Properties in a Chaparral Stand," *Soil Science Society of America Journal*, Vol. 40, 1976, pp. 14–18.

Measurements of rainfall, overland flow, soil moisture, and hydraulic properties were obtained from a sloping plot in a chaparral stand. The moisture characteristic and dynamic conductivity were determined from core samples of several soil layers to a depth of 420 cm. A water balance model requiring the above parameters and a Darcian moisture flux analysis was used to predict drainage below the root zone and loss by evapotranspiration. Daily results of the water balance were summarized during 2 water years. Predicted values agreed well with values measured on a nearby watershed during both years–the first an unusually dry year, the second unusually wet.

238. Schumann, H. H.

"Water Resources of Lower Sycamore Creek, Maricopa County, Arizona," *U. S. Geological Survey Open File Report* (University of Arizona, Master of Science Thesis, Department of Watershed Management), 1967, 52 pp.

Like many small watersheds in the Southwest streamflow originating in the upper mountainous part of the Sycamore Creek watershed disappears quickly into the alluvial deposits adjacent to the mountains. Streamflow from the upper 165 mi^2 of the watershed ranged from 167 to 14,320 acre-ft per water year and averaged 6,110 acre-ft per water year for the 5 years of record.

Streamflow measurements indicate that most of the water that enters the lower portion of the watershed does not reach the Verde River as surface flow. On an annual basis, from 0 to 10 percent of the streamflow entering the area is discharged to the Verde River as streamflow.

Most of the streamflow that disappears in the lower area rapidly percolates down to the water table and recharges the groundwater reservoir. Most of this water is released as groundwater discharge at a relatively constant rate of about 4,000 acre-ft per year to the Verde River.

Water losses to evapotranspiration by phreatophytic riparian vegetation in the lower Sycamore Creek area are controlled by the depth to the water table. Annual water losses ranged from as little as about 0.1 acre-ft per acre during a very dry year to as much as about 3.1 acre-ft per acre during a very wet year based on a water-budget analysis of these periods. The average annual water loss from the lower area was about 1.1 acre-ft per acre based on a water-budget analysis of the 5-year period of record.

239. Schumann, H. H., and Thomsen, B. W.

"Hydrologic Regimen of Lower Tonto Creek Basin, Gila County, Arizona, A Reconnaissance Study," *Arizona Water Commission Bulletin 3*, prepared by U.S. Geological Survey, Phoenix, Arizona, November, 1972, 39 pp.

The 280-mi^2 lower Tonto Creek basin is in the Central highlands water province of central Arizona. The basin is drained by Tonto Creek, which flows southward and discharges into Roosevelt Lake. The mountains that border the basin are composed chiefly of igneous and metamorphic rocks, and the basin is underlain by more than 2,000 ft of unconsolidated to semiconsolidated sedimentary deposits. The channel and flood plain of lower Tonto Creek are underlain by as much as 65 ft of alluvium.

In the lower Tonto Creek basin the principal sources of water are the precipitation, which ranges from 17 to more than 20 in. per year, and the streamflow that enters the area from the upper Tonto Creek basin. The precipitation that falls on the lower Tonto Creek basin produces about 20,000 acre-ft per year of streamflow. The streamflow that enters the lower basin from the 675-mi^2 upper basin is measured at the northern end of the study area and averages about 80,000 acre-ft per year. An estimated 17,000 to 20,000 acre-ft of streamflow infiltrates annually into the highly permeable alluvium.

The alluvium is the principal aquifer in the lower Tonto Creek basin. Water levels in wells drilled in this aquifer rise quickly in direct response to flood flow in Tonto Creek, which indicates that a large part of the flow loss is recharged to the groundwater reservoir.

In the lower Tonto Creek basin, water is discharged to Roosevelt Lake by streamflow and subsurface flow and to the atmosphere by evapotranspiration. The flow from Tonto Creek that enters Roosevelt Lake averages about 80,000 acre-ft per year, the subsurface flow that enters the lake from the alluvium averages about 4,000 acre-ft per year, and the evapotranspiration losses average about 13,000 acre-ft per year.

Flows in Tonto Creek and groundwater in the alluvium and the lower part of the basin fill are of excellent chemical quality and are suitable for most uses. The chemical quality of groundwater in the alluvium and that of flow in Tonto Creek is similar because the alluvium receives most of its recharge from the creek. Water from a well drilled in the fine-grained facies of the upper part of the basin fill is unsuitable for drinking purposes.

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

"Water Consumption by Phreatophytes," *Progressive Agriculture in Arizona*, Vol. 19, No. 2, 1967, pp. 10–11.

This report summarizes a study conducted on the San Pedro River flood plain in Arizona, on transpiration by tamarisk shrubs during the summer of 1966. Measurements were made by a modified evapotranspiration tent (Mace and Thompson 1969). Evapotranspiration as measured with the tent exceeded pan evaporation data recorded at several sites in southern Arizona.

At the study site there were 895 shrubs per acre. The average monthly loss of water was computed at 1.1 acre-ft from July to September. It is concluded that it is not possible to predict the actual amount of water that could be saved each year by clearing the bottom lands, since the rate of water use from the area after clearing would depend on subsequent treatment of the area.

241. Shown, L. M., Lusby, G. C., and Branson, F. A.

"Soil-Moisture Effects of Conversion of Sagebrush Cover to Bunchgrass Cover," *Water Resources Bulletin*, Vol. 8, No. 6, December, 1972, pp. 1265–1272.

Precipitation, soil moisture, runoff, and vegetation were measured on two, 5- to 10-acre, big sagebrush watersheds and two, equally small, beardless bluebunch wheatgrass watersheds that were converted from big sagebrush in 1967. The watersheds are located near Wolcott, Colorado, at an elevation of 7,200 ft, and are mantled with 2 to 3 ft of silty clay soils. Annual precipitation was about 13.5 in.; about 9 in. occurred as rain or snow from April through October and about 4.5 in. accumulated as a snowpack from November through March.

Evapotranspiration was about 2 in. greater in 1968 and 1 in. greater in 1969 from the sagebrush watersheds than from the grass watersheds. With a mature stand of grass in 1970 and 1971, the differences in evapotranspiration were within the range of differences measured during the 3-year calibration period when all four watersheds were sagebrush. Water use was similar in the top one foot (ft) of soil but slightly more water was used by the grass in the 1- to 2-foot zone and more water was being used by the sagebrush below 2 ft. Soil water potential data indicated that only the big sagebrush used a small amount of water from the fractured shale at depths below 40 in. Sagebrush used more water in August and September than the grass.

242. Skidmore, E. L., Jacobs, H. S., and Powers, W. L.

"Potential Evapotranspiration as Influenced by Wind," *Agronomy Journal*, Vol. 61, No. 4, July–August, 1969, pp. 543–546.

The contribution of wind to calculated potential evapotranspiration was investigated with applications for the climate of the Great Plains. A revised combination model proposed by van Baval for computing instantaneous potential evapotranspiration was used. The model contains two terms that are expressions for the portions of potential evapotranspiration primarily due to net radiation and wind, respectively. With ambient water vapor pressure 20 mb, temperature 30C, wind 2, 4, and 6 m sec^{-1} at 2 m with a roughness length of 1 cm, contribution of wind dominant term to evaporation from a wet surface is 0.15, 0.30, and 0.45 mm hr^{-1} , respectively. at 10-mb vapor pressure, and the same temperature, the corresponding evaporation rates are 0.22, 0.43, and 0.65 mm hr^{-1}. On representative and consecutive "nonwindy" and "windy" days at Manhattan, Kansas (average daily windspeeds at 45 cm were 0.88 and 2.26 m sec^{-1}, the wind dominant term contributed 33 and 113 percent, respectively, as much as the radiation dominant term to the total calculated potential evapotranspiration. For these 2 days, the ratio of potential evapotranspiration to net radiation was 0.98 and 1.60.

243. Smith, J. L.

"Forest Soils and the Associated Soil-Plant Water Regime," Invited Paper, Proceedings of a Symposium: Isotopes and Radiation in Soil-Plant Relationships Including Forestry, Vienna, Austria, December 13–17, 1971, *International Atomic Energy Agency*, Vienna, 1972, pp. 399–412.

In forest lands, maximum stream discharges, peak flows, soil erosion, plant growth and water yield improvement through vegetation change depend on the hydrologic regime of the soil. The use of radioactive isotopes has made it easier to trace water movement in soils and trees. The technique was used to measure water movement in soils on the Sierra Nevada of California and in two major tree species–red fir (*Abies magnifica* A. Murr.) and lodgepole pine (*Pinus contorta* Dougl.)–growing there. Water flow through a pyroclastic soil having porosities of 44 to 61 percent was traced by tritium and 32P isotopes. The rate of flow in saturated zones of the soil ranged from 12.2 to 30.5 cm/hr, the rate depending on depth of the water table. Water movement in trees in daytime in winter was traced by 32P; it ranged from 0.3 to 1.3 cm/h. Water movement in these tree species in early spring when the soil was covered to a depth of 360 cm of snow ranged from 1.5 to 2 m/h. Evapotranspiration could not be determined by measuring soil moisture because snowmelt quickly replenished soil moisture. Total water use by lodgepole pine was estimated by combining rates and area of water movement within tree stems. Estimates of water use ranged from 0.1 litre/h for long-term movement in winter to 30.6 litre/h for short-term movement in early spring during ideal transpiration conditions. The results suggest that coefficients for water balance formulas based on the energy balance approach can be estimated by using data on water movement determined by isotope tracers.

244. Sopper, W. E.

"Watershed Management–Water Supply Augmentation by Watershed Management in Wildland Areas," Final Report for National Water Commission, *Report NWC 71-008*, September 1971, 155 pp.

Existing literature was surveyed and analyzed to determine the present state of knowledge regarding the extent to which water supplies can be augmented by vegetation management and the efficacy of such management methods. Effects of total and partial vegetation removal on water quantity and quality are discussed in detail. Vegetation conversion effects on streamflow are also considered. Special attention is given to snow pack management, phreatophyte vegetation management, and the potential for combining watershed management with weather modification to increase water yield. National and regional estimates of potential increases in water yield that might be obtained through vegetation manipulation are presented. An extensive bibliography is included.

245. Sorooshian, S., and Ritzi, R.

"Reduction in Ground-water Losses Due to Phreatophyte Uptake, Spring 1984, Initial Investigation," University of Arizona, Department of Hydrology and Water Resources, unpublished report submitted to U.S. Water Conservation Laboratory, USDA-Agricultural Research Service, Phoenix, Arizona, 1984, 8 pp.

As proposed to the United States Water Conservation Laboratory, study has begun of water loss along floodplains due to phyreatophyte transpiration, with application to reducing this consumption. The project is seen as two phased. The crucial initial phase has a goal to examine the relationship between evapotranspiration (ET) for phreatophyte species, and both the depth to water and the height and density of the vegetation. Also, various pumping scenarios will be modeled resulting in different water table profiles along a given river floodplain. Water savings through decreased consumption will then be calculated as depth to the water table is changed, and an economic analysis of such pumping will be possible.

The second phase has a goal to develop a mathematical model for the management of water table depth; investigating various scenarios of pump allocation, distribution, and operation as well as water transmission with the purpose of coming up with the most economical scheme of reducing ET losses.

A complete literature review has been conducted. Seven computer data bases were searched resulting in a printout of several hundred titles and abstracts of existing articles and reports. The goal of this search was to locate previous field investigations with ET/watertable (WT) depth or ET/height-density data, as well as to examine the methodologies employed in these studies. (Author's Introduction)

246. Sorooshian, S., and Ritzi, R.

"Reduction in Ground-Water Losses Due to Phreatophyte Uptake," *Progress Report*, University of Arizona, Department of Hydrology and Water Resources, unpublished progress report submitted to U.S. Water Conservation Laboratory, USDA-Agricultural Research Service, Phoenix, Arizona, 1985, 27 pp.

The scope of the report includes distinct sections of discussion. First, is a brief recount of the history of water conservation by reducing phreatophyte evapotranspiration (ET). It may be beneficial to place our present research into a historic perspective, and thus recount the growth of concern over the large losses of water through phreatophytes, the scientific effort towards its study, and the engineering effort towards water salvage.

Subsequent sections attempt to better define the model that has been used thus far to analyze the proposed water table management approach to controlling floodplain Et, development. Finally, for application to continued studies, variations in floodplain aquifers and their supported riparian communities have been assessed and are summarized in the last section. (Author Introduction)

247. Spittlehouse, D. L., and Black, T. A.

"Determination of Evapotranspiration Using Bowen Ratio and Eddy Correlation Measurements," *Journal of Applied Meteorology*, Vol. 18, No. 5, May, 1979, pp. 647–653.

Rates of evapotranspiration from a 14-m high Douglas fir forest on the southwest coast of British Columbia were obtained using the energy balance/Bowen ratio method and an energy balance/eddy correlation method. In the former method, the Bowen ratio was measured using reversing diode psychrometers. In the latter, the sensible heat flux was obtained by eddy correlation analysis of data obtained from a fast response thermistor and Gill anemometers mounted horizontally and at 30° from the vertical. The generally low wind speed above the forest resulted in occasional stalling of the anemometers and made obtaining adequate eddy correlation data difficult. Spectral analysis of the eddy correlation data indicates that a significant fraction of the sensible heat flux was at low frequencies. The regression relationship between evapotranspiration rate obtained using the energy balance/eddy correlation method (E_P) and that obtained using the energy balance/Bowen ratio method (E_β) was found to be

$$E_P = 0.96\ E_\beta - 0.02\ [\text{mm h} - 1],\ r^2 = 0.93,\ = 0.07\ \text{mm h}^{-1}.$$

The experiment suggests that an eddy correlation system using mechanical anemometers is not suitable for extended water balance studies of forests where low wind speeds predominate.

248. Spittlehouse, D. L., and Black, T. A.

"A Growing Season Water Balance Model Applied to Two Douglas Fir Stands," *Water Resources Research*, Vol. 17, No. 6, December, 1981, pp. 1651–1656.

The forest water balance model presented requires only daily solar radiation, maximum and minimum air temperature, and rainfall as the input weather data. Site parameters are root zone depth, soil water retention and drainage characteristics, estimated canopy leaf area index, and the coefficients of the evapotranspiration and rainfall interception submodels. The evapotranspiration submodel calculates the forest evapotranspiration rate as the lesser of energy-limited and soil-limited rates. The former is calculated from the 24-hour net radiation and the latter from the fraction of extractable water in the root zone. Solar radiation and air temperature are used to calculate net radiation. Interception is calculated from the daily rainfall. The root zone is treated as a single layer with drainage calculated as a function of the root zone water content. Water deficits and the matric potential of the root zone are used to indicate tree water stress. The model was tested on two Douglas fir stands of different stand density and leaf area index. The coefficients used in the evapotranspiration submodel were found to be the same for both stands. It was also found that over 20 percent of the growing season rainfall was lost through interception.

249. Stark, N.

"Spring Transpiration of Three Desert Species," *Journal of Hydrology*, Vol. 6, 1968, pp. 297–305.

Transpirometer data which are not corrected for weight differences show that sagebrush (*Artemisia tridentata* Nutt.) loses more water per plant per minute than does rabbitbrush (*Chrysothamnus nauseosus albicaulis* (Nutt.) Hall & Clem.) on a dry site. With corrections for dry leaf weight differences, the reverse is true. Rabbitbrush transpires more rapidly on a dry site per gram of dry weight than does sagebrush. On wet sites, sagebrush and horsebrush (*Tetradymia canescens* D.C.) transpire more rapidly than on dry sites in spring. The dry weight of leaves is a more desirable reference for transpiration rate than is leaf area which is used for broad-leaved plants. Deep shade causes an abrupt decrease in the transpiration rate of sagebrush over the full sun rate. After seven minutes in shade, the plant does not immediately regain its full sun transpiration rate when restored to full sunlight.

250. Stark, N.

"The Transpirometer for Measuring the Transpiration of Desert Plants," *Journal of Hydrology*, Vol. 5, No. 2, 1967, pp. 143–157.

This paper compares transpiration results obtained through use of the electronic hygrometer and quick-weighing methods. It was determined that quick-weighing results from several species compared closely in direction with hygrometer data. The paper describes the water loss from greasewood (*Sarcobatus vermiculatus*) branches differing in condition and from separate clumps of saltgrass (*Distichlis stricta*). The dark-green leaves of greasewood appear to be better able to control water loss than the yellow-green leaves. The study followed the curves for water loss during flowering and fruiting of sagebrush (*Artemisia tridentata*) and rabbitbrush (*Chrysothamnus nauseosus albicaulis*), using the same 10 branches for study over a 2-month period. Both of these species appear to be able to control water loss during the period of fruit expansion somewhat independently of air temperatures and relative humidity. Water loss is rapid in rabbitbrush as the fruit accessory tissues dry out.

251. Stearns, H. T., Bryan, L. L., and Crandall, L.

"Geology and Water Resources of the Mud Lake Region, Idaho," *U.S. Geological Survey Water Supply Paper 818*, U.S. Government Printing Office, Washington, D.C., 1939, 125 pp.

This report relates primarily to the area that contributes water to Mud Lake through surface or underground channels, but the entire area covered is somewhat more extensive. The purpose of the investigation was to determine the source of the water supplying Mud Lake and its safe yield for irrigation. Prior to about 1900, Mud Lake was an intermittent pond that seldom if ever covered more than a few hundred acres. Beginning about that time the lake increased in size, until in 1921 the aggregate area of Mud Lake and a group of smaller lakes that had come into existence reached 17,530 acres; moreover, tracts of swampy land in 1921 aggregated about 10,000 acres. The special objective of the investigation was to determine the cause of this phenomenal increase in the water supply, the quantity and permanence of this supply, and the best methods of conserving and utilizing it.

The mountains bordering the basin are made up of pre-Tertiary sedimentary rocks with complicated structure, the Tertiary rhyolites, pyroclastic rocks, and related rocks, most of which have relatively low permeability. Covering the plains area are extensive flows of Quaternary basalt and the oceans from which they were derived. These flows attain a thickness of about 1,000 ft, are extremely permeable, and constitute the chief aquifers of the area. Depressions in these basalts are filled by the ancient lake beds that underlie and surround Mud Lake and Market Lake. Because of their low permeability, these lake beds give rise to perched water tables. Artesian water occurs in parts of the area where the basalt flows are intercalated with these beds. Overlying and interfingering with the basalt along the foot of the mountains are extensive alluvial deposits, and at Camas Meadows there are pre-Wisconsin glacial deposits.

The report contains data as to the discharge of the streams, their contributions to the water table, the area and capacity of the several lakes, the losses from them by diversion and evaporation, and the losses by transpiration from the swampy areas. It contains descriptions and water-level records of nearly 600 wells and analyses of 17 samples of water collected in the area. It describes the principal springs and the water tables in the Mud Lake area, Camas Meadows, Island Park Basin, Market Lake Basin, and Egin Bench and gives an inventory of the water supply.

The investigation showed that the large increase in the water supply has resulted from percolation of water used in irrigation on the Egin Bench, about 30 miles away, which caused the water table to rise and the springs to become perennial. Mud Lake reached its maximum volume in 1923. As the rate at which water percolates from the Egin Bench is nearly constant, the ground-water supply to the lake now fluctuates in response to changes in precipitation and run-off from the tributary drainage area. Methods are described for increasing the use of the water supply of the area by drilling wells and utilizing the underground reservoir formed by the water-bearing basalt.

252. Stephens, J. C.

“Hydrologic Reconnaissance of the Tule Valley Drainage Basin, Juab and Millard Counties, Utah,” U.S. Geological Survey in cooperation with Utah Department of Natural Resources, Division of Water Rights, State of Utah, Department of Natural Resources, *Technical Publication No. 56*, 1977, 29 pp.

The Tule Valley drainage basin is an area of about 940 mi^2 (2,430 km^2) in Juab and Millard Counties in west-central Utah. Precipitation in the basin averages about 8 in. (203 mm) annually. There is no surface outflow and all streams are ephemeral. Annual runoff averages about 0.09 in. (2.3 mm). Because there is no sustained runoff, and flow is local and infrequent, reservoirs do not provide dependable water supplies.

Groundwater recharge from precipitation in the basin is estimated to average 7,600 acre-ft (9.4 cubic hectometers (hm^3)) annually. Discharge, principally by evapotranspiration, averages about 40,000 acre-ft (49 hm^3) annually. Subsurface inflow from adjacent areas is estimated to average about 32,000 acre-ft (39.5 hm^3) annually.

Nearly all discharge from the groundwater system is evaporated directly from the water table or transpired by phreatophytes in the 68,000 acres (27,500 square hectometers (hm^2)) that constitute a natural discharge area on the northern valley floor.

Dissolved-solids concentrations in the water range from 516 to 1,580 milligrams per liter. Water from all sources sampled apparently is of satisfactory chemical quality for livestock use. The temperature of water discharged by springs ranges from 12.5 to 28.0° Celsius.

More than 700,000 acre-ft (863 hm^3) of water might be obtained from storage and by capture of water now being consumed by evapotranspiration if wells in the principal area of natural discharge were pumped to lower the water table 100 ft (30 m). Supplies for livestock could be obtained from wells at many locations on the alluvial fans and nearly anywhere on the valley floor.

253. Sturges, D. L.

"Evaporation at a Wyoming Mountain Bog," *Journal of Soil and Water Conservation*, January–February, 1968, pp. 23–25.

Two major water supply problems common to all western states are quantity and timing of streamflow. On unregulated streams the bulk of flow may go unused because of small downstream water requirements during the snowmelt period.

The principal technique for augmenting flows from western forest lands has been timber harvest, but streams in these same watersheds often originate in bogs or are bordered by boggy areas. The wetland sites may be useful in altering the quantity or timing of streamflow. Any possible management procedures, however, must be grounded on knowledge of a bog's hydrologic function. Such information is not presently available.

Evapotranspiration losses from mountain bogs are an important aspect of bog hydrology. Measurements of (a) evaporation from a free-water surface, (b) calculated potential evapotranspiration, and (c) actual bog evapotranspiration were made from 1963 to 1965 at a mountain bog in Wyoming and form the subject of this report. (Author Introduction)

254. Sturges, D. L.

"Soil Water Withdrawal and Root Distribution Under Grubbed, Sprayed, and Undisturbed Big Sagebrush Vegetation," *Great Plains Naturalist*, Vol. 40, No. 2, 1980, pp. 157–164.

Seasonal depletion by vegetation where sagebrush was selectively removed by grubbing and where sagebrush was sprayed with 2.4-D was 33 and 12 percent less, respectively, than that for undisturbed big sagebrush vegetation in the surface 122 cm of soil. Differences were located primarily below 61 cm in vegetation grubbed the previous fall and below 91 cm in vegetation sprayed three years previously. Total root weights under grubbed and sprayed vegetation were 29 and 16 percent less, respectively, than for undisturbed big sagebrush vegetation. Total herbaceous production by grubbed and sprayed vegetation was 69 and 43 percent less, respectively, than production by undisturbed vegetation.

255. Sumsion, C. T.

"Geology and Water Resources of the Spanish Valley Area, Grand and San Juan Counties, Utah," *Technical Publication No. 32*, State of Utah, Department of Natural Resources, Prepared by U.S. Geological Survey in cooperation with the Utah Department of Natural Resources, Division of Water Rights, 1971, 45 pp.

The Spanish Valley area covers about 144 mi^2 on the western slopes of the La Sal Mountains in southeastern Utah; within it, Spanish Valley comprises about 18 mi^2. Altitudes of land surface within the area range from about 3,950 ft at the Colorado River near Moab to 12,646 ft at Mount Mellenthin in the La Sal Mountains. Principal streams in the area are Mill and Pack Creeks; they join near Moab, and Mill Creek enters the Colorado River.

The climate ranges from arid and semiarid in the canyons and valleys at lower altitudes to generally humid and cool in the higher parts of the La Sal Mountains. The precipitation at Moab is fairly evenly distributed throughout the year, but slightly more falls during the winter than during the summer. Mean annual precipitation is about 8 in. at the city of Moab in Spanish Valley, and the weighted normal annual precipitation on the entire Spanish Valley area is about 15 in.

Sedimentary formations exposed in the area range in age from Middle Pennsylvanian to Holocene, attaining a total maximum exposed thickness of nearly 6,400 ft. They are intruded by igneous stocks, laccoliths, sills, and dikes of Tertiary age which form the La Sal Mountains. The unconsolidated valley fill of Pleistocene and Holocene age in Spanish Valley attains a maximum thickness of more than 360 ft.

Little of the precipitation on Spanish Valley enters the groundwater system. Snowfall in the upland areas melts slowly and contributes most of the groundwater recharge by movement through sandstones of the Glen Canyon Group to the valley fill of Spanish Valley. Groundwater occurs under water-table conditions in the valley fill, which consists generally of gravelly sand. The long-term specific yield of the valley fill is estimated to be about 0.25, and total groundwater storage about 200,000 acre-ft. Aquifer characteristics vary throughout the valley. Well yields may be as much as 1,000 gallons per minute with but 35 ft of drawdown in the valley fill. Where sandstones of the Glen Canyon Group are intensely fractured northeast of Spanish Valley, they yield large quantities of groundwater to springs and wells.

Inflow to the Spanish Valley area is about 115,000 acre-ft annually from precipitation; of this, about 28,000 acre-ft is discharged annually from Spanish Valley by surface streams and from the groundwater reservoir, and the remainder is discharged by evapotranspiration in the Spanish Valley area.

Annual recharge to and discharge from the groundwater basin in Spanish Valley are estimated to be 14,000 acre-ft. Only 3,300 acre-ft are used for beneficial purposes in the valley. Of the remainder, groundwater outflow to the Colorado River is estimated to be 8,000 acre-ft, and about 3,000 acre-ft is consumed in an area of phreatophytes and hydrophytes.

256. Swartz, T. J., Burman, R. D., and Rechard, P. A.

"Consumptive Use by Irrigated High Mountain Meadows in Southern Wyoming," *Water Resources Series No. 29*, Water Resources Research Institute, University of Wyoming, Laramie, Wyoming, 1972, 89 pp.

An area along the Medicine Bow River in south central Wyoming was instrumented to obtain estimates of consumptive use (evapotranspiration) from irrigated high mountain meadows. Four basic methods were employed: non-weighing tank lysimeters, the hydrologic budget, the modified Jensen-Haise method, and an adaptation of the Blaney-Criddle method.

A description of the instrumentation required to secure the necessary data for these methods, the results of the application of these methods, and comparisons of the results are presented.

Analysis revealed that estimates by the Blaney-Criddle method were consistently less than the values obtained by any of the other methods. Estimates by the Jensen-Haise method compared favorably, on a weekly basis, with the evapotranspiration measured from the tank lysimeters. Comparisons also showed that estimates by the modified Jensen-Haise method produced the least discrepancy from the seasonal consumptive use determined by the hydrologic budget.

257. Tew, R. K.

"Soil Moisture Depletion by Aspen in Central Utah," *U.S. Forest Service Research Note INT-73*, Intermountain Forest & Range Experiment Station, Ogden, Utah, 1967, 8 pp.

Aspect and elevation of site and age of vegetation affect the amount of soil moisture depleted by aspen (*Populus tremuloides* Michx.) during the growing season in central Utah. Clones on west aspects used more soil moisture than those on either north- or south-facing slopes. Differences in elevation had little effect on the amount of soil moisture depleted by mature aspen, but sprout stands used significantly greater amounts of soil moisture on the lower elevation sites. As much as 5 in. of moisture was conserved in the upper 6 ft of soil during the first season after aspen removal, but as sprout stands became re-established, there was a decrease in these moisture savings.

258. Tew, R. K.

"Soil Moisture Depletion by Gambel Oak in Northern Utah," *U.S. Forest Service Research Note INT-54*, Intermountain Forest & Range Experiment Station, Ogden, Utah, 1966, 7 pp.

In years of normal rainfall, 11 to 13 in. of moisture are extracted by Gambel oak from the upper 8 ft of soil during the growing season. The total evapotranspirational loss ranges from 15 to 19 in., depleting moisture from the entire profile. Early season moisture depletion occurs mainly in the upper 4 ft of soil with losses occurring lower in the profile later in the season. Winter precipitation usually provides sufficient moisture to fully recharge the soil profile after the growing season.

259. Thomas, H. E.

"Hydrologic Reconnaissance of the Green River in Utah and Colorado," *U.S. Geological Survey Circular 129*, Washington, D.C., 1952, 32 pp.

The Green River, rising in Wyoming and draining high mountains in that state, northeast Utah and northwest Colorado, is a major tributary of the Colorado River. In the late summer, after the snow has melted from these mountains, the flow in the Green River reaches its minimum for the year. At that time a large proportion of the water in the river is returned to the atmosphere by evaporation and transpiration.

During a 21-day period in September 1948, when the flow was least for the year, the average flow of the river as it entered Utah from Wyoming was 515 cfs. In the 437 miles of its course through Utah and Colorado evapotranspiration losses averaged 430 cfs. The average discharge of the Green River into the Colorado was about 975 cfs. Contributions to the river in Utah and Colorado totaled 890 cfs, including 560 from tributaries. The calculated groundwater inflow was about 330 cfs, of which about 75 percent was contributed within the Uinta Basin. Very little groundwater was contributed to the river in the lower 180 miles of its course, where the river flows through canyon lands of the Colorado Plateaus.

These estimates are based upon information collected during a boat reconnaissance in September 1948, and upon data available from stream-gaging stations along the Green River and many of its tributaries. From these data an accounting was made of the water—as to both quantity and quality—in several segments of the river. For each segment determinations were made of the surface outflow, loss by evapotranspiration, and surface and groundwater inflow. During the reconnaissance information was also obtained as to the relation of streamflow to regional geology and groundwater hydrology.

No detailed hydrologic studies have yet been made within the drainage basin of the Green River. On the basis of this reconnaissance, detailed studies in the Uinta Basin, Browns Park, and Echo Park areas are recommended as highly desirable, because of the possible relations of groundwater hydrology to river basin development projects. Similar reconnaissance can be of value in delineating the areas where detailed hydrologic studies would be most fruitful throughout the upper Colorado River basin.

260. Thompson, C. B.

"Importance of Phreatophytes in Water Supply," Proceedings, *American Society of Civil Engineers, Journal of the Irrigation and Drainage Division,* Vol. 84, No. IR 1, Paper 1502, January, 1958, 17 pp.

Salt cedar (tamarisk) is the dominant type of 80 different species of phreatophytes that infest 17,000,000 acres of land and waste 25,000,000 acre-ft of water in the western United States. This illustrated paper describes its occurrence and spread over 440,000 acres in New Mexico. Water use and methods of eradication and control are also discussed.

261. Thompson, J. R.

"Energy Budget Measurements Over Three Cover Types in Eastern Arizona," *Water Resources Research,* Vol. 10, No. 5, October, 1974, pp. 1045–1048.

Three years of continuous records of net radiation, R_n, were taken over a pine forest, a cienega, and a clear-cut opening. Seasonal patterns of the portion of R_n going into evapotranspiration E_t were determined for these cover types by energy budget measurements in the Bowen ratio equation. By using the average daily R_n over two summer periods (May to June and July to September) and the mean ratios of E_T to R_n , E_t for the three cover types for the growing season was estimated at 19.4 in. for the forest, 15.3 in. for the clear-cut opening and 13.2 in. for the cienega. Weighting these amounts by the extent of the type resulted in a watershed average E_t of 18.4 in. for the growing season.

262. Thomsen, B. W., and Schumann, H. H.

"Water Resources of the Sycamore Creek Watershed, Maricopa County, Arizona," *U.S. Geological Survey Water Supply Paper 1861*, 1968, 53 pp.

The Sycamore Creek watershed is representative of many small watersheds in the Southwest where much of the streamflow originates in the mountainous areas and disappears rather quickly into the alluvial deposits adjacent to the mountains. Five years of streamflow records from the Sycamore Creek watershed show that an average annual water yield of 6,110 acre-ft was obtained from the 165 mi^2 (105,000 acres) of the upper hard-rock mountain area, which receives average annual precipitation of about 20 in. Only a small percentage of the annual water yield, however, reaches the Verde River as surface flow over the 9-mile reach of the alluvial channel below the mountain front. Flows must be more than 200 cubic ft per second to reach the river; flows of less than this rate disappear into the lower alluvial area and are stored temporarily in the groundwater reservoir; most of this water is released as groundwater discharge to the Verde River at a relatively constant rate of about 4,000 acre-ft per year. Evapotranspiration losses in the lower alluvial area are controlled by the depth of the water table and averaged about 1,500 acre-ft per year.

263. Thorud, D. B.

"The Effect of Applied Interception on Transpiration Rates of Potted Ponderosa Pine," *Water Resources Research*, Vol. 3, No. 2, Second Quarter, 1967, pp. 443–449.

Water was artificially applied to the foliage of small potted ponderosa pine trees to determine the effect of wetting on transpiration rates. By means of unwetted control trees and a prediction equation, the transpiration of wetted trees could be estimated had they not been wetted. The difference between the estimated and actual transpiration was a measure of the transpiration reduction due to treatment. For thirty-six 2-hour periods, the average transpiration reduction was 14 percent, or 9 percent of the applied water. Thus, about 91 percent of the applied water was a net loss to soil moisture supplies. The saving as a percent of the applied water varied from 4 to 14 and appeared to be weather related. Minimum values were generally observed on both cool, humid days and dry, hot, windy days. Higher savings were observed with more moderate weather.

264. Tomanek, G. W., Hulett, G. K., Goodman, C., and Eulert, G.

"A Survey of Phreatophytes in the Cedar Bluff Reservoir Area, Kansas, May 1966," Fort Hays Kansas State College, Division of Biological Sciences, Hays, Kansas, 1966, 39 pp.

The purpose of this study was to identify and study the phreatophyte communities that occurred at Cedar Bluff Reservoir in Kansas. The extent and nature of each community were studied along with their relation to water table depth, soil texture, soil pH, and soil salinity. An attempt was also made to estimate the water usage of woody phreatophytes.

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

"Ecological Studies of Salt Cedar," Fort Hays Kansas State College, Division of Biological Science, Hays, Kansas, 1962, 128 pp.

Though this paper primarily covers the ecology of the saltcedar (*Tamarix pentandra*), a section is devoted to transpiration studies conducted in greenhouse and field. The gravimetric method was used for the greenhouse studies, with the plants sealed in polyethylene plastic over glazed crocks. Tests were run for about 2 months; saltcedar, cottonwood, and willow were used. A comparison demonstrated an average total water loss for the period of 5,775 gm for saltcedar, 5,047 gm for willow, and 2,791 gm for cottonwood. The plants were similar in size, but saltcedar had a much greater leaf surface per plant. The average daily water loss from the study plants per dm^2 of leaf surface was 3.80 gm for saltcedar, 5.55 gm for cottonwood, and 8.23 gm for willow.

For field studies, an apparatus was used in which a stream of air was passed through a plastic chamber containing a plant or a portion of a plant. The airstream then passed out of the chamber through glass tubes which contained calcium chloride, a water-absorbing agent. A second identical apparatus was used without a plant to determine the portion of water vapor which came from the atmosphere. This method was compared with the gravimetric method used in the greenhouse test and found to yield comparable results.

Results from the field tests showed a large (5-ft tall) saltcedar transpired 27.6 gm per hour as compared with 20.4 gm for a 5-ft willow, 14.9 gm for a 3.5-ft cottonwood, and 16.1 gm for a small saltcedar. When related to the leaf surface, the dm^2 loss per hour was 0.050 gm for the large saltcedar and 0.129 for the small saltcedar as compared to 0.080 for the willow and 0.052 for the cottonwood. Thus, the small saltcedar had the greatest evapotranspiration rate per leaf area and the large saltcedar had the least.

266. Toy, T. J.

"Potential Evapotranspiration and Surface-mine Rehabilitation in the Powder River Basin, Wyoming and Montana," *Journal of Range Management*, Vol. 32, No. 4, July, 1979, pp. 312–317.

Energy resource development in the western United States must contend with the problem of water deficiency resulting from potential evapotranspiration rates which usually exceed precipitation rates. In this report the Blaney-Criddle method, with locally calibrated monthly natural vegetation coefficients, was used to estimate potential evapotranspiration (PET) for the Powder River Basin, Wyoming and Montana. In this area PET ranges from 15.02 in. per year to 26.76 in. A radiation-based method for microclimatic adjustment of PET is presented. According to this procedure it might be expected that, for slopes of 20 percent inclination at 44′ North latitude, annual PET is 17 percent less on northerly-facing slopes than a horizontal surface and 14 percent more on southerly-facing slopes.

267. Tromble, J. M.

"Use of Water by a Riparian Mesquite Community," *Proceedings of National Symposium on Watersheds in Transition*, Fort Collins, Colorado, June 19–22, 1972, American Water Resources Association, Urbana, Illinois, 1972, pp. 267–270.

In the semiarid regions of the Southwest where water resources may limit the development of industry and agriculture, an assessment of the water resources and future plans for water use is necessary. The objective of the study was to determine the amount of water lost by evapotranspiration from mesquite on an alluvial pocket aquifer which performed as a lysimeter. Water loss was determined by measuring fluctuations in the groundwater table and partitioning into two major categories; subsurface outflow, and evapotranspiration. The amount of water lost was 0.11 cm/day/unit area for March and increasing to 1.18 cm/day/unit area in June. Assuming 0.11 cm/day/unit area to be attributable to subsurface seepage, values for evapotranspiration were calculated at 0.01 cm/day/unit area for the first of April to 1.07 cm/day/unit area for the first half of June. A relationship between transpiration rates and air temperature was manifest as three nights of below freezing temperatures caused a lag in transpiration rates.

268. Tromble, J. M.

“Water Requirements for Mesquite (*Prosopis juliflora*),” *Journal of Hydrology*, Vol. 34, 1977, pp. 171–179.

Evapotranspiration (ET) determined by different investigators, compared with values determined by the White and Troxell methods, showed that their values provided 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 rates for June were calculated, and ratios were compared with values from other independent studies. Since ET rates, determined by White and Troxell methods, indicated plausible values of water use when compared to other independent studies, they could be considered index values useful as guidelines for water abstracted by mesquite.

269. Tromble, J. M. and Simanton, J. R.

“Net Radiation in a Riparian Mesquite Community,” *Water Resources Research*, Vol. 5, No. 5, 1969, p. 1139–1141.

Net radiation patterns for a riparian mesquite community are similar to net radiation patterns obtained for a humid forest. The net radiation peak of the open area was 61 percent of the net radiation peak above the canopy. The net radiation within a mesquite canopy peaked 9 percent higher but had a lower daily total value than the radiation above the canopy. The differences in net radiation peaks were attributed to differences in the canopy geometry, solar position, and surface reflectance, whereas differences in daily net radiation were attributed to differences in surface reflectance characteristics.

270. Tucci, P.

“Use of a Three-Dimensional Model for the Analysis of the Ground-Water Flow System in Parker Valley, Arizona and California,” *U.S. Geological Survey Open-File Report 82-1006*, Tucson, Arizona, December, 1982, 40 pp.

A three-dimensional, finite-difference model was used to simulate groundwater flow conditions in Parker Valley. The purpose of the study was to evaluate present knowledge and concepts of the groundwater system and the ability of the model to represent the system. Modeling assumptions and generalized physical parameters that were used may have transfer value in the construction and calibration of models of other basins along the lower Colorado River.

The aquifer was simulated in two layers to represent the three-dimensional system. Groundwater conditions were simulated for 1940–41, the mid-1960's, and 1980. Overall model results generally compared favorably with available field information. The model results showed that for 1940–41 the Colorado River was a losing stream throughout Parker Valley. Infiltration of surface water from the river was the major source of recharge. The dominant mechanism of discharge was evapotranspiration by groundwater system. Model results for conditions in the mid-1960's showed that the Colorado River had become a gaining stream in the northern part of the valley as a result of higher water levels. The rise in water levels was caused by infiltration of applied irrigation water. Diminished water-level gradients from the river in the rest of the valley reduced the amount of infiltration of surface water from the river. Model results for conditions in 1980 showed that groundwater level rises of several feet caused further reduction in the amount of surface-water infiltration from the river.

Model results indicated that previous estimates of riverbed hydraulic conductivity may be too low and estimates of inflow from tributary areas may be too high. Model results were most sensitive to changes in the simulated average evapotranspiration rate and less sensitive to changes in hydraulic conductivity, drain leakance, and river leakance.

271. Turner, P. M.

"Annual Report of Phreatophyte Activities–1968," *Bureau of Reclamation Report REC-OCE-70-27*, Chemical Engineering Branch, Denver, Colorado, July, 1970, 21 pp. (Similar reports for 1962 through 1967)

Bureau of Reclamation activities on phyreatophyte research and control are described. Regional research contracts have been negotiated with universities in Arizona and Nevada. At Denver, Colorado, saltcedar plants are greenhouse- and nursery-cultured and used as test specimens for foliar-applied herbicides. Herbicides are evaluated on saltcedar in plots along the Arkansas River near North Avondale, Colorado. Helicopter herbicide spraying was performed on 920 acres (372 ha) of saltcedar at Rye Patch Reservoir by the Bureau and the Pershing County Water Conservation District. Fourteen-thousand acres (5,667 ha) of phreatophytes have been removed from the Colorado Indian Reservation near Parker, Arizona, since 1965. Phreatophytes have been controlled by tree crusher, root plow, cutter dozer, and spraying on 38,600 acres (15,645 ha) along the Pecos River in New Mexico.

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

"Ground-water Inventory in the Upper Gila River Valley, New Mexico and Arizona: Scope of Investigation and Methods Used," *American Geophysical Union Transactions*, Vol. 22, No. 3, 1941, pp. 738–744.

An inventory of water resources of the upper Gila River is covered in this report. The inventory covered inflow-outflow measurements from several gauging stations, estimation of transpiration from cultivated crops and phreatophytes, and evaporation from water surfaces and moist soil. Of particular interest are the tank studies using tamarisk, baccharis (seepwillow), and bare soil.

The tanks were surrounded by bare soil, but the plants were very thin for most of the summer. By October, both tamarisk and baccharis measured only 3 to 4 ft in height; thus, results are not indicative of true water losses. For the period May 10 (date of installation) to December 31, 1940, tamarisk with a 4-ft water level used 47.9 in. of water and with a 2-ft water level used 61.1 in. Baccharis used 31.6 and 52.0 in. respectively, when grown under the same conditions. Bare soil with a 2-ft water level evaporated 39.7 in. of water.

273. Turner, S. F., and Skibitzke, H. E.

"Use of Water by Phreatophytes in 2,000-ft channel between Granite Reef and Gillespie Dams, Maricopa County, Arizona," *American Geophysical Union Transactions*, Vol. 33, No. 1, 1952, pp. 66–72.

This paper summarizes data obtained in a study of transpiration by phreatophytes in the channels of the Salt and Gila Rivers, between Granite Reef and Gillespie dams, Maricopa County, Arizona. The study was made in the spring of 1950 by the U.S. Geological Survey in cooperation with the Corps of Engineers, United States Army. The kind and amount of phreatophytic growth was mapped in the area covered by a proposed flood-control channel, 2,000 ft wide, extending between the two dams. Most of the mapping was done from the air; recent aerial photographs were used. Transpiration by the phreatophytes was computed through use of the results of the mapping combined with water-use factors developed y experimental work done by the Geological Survey in Safford Valley, Arizona, during 1943 and 1944.

Estimates of future phreatophyte use of water and of the amount of water that might be saved by clearing and maintaining the channel area were based on extensions of water-level graphs to include the next 50 years and on the experimental work at Safford. The calculations were as follows: (1) Total estimated transpiration from groundwater at the time of the investigation, 29,000 acre-ft per year; (2) estimated average transpiration from groundwater, within the channel area, during the period 1950–99 (a) without Colorado River water, 22,200 acre-ft per year and (b) with Colorado River water in 1960, 29,900 acre-ft per year; (3) estimated average water saving effected by channel clearing, 1950–99 (a) without Colorado River water, 16,600 acre-ft per year and (b) with Colorado River water in 1960, 22,400 acre-ft per year.

274. U.S. Senate, Select Committee on National Resources.

"Water Resources Activities in the United States, Evapotranspiration Reduction," *Committee Print No. 21*, 86th Congress, 2nd Session, 1960, 55 pp.

The Senate Select Committee on National Water Resources was directed to consider new methods and processes for increasing the availability of water resources including the reduction of evapotranspiration. As a result, the Department of Interior reported on the background and future actions that might be taken to increase water yield by management of phreatophytes and hydrophytes, while the Department of Agriculture prepared a report on vegetation management as a means of increasing water yield in the western United States.

The report of the Department of the interior on phreatophytic and hydrophytic plants along western streams indicates that nonbeneficial phreatophytes in the 17 Western States cover nearly 16 million acres and that they may discharge from 20 million to 25 million acre-ft of water into the atmosphere annually. The report discusses methods which care being used to control phreatophytes and the need for future research in the field of water use by phreatophytes, and the hope is expressed that as much as one-quarter of the total estimated savings can be accomplished by 1980 and one-half by the year 2000.

The Agriculture Department's report indicates that opportunities for improved water yields through management of vegetation appear favorable on about 15 percent of the area of the 17 Western States with a possibility for increasing water yields in amounts ranging from about 1 to 6 in. in certain forest areas of heavy winter precipitation to as low as one-fourth inch in the pinon-juniper areas of very low precipitation. No increase at all is possible on semiarid lands covered with grass and shrub which make up the great bulk of the area of the West. Possibilities of reduction of losses from phreatophytes, water-loving plants which cause a major loss of water along rivers in the Western States are also discussed with an indication that a saving of up to 25 percent of water now lost through these plants appears possible. This saving would amount to about 6 million acre-ft per year. The report is qualified by the statement that there are insufficient economic data and analysis techniques available at this time upon which to base decisions to use lands for water yield alone as against other uses. The report concludes with suggestions as to research in the field of vegetal management which might furnish information which would increase our knowledge in this field. (Compiler's Summary)

275. van Hylckama, T. E. A.

"Effect of Soil Salinity on the Loss of Water from Vegetated and Fallow Soil," in *Symposium on Water in the Unsaturated Zone*, Wageningen, The Netherlands, June 19–25, 1966, International Association of Scientific Hydrology Publications [Gentbrugge], Vol. 83, 1968, pp. 635–643.

In the semiarid zone of the southwestern United States, some six million hectares near washes and along rivers are covered by a dense growth of riparian or phreatophytic vegetation, consisting very often of pure stands of saltcedar (*Tamarix pentandra*). This vegetation, having a nearly unlimited access to water, transpires large quantities of water, estimated to total over 29×10^9 cubic meters per year.

In order to measure the actual rate of evapotranspiration, six large evapotranspirometers (surface area about 80 m^2) were installed near Buckeye, Arizona, in 1959 and another five in 1962. In 1963 the salinity of the groundwater in the older tanks (evapotranspirometers) had risen from an original 4 to over 200 parts per thousand. Although saltcedar is reported to tolerate and thrive on soil moisture of high salinity, the tanks were flushed out until the salinity of the effluent was back to the original concentration. Whereas in 1963 the water use varied between 80 and 200 m^3 per tank per year (depending on depth to water in the tanks), after flushing the use increased by more than 50 percent.

It is frequently assumed, when water use by phreatophytes is estimated, that plants have access to water of low salinity. The data presented in this paper show that this assumption may not always be right and that the actual water losses may be less than estimated by as much as 40 percent.

276. van Hylckama, T. E. A.

"Estimating Evapotranspiration by Homoclimates," *Geographical Review; The American Geographical Society*, January, 1975, pp. 37–48.

In principle, homoclimates can be a reliable means of estimating evapotranspiration rates with the model presented. Difficulties arise from the fact that few homoclimatic maps exist–and those do not always use the best method of classifying climates. The need for more homoclimatic maps is obviously great. These maps should show the locations of stations for which complete sets of microclimatological data can be obtained for estimating the potential evapotranspiration with a desirable degree of accuracy. If climatic classification is detailed enough and if one has sufficient quantitative and qualitative information in one part of such an area, it is reasonable to assume that in other parts of this homoclimate the same data are applicable.

277. van Hylckama, T. E. A.

"Growth, Development and Water Use by Saltcedar (*Tamarix Pentandra*) Under Different Conditions of Weather and Access to Water," in General Assembly of Berkeley, August 19–31, 1963, International Union of Geodesy and Geophysics, International Association of Scientific Hydrology Publications [Gentbrugge], Vol. 62, 1963, pp. 75–86.

Near Buckeye, Arizona, six evapotranspirometers were installed in 1959 and planted to saltcedar in a cooperative endeavor by the U.S. Bureau of Reclamation and the U.S. Geological Survey to determine the use of water by this phreatophyte.

During the spring and summer of 1961 and 1962, growth (increase in length of branches) and development (increase in number of side shoots on these branches) were observed and recorded. The data so obtained could be correlated with the measured use of water and with accessibility to water.

Results of the studies follow. Saltcedar does not grow or develop in this area when the depth to water is 18 ft or more. Saltcedar tanks use more water with higher water tables, but there are no significant differences in growth or development if the depth to water is 9 ft or less. Saltcedar grows and develops fast in the early spring, with rapid increase in use of water; by mid-summer both growth and development level off sharply, with a drastic reduction in water use, even though accessibility of water remains the same.

278. van Hylckama, T. E. A.

"Water Level Fluctuation in Evapotranspirometers," *Water Resources Research*, Vol. 4, No. 4, 1968, pp. 761–768.

Eleven plastic-lined evapotranspirometer tanks were constructed near Buckeye, Arizona. The levels of the artificially maintained groundwater in these instruments shows distinct diurnal fluctuations. On bare tanks or on vegetated tanks that are not transpiring, this fluctuation is highly correlated with diurnal and semidiurnal atmospheric fluctuations. Two possible reasons for such response are discussed: There might be air bubbles in the saturated zone, or it might be caused by the flexible plastic lining of the tank. The barometric efficiency is about 40 percent. On vegetated tanks that are transpiring, the water level and barometric curves are out of phase, but if the water levels are corrected for atmospheric pressure fluctuations, a curve appears that represents the hourly rate of water use. The results may be important in the interpretation of transpiration-well data.

279. van Hylckama, T. E. A.

"Water Use by Saltcedar," *Water Resources Research*, Vol. 6, No. 3, 1970, pp. 728–735.

Six years of observations on water used by saltcedar conducted in a battery of evapotranspirometers, or tanks, have shown that thinned-out stands use nearly as much water as control tanks if the 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 to a 100 percent density can lead to serious overestimation of water use. Thinning and cutting are ineffective methods of saving water. In cutoff stands, under favorable conditions, shoots can increase in length by as much as 5 cm per day. Only a few plants, such as bamboo and cucumber, are reported to grow faster than that.

The assumption that phreatophytes always transpire at a potential rate is not sustained by the facts presented in this paper. When differences in depth to water as small as 1.5 to 2.1 m 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 (a situation not unusual along dry river beds), saltcedars still may thrive but use comparatively little water, and the claims as to the quantity of water potentially saved by their eradication could well be overestimated.

280. van Hylckama, T. E. A.

"Water Use by Saltcedar as Measured by the Water Budget Method," *U.S. Geological Survey Professional Paper 491-E*, 1974, 30 pp.

Studies of water use by saltcedar (*Tamarix pentandra*) were carried out during a 7-year period (1960–1967) near Buckeye, Arizona, using six plastic-lined evapotranspirometers.

With a depth to groundwater of 5 ft, the average water use was about 85 in. per year; with a water table at 7 ft the use diminished to about 60 in. per year; and with a water table at 9 ft the yearly water use was less than 40 in. per year. Water use also decreased significantly as the salinity of the soil moisture increased.

When the vegetation was cut twice a year to a height of 18 in., the water use decreased to about half that in tanks where the vegetation was not cut. Where the vegetation was thinned to 50 percent of the original, the water use diminished by only 10 percent.

The daily fluctuations of the water use from bare soil show that in the summer the evaporation at mid-day diminishes because of the formation of the vapor barrier, in contrast to water losses from the soil underneath a dense vegetation, where evaporation continues. (From Author's Abstract)

281. van Hylckama, T. E. A.

"Water Use by Saltcedar Varies with Many Factors," U.S. Geological Survey, Texas Technological College, Lubbock, Texas, 1969, 20 pp.

During six years of observations on water use by saltcedar, conducted in a battery of evapotranspirometers (hereafter called tanks), the following relationships were established.

1. The quantity of water used by evaporation or transpiration depends on the depth of groundwater in the tanks.

2. The quantity of water evaporated or transpired depends on the salinity of the soil moisture. When the electrical conductivity of the saturation extract (ED_e) reaches 30 mmho (millimhos), the water use is only half of that measured in tanks with an EC_e = 10 mmho.

282. van Hylckama, T. E. A.

"Weather and Evapotranspiration Studies in a Saltcedar Thicket, Arizona," *U.S. Geological Survey Professional Paper 491-F*, 1980, 78 pp.

Water use by saltcedar, *Tamarix chinensis*, was studied from 1961 through 1967 near Buckeye, Arizona. The test site was located on the rim of the Gila River flood plain and was bordered on the north, east, and west sides by fetches of dense saltcedar thickets one or more kilometers wide. On the south side, however, the fetch was less than 100 m.

The climate of the area, typical of the Sonoran Desert, is characterized by low humidities, strong winds, and temperature extremes of $< -10°$ C in the winter and $>$ 50° C in summer. Potential evaporation values are among the highest observed in the United States.

Rates and quantities of evapotranspiration were observed in six plastic-lined evapotranspirometers (tanks) whose 81 m^2 surfaces were planted to saltcedar having heights and density equal to those of the surroundings.

The test site was further equipped with instrumentation to measure the following data: solar short-wave radiation; long- and short-wave net radiation; albedo; humidity, temperature, and wind profiles in and over the vegetation; soil-temperature gradients and soil-heat flux; moisture content of the soil; and carbon dioxide content of the air. Detailed studies were made of the microclimate in and over a typical saltcedar thicket. Analyses showed that, above the vegetation, the wind profiles in more than 80 percent of the observations were logarithmic. Within the thickets considerable turbulence and irregular wind inversions (tunneling) occurred during daylight hours.

It was concluded that transport constants for momentum, heat, and vapor are the same more than 80 percent of the time because plots of windspeeds versus vapor pressure at those heights fall on straight lines. Fluxes of carbon dioxide and vapor are closely related. Vapor fluxes diminish, as do rates of photosynthesis, during hot afternoons when temperatures exceed 40° C, suggesting a variable stomatal resistance factor.

Estimates of potential evapotranspiration rates using various models were plotted against measured values. For rough estimates of total yearly quantities of evapotranspiration, three independent methods gave values closest to those measured by evapotranspirometers with the shallowest (1.5 m) depth to water and with low salinity of soil moisture.

For short-term estimates (of the order of 1 hour), the 1966 combination method of C. H. M. 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, thus diminishing evapotranspiration even though water is freely available (as it is in evapotranspirometers with favorable water and soil conditions). 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.

283. van Hylckama, T. E. A.

"Winds Over Saltcedar," *Agricultural Meteorology*, Elsevier Publishing Company, Amsterdam, The Netherlands, Vol. 7, 1970, pp. 217–233.

An analysis of hourly wind speeds above and within a stand of saltcedar near Buckeye, Arizona, reveals that in 90 percent of all observed cases, the wind profiles above the stand can be represented by the simple logarithmic equation:

$$u_z = u^*/k \ln (z/z_o)$$

where u_z is the velocity at height z. The roughness length (z_o), (disregarding zero displacement), varies with a stability ratio similar to Richardson's number. The friction velocity, u*, depends on the wind speeds above the vegetation. Von Karman's constant, k, equals 0.41.

Within the thickets there is considerable turbulence, and irregular wind inversions occur during daylight hours.

The results are important for estimating water losses by evapotranspiration by either the energy-budget or the mass-transfer formulae.

284. VanKlaveren, R. W., Pochop, L. O., and Hedstrom, W. E.

"Evapotranspiration by Phreatophytes in the North Platte Basin of Wyoming," University of Wyoming, Water Resources Research Institute, *Water Resources Series No. 56*, June, 1975.

A survey of phreatophyte vegetation and its water usage was conducted for the North Platte Basin of Wyoming. The study was limited to the phreatophyte vegetation along the North Platte River and its three main tributaries: the Laramie, Medicine Bow, and Sweetwater Rivers.

An estimated 90 to 95 percent of the phreatophytes were either cottonwoods or willows. Long-term annual average evapotranspiration rates of .94, .81, and .67 m for high, medium, and low-density vegetation, respectively, were estimated using the Blaney-Criddle method. The total estimated long-term annual evapotranspiration was 8,121 hectare-meters for the four major rivers in the North Platte Basin of Wyoming.

285. Veihmeyer, F. J.

"Use of Water by Native Vegetation Versus Grasses and Forbs on Watersheds," *American Geophysical Union Transactions*, Vol. 34, No. 2, 1953, pp. 201–212.

Soil moisture records for several years were obtained for plots on potential rangelands in California on which native vegetation (mostly wood brush species) was left intact and from adjacent plots which were denuded by burning. Samplings, by which the amounts of soil moisture could be measured quantitatively, were taken with soil tubes, generally under extremely difficult conditions, frequently enough to give a satisfactory picture of the water regimen of the area.

More than 23 paired plots were used in the experiments. They were selected to give a wide variety of vegetation types, rainfall patterns, topography, and soils. At all of the sites the rain generally fell from October through March; most of it fell in December, January, and February. The growth of the plants, therefore, was dependent to a large extent upon the amount of water that could be stored in the soil mantle. Following the fire, grasses and forbs usually succeeded the brush, but with some species, several annual burnings were necessary before the brush was eliminated. The removal of the brush resulted in a saving of moisture.

The moisture content of the soil was higher in the burned plots than in the unburned plots at the end of the growing season; consequently, less water was required to restore the soil in the burned plots to it field capacity. In most cases, the results led to the conclusion that appreciable savings of water could be effected by burning woody brush to substitute grasses or forbs which have forage value. The soil-moisture records show that the soil in the burned areas was wet to its field capacity as early as, and in may cases earlier than, in the unburned ones, thus indicating that the permeability of the soil for water was not adversely affected by burning.

286. Wallace, R. W.

"Waste Isolation Safety Assessment Program: A Comparison of Evapotranspiration Estimates using DOE Hanford Climatological Data," *Report No. PNL-2698*, Battelle Memorial Institute, Pacific Northwest Laboratory, Richland, Washington, October, 1978, 20 pp.

Three methods of estimating monthly values of evapotranspiration on a year-round basis were compared by using the same set of long-term Hanford climatological data as input. Potential evapotranspiration calculated by all three methods yielded an annual value 5 to 9 times the mean annual precipitation. One method yields a value for actual evapotranspiration and one yields a value for areal evapotranspiration. These are compared on a monthly basis and show quite different distributions over the year. The third method examined is relatively new, was calibrated using data from arid stations and yields results that may be truly representative of arid areas like Hanford.

287. Walters, M. A., Teskey, R. O., and Hinckley, T. M.

"Impact of Water Level Changes on Woody Riparian and Wetland Communities," Vol. VII, Mediterranean Region, Western Arid and Semiarid Region, performed for U.S. Department of Interior, Fish and Wildlife Service, Office of Biological Services, FWS/OBS-78/93, 1980, 84 pp.

This volume covers the important woody plant species in the Mediterranean, Western Arid and Semiarid Regions. These regions cover Arizona, New Mexico, California, Utah, Nevada, southern Idaho, eastern Washington and Oregon. This discussion centers primarily on the lower elevations of these states, while the mountainous areas of the western states will be discussed in a subsequent volume.

This review attempts to synthesize existing information on the effect of water level changes on woody plants found in riparian and wetland communities. In addition, the effect of drought on woody plants of these regions is described. Riparian vegetation is normally exposed to high groundwater levels as well as to periods of excess water due to flooding. The effect of excess water often causes stress to the plant resulting in decreased growth or even death. A plant's response to flooded conditions depends on many factors, including the species tolerance, water level, duration of flooding and time of year. Available information for individual species of the region has been listed in a tabular format.

In this arid region of the United States, the majority of precipitation falls in the dormant season, thus flooding effects are not as prominent as in other sections of the

United States. Drought and the plant's resistance to drought are also important factors to consider. Therefore, a table of species responses to drought for these regions has been included.

288. Weaver, H. L., Weeks, E. P., Campbell, G. S., Stannard, D. I., and Tanner, B. D.

"Phreatophyte Water Use Estimated by Eddy-Correlation Methods," *Proceedings of Water Forum '86,* American Society of Civil Engineers Specialty Conference, Long Beach, California, Aug. 4–6, 1986, pp. 847–854.

Water-use was estimated for three phreatophyte communities: a saltcedar community and an alkali-Sacaton grass community in New Mexico, and a greasewood rabbit-brush-saltgrass community in Colorado. These water-use estimates were calculated from eddy-correlation measurements using three different analyses, since the direct eddy-correlation measurements did not satisfy a surface energy balance. The analysis that seems to be most accurate indicated the saltcedar community used from 58 to 87 cm (23 to 34 in.) of water each year. The other two communities used about two-thirds this quantity.

289. Weeks, E. P., and Sprey, M. L.

"Use of Finite-difference Arrays of Observation Wells to Estimate Evapotranspiration from Groundwater in the Arkansas River Valley, Colorado," *U.S. Geological Survey Water-Supply Paper 2029-C*, 1973, 27 pp.

A method to determine evapotranspiration from groundwater was tested at four sites in the flood plain of the Arkansas River in Colorado. Approximate groundwater budgets were obtained by analyzing water level data from observation wells installed in five-point arrays. The analyses were based on finite-difference approximations of the differential equation describing groundwater flow.

Data from the sites were divided into two groups by season. It was assumed that water levels during the dormant season were unaffected by evapotranspiration of groundwater or by recharge, collectively termed "accretion." Regression analysis of these data were made to provide an equation for separating the effects of changes in aquifer heterogeneity from those due to accretion during the growing season. The data collected during the growing season were thus analyzed to determine accretion.

290. Weeks, E. P., Weaver, H. A., Campbell, G. S., and Tanner, B. D.

"Water Use by Saltcedar and by Replacement Vegetation in the Pecos River Floodplain Between Acme and Artesia, New Mexico," *U.S. Geological Survey Professional Paper 491-6*, 1987, 33 pp.

Water use estimates for saltcedar and for replacement plant communities following root plowing in the Pecos River floodplain between Acme and Artesia, New Mexico were made by the eddy-correlation technique and a combined eddy-correlation energy-budget technique during 1980–82. Twenty-seven measurements of daily water use were obtained for various periods during the growing season, including 17 obtained from four saltcedar thickets and 10 from three stands of replacement vegetation. Large uncertainties exist in these estimates because of problems in extrapolating the data seasonally and areally, and because of discrepancies between the two methods. Nonetheless, the measurements indicate that annual water use by saltcedar probably is about 0.3 m greater than that by the replacement vegetation. Such reductions in water use should have resulted in increased baseflow of the Pecos River of $1.2 - 2.5 \times 10^7$ m^3/year (10,000 to 20,000 acre-ft per year). The fact that such gains have not been identified from the stream gage records may arise from masking of short-term gains by variations in climate and in groundwater pumpage and by a continuing decline in the groundwater contribution to baseflow from the shallow aquifer.

291. Went, C. W., Haas, R. H., and Runkles, J. R.

"Influence of Selected Environmental Variables on the Transpiration Rate of Mesquite, (*Prosopis glandulosa* var. *glandulosa* (Torr.) Cockr.)," *Agronomy Journal*, Vol. 60, No. 4, 1968, pp. 382–384.

The influence of soil moisture, soil temperature, and vapor pressure deficit on the transpiration rate of mesquite was studied in controlled environment chambers.

Four soil moisture levels were maintained by adding water when the soil moisture contents were 12.9, 15.4, 19.0, and 25.2 percent to increase moisture content to 39.3 percent. The suction at these moisture contents was 15.0, 6.3, 1.5, 0.5, and 0.1 bar, respectively. There was no significant difference in the transpiration rate between the different soil moisture levels.

The plants were grown at soil temperatures of 13, 21, 29, and 38° C. The transpiration rate was highest at 29° C.

As the mean vapor pressure deficit of the atmosphere was increased from 3.5 to 20.9 mm Hg., it had a diminishing effect on the transpiration rate, indicating the mesquite does not increase its transpiration rate proportionally with increasing vapor pressure deficit.

292. White, L. M., and Brown, J. H.

"Nitrogen Fertilization and Clipping Effects on Green Needlegrass (*Stipa viridula* trin.): II. Evapotranspiration, Water-Use Efficiency, and Nitrogen Recovery," *Agronomy Journal*, Vol. 64, July–August, 1972, pp. 487–490.

Soil water and N are the major factors limiting forage production of green needlegrass (*Stipa viridula* Trin.) on the northern Great Plains. We studied the effects of N fertilization rate and clipping frequency on evapotranspiration (ET), water extraction pattern in soil profiles, water-use efficiency, and fertilizer N recovery by dryland green needlegrass. Nitrogen was broadcast at 0, 70, and 140 kg of N/ha in November 1968. Green needlegrass was either left unclipped or clipped to a 5-cm height five times during 1969 at approximately 21-day intervals.

Green needlegrass showed visual signs of water stress when water was deficient in the surface 30 cm of soil. On unclipped plots, 80 percent of the ET was from the 0- to 30-cm depth. Water-use efficiency of unclipped green needlegrass increased during May and June and decreased during July, but that of clipped plants decreased from May through July. Nitrogen fertilization increased and clipping decreased water-use efficiency.

Average N recoveries with 70 and 140-kg rates were 22 percent for the first year and 8 percent for the second year. Recovery was highest with 70 kg of N/ha and frequent clipping. Low recovery of N fertilizer was not due to loss of nitrate-N by leaching. At the end of the first crop season, 7 percent of the 70 kg N/ha applied and 17 percent of the 140 kg of N/ha applied the previous year remained in the soil as nitrate-N.

293. White, W. N.

"A Method of Estimating Ground-water Supplies Based on Discharge by Plants and Evaporation from Soil," *U.S. Geological Survey Water-Supply Paper 659-A*, 1932, 105 pp.

The amount of available groundwater supplies can be estimated by measurement of daily fluctuations of the water table. This approach was used in a study in Escalante Valley, southwestern Utah. The procedure was to install observation wells equipped with water-stage registers at representative locations in the area under consideration to obtain graphic records of the groundwater fluctuations. The diurnal cycle, as indicated by the groundwater table, represents a curve showing the relation of consumptive use to groundwater discharge or recharge.

The records obtained from 75 observation wells showed that during the growing season there was a marked daily fluctuation of the water table nearly everywhere. The maximum daily drawdown amounted to about 1½ in. in greasewood and shadscale, 2½ in. in alfalfa, 3¾ in. in saltgrass, and 4½ in. in sedges and associated marsh grasses. These fluctuations did not occur in plowed fields, cleared land, tracts of sagebrush, and tracts where the water table is far below the surface.

To determine specific yield of the soils, cylinders were driven near observation wells so as to enclose columns of undisturbed soil in the zone in which the fluctuations take place, and the rise and fall of the water table in the enclosed columns after the addition or subtraction of measured amounts of water were carefully noted. The amount of groundwater discharged daily by the plants was then computed by the formula q = y (24r + s), in which q is the depth of groundwater withdrawn in inches, y is the specific yield of the soil in which the daily fluctuation of the water table takes place, r is the hourly rate of rise of the water table in inches from midnight to 4 a.m. (when it was determined that transpiration and evaporation were practically nil), and s is the net fall or rise of the water during the 24-hour period in inches. In field experiments the quantities on the right-hand side of the formula, except the specific yield, can be readily determined from the automatic records of water-table fluctuations.

294. Wight, J. R.

"Comparison of Lysimeter and Neutron Scatter Techniques for Measuring Evapotranspiration from Semiarid Rangelands," *Journal of Range Management*, Vol. 24, No. 5, 1971, pp. 390–393.

Evapotranspiration (ET) calculated from changes in soil water content measured by the neutron scatter method was compared to ET measured by lysimetry. During 1968, a near-average precipitation year (33 cm), the neutron method was effective for determining ET over periods of 4 weeks or longer. Cumulative ET curves as determined by lysimetry and the neutron method were in excellent agreement. In 1969, a year with high precipitation in June and July, reliability of the neutron method was severely limited by deep percolation and possibly by surface runoff. Failure of the neutron method to measure accurately water content near the soil surface following periods of precipitation was the major source of error when percolation and runoff were not factors. Sensitivity of the neutron method during a 30-day drying cycle was equal to that of a hydraulic lysimeter. Upward soil water fluxes were evident and are potential sources of error.

295. Wight, J. R. (ed.)

"SPUR–Simulation of Production and Utilization of Rangelands: A Rangeland Model for Management and Research," *Miscellaneous Publication 1431*, U.S. Department of Agriculture, Agricultural Research Service, 1983, 120 pp.

This publication describes a rangeland simulation model which was developed to provide information relative to management and research. It provides a narrative description of the model's five basic components: 1) climate; 2) hydrology; 3) plant; 4) animal; and 5) economic; and their interfaces. An option for evaluating the impact of grasshoppers and their control is included   Input data requirements and model outputs are described. Application of the model to problems of resource management and research planning and administration is discussed. Model documentation and user guides are not included but will appear in subsequent publications.

296. Wight, J. R., and Black, A. L.

"Energy Fixation and Precipitation Use Efficiency in a Fertilized Rangeland Ecosystem of the Northern Great Plains," *Journal of Range Management*, Vol. 25, No. 5, September, 1972, pp. 376–380.

Results of a 2-year study conducted on the mixed prairie near Sidney, Montana, indicated that high rates of nitrogen (N) fertilization accompanied by phosphorus (P) were necessary to obtain maximum levels of energy fixation. Total energy fixed over a 2-year period (1969–70) by the aboveground portion of native vegetation was 1136 kcal/m^2 or 2384 lb/acre yield equivalent. Single applications of 100, 300, and 900 lb/acre of N increased the level of energy fixation 1.6-, 2.2-, and 2.0-fold, respectively, when applied without P; 1.7-, 3.2-, and 2.8-fold, respectively, when applied with 100 lb P/acre; and 2.0-, 3.0-, and 3.3-fold, respectively, when applied with 200 lb P/acre. The high N-P treatment decreased the grass plus sedge portion of total yield from 77 to 70 percent in 1969, but increased it from 61 to 98 percent in 1970. Increased growth of individual plants and changes in species composition accounted for the high levels of energy fixation by the fertilized vegetation. Precipitation-use efficiency for the 1970 growing season was 110 lb/acre/inch on the unfertilized plots and 336 lb/acre/inch on the high N-P treatment plots.

297. Wight, J. R., and Black, A. L.

"Nitrogen and Phosphorus Uptake and Soil Water Use in a Mixed Prairie Plant Community," in Marshall, J. K. (ed.), *The Belowground Ecosystem: A Synthesis of Plant-Associated Processes*, Range Science Department Science Series No. 26, Colorado State University, Fort Collins, 1977, pp. 177–183.

Nitrogen (N) and phosphorus (P) concentrations were measured over a 6-year period (1967 to 1972) in the aboveground standing crop harvested in mid-July (approximate peak standing crop). Annual yield (kg/ha) of N ranged from 7.1 to 16.6, with a mean of 13.0; annual yield (kg/ha) of P ranged from 1.00 to 2.06, with a mean of 1.61. Soil water use (cm) for the growing season (April to mid-July) ranged from 17.6 to 25.3, with an average of 21.8. Soil water availability measured as cm-days varied from 209 to 385, with a mean of 303. Aboveground production and N and P yield were more closely related to soil water availability in the upper 30 cm of profile with r-values of 0.92, 0.83, and 0.95, respectively, than to total water use with r-values of 0.79, 0.71, and 0.78, respectively. N concentration in the aboveground standing crop decreased linearly as plants matured; P concentration also decreased with plant maturity, but fluctuated in direct proportion to soil water availability.

Root samples in 1973 indicated that most of the root material (20,700 kg/ha) was in the top 30 cm of soil profile, with over 16,000 kg/ha in the top 9 cm of soil profile. Root material in the top 30 cm of profile contained 211 kg N/ha and 15.6 kg P/ha. If 25 percent of the root material is recycled annually, then minimum N and P requirements for this mixed prairie community (above and below ground) would be 66 and 5.5 kg/ha, respectively.

298. Wight, J. R., and Black, A. L.

"Range Fertilization: Plant Response and Water Use," *Journal of Range Management*, Vol. 32, No. 4, 1979, pp. 345–349.

During the 10-year study, herbage production on an unfertilized, mixed prairie range site in eastern Montana averaged 1,047 kh/ha and ranged from 720 to 1,321 kg/ha. Elimination of nitrogen (N) and phosphorus (P) deficiencies by fertilizing increased herbage yields an average of 114 percent (ranging from a low of 32 percent in a "dry" year to a high of 218 percent in a "wet" year). Nitrogen was the major growth-limiting plant nutrient with measurable responses to P occurring only when N was nonlimiting. Single high-rate applications were about equal to annual N applications when compared on an annual rate equivalent basis. Species composition varied as much among years as among fertilizer treatments. At N rates of 336 kg/ha or less, cool-season grasses increased in about the same proportion as did forbs and shrubs, maintaining a relatively constant composition of the major species groups. On unfertilized plots, herbage yields and water use reached maximum values of about 1,250 kg/ha and 265 mm, respectively, regardless of further increases in available water. Unfertilized plots produced an average of 2.60 kg/ha for each 1 mm of precipitation received as compared with 5.81 kg/ha on fertilized plots.

299. Wight, J. R., and Black, A. L.

"Soil Water Use and Recharge in a Fertilized Mixed Prairie Plant Community," *Journal of Range Management*, Vol. 31, No. 4, July, 1978, pp. 280–282.

Nitrogen fertilization on a mixed prairie, upland range site increased soil water extraction, overwinter recharge, and water- and precipitation-use efficiency. Overwinter recharge was inversely related to soil water content in the fall.

300. Wight, J. R., and Hanks, R. J.

"A Water-balance, Climate Model for Range Herbage Production," *Journal of Range Management*, Vol. 34, No. 4, July, 1981, pp. 307–311.

A crop production model was modified and evaluated for application to native grassland ecosystems. The model effectively predicted annual herbage production for range sites near Sidney, Montana, and Mandan, North Dakota, where model-predicted yields were within 10 percent of field-measured yields for 12 of the 15 test years. Soil water content, as calculated by the model, was also closely correlated ($r^2 = 0.91$) with field-measured soil water. Model inputs include beginning soil-water content, daily precipitation, and an estimate of potential evapotranspiration. Soil-water content, evaporation, and transpiration are calculated daily. Yields are determined as a function of the actual-to-potential transpiration ratio. Availability of input data, relative simplicity, and low computer costs make this model a viable tool for both research and resource management.

301. Wight, J. R., Hanson, C. L., and Cooley, K. R.

"Modeling Evapotranspiration from Sagebrush-grass Rangeland," *Journal of Range Management*, Vol. 39, No. 1, 1986, pp. 81–85.

Three models, CREAMS, SPAW, and ERHYM, were used to predict evapotranspiration (ET) from a sagebrush-grass range site in southwest Idaho. Model-predicted ET was compared with ET measured by a lysimeter and ET calculated from a water-balance equation using field-measured soil water and precipitation values. There was generally good agreement between the lysimeter and water-balance calculated ET and between these ET values and the model-predicted ET. Maximum averaged daily ET rates were about 2.5 mm for April, May, and June with single day ET values from the lysimeter as high as 5.0 mm. Although the CREAMS predicted ET rates were generally higher than those predicted by SPAW and ERHYM or measured by the water-balance method, all three models were functionally capable of simulating ET from sagebrush-grass range sites. ERHYM was the simplest of the three models to operate.

302. Wight, J. R., and Neff, E. L.

"Soil-Vegetation-Hydrology Studies, Volume II. A User Manual for ERHYM: The *E*kalaka *R*angeland *H*ydrology and *Y*ield *M*odel," *ARR-W-29*, U.S. Department of Agriculture, Agricultural Research Service, Agricultural Research Results, January, 1983.

ERHYM was developed to simulate runoff and herbage production for northern Great Plains rangelands. It is a range site scale model that provides daily simulation of runoff, soil water evaporation, transpiration, and soil water routing. Herbage yield is computed annually at peak standing crop. The model can utilize real-time climatic data to simulate ongoing processes, or it can utilize historical climatic data to simulate runoff and herbage production under a range of climatic conditions and management practices. It can run either on a seasonal basis, with new soil water boundary conditions required at the beginning of each year's growing season, or continuously, utilizing a simple snowmelt-temperature relationship to account for snowmelt infiltration and runoff. The model calculates infiltration and runoff from daily rainfall, and also calculates evapotranspiration (ET), soil water routing, and herbage yield.

303. Williams, M. E., and Anderson, J. E.

"Diurnal Trends in Water Status, Transpiration, and Photosynthesis of Saltcedar," in Hydrology and Water Resources in Arizona and the Southwest, Vol. 7, pp. 119–124, *Proceedings* of the 1977 meetings of the Arizona Section of the American Water Resources Association and the Hydrology Section of the Arizona Academy of Science, Las Vegas, Nevada, April 15–16, 1977.

Relative water content (RWC), water potential (ψ), and gas exchange were measured on saltcedar at the Bernardo, New Mexico, lysimeter site. RWC and ψ were closely correlated; but, water potential measurements, taken with a pressure bomb, were more convenient and reliable. RWC and decreased sharply from sunup until about 0900, when minimum values of about –26 bars ψ or 80 percent RWC were reached. Water status then remained constant or improved slightly through late afternoon. Transpiration rates typically remained high until about noon and then began a steady, gradual decrease that continued throughout the afternoon. The data suggest that water stress may be a factor in initiating stomatal closure; however, transpiration continued to decline despite a constant or improved leaf water status. Maximum net photosynthetic rates occurred by 0900, and depressions throughout the remainder of the day were largely accounted for by increased leaf temperatures. Afternoon depressions in transpiration and photosynthesis occurred in twigs held at constant temperature and relative humidity, suggesting that a diurnal rhythm may be involved in control of gas exchange. Water status of plants growing on the lysimeters was comparable to that of plants in adjacent natural stands; gas exchange rates were slightly higher for the lysimeter-grown plants.

304. Williams, R. G.

"Watershed Evapotranspiration Prediction Using the Blaney-Criddle Approach," *Transactions of the American Society of Agricultural Engineers*, Vol. 28, No. 6, 1985, pp. 1856–1866.

The Blaney-Criddle approach was applied to produce a watershed-scale estimate of evapotranspiration. The application was tested on seven Coastal Plain watersheds ranging in size from 15.7 to 334.3 km^2 with mixed forest, crop, and pasture use. Seasonal and annual empirical consumptive use coefficients are presented for the test drainage areas. Also, the consumptive use coefficients were related to percentages of open water and open water/wetlands. Results indicate that this application explains in excess of 98 percent of the observed variation in annual and seasonal watershed evapotranspiration.

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

"Efficiency of Water Use and Associated Characteristics of Lehmann Lovegrass," *Journal of Range Management*, Vol. 26, No. 3, 1973, pp. 210–212.

Efficiency of water use of five lines and the cultivar ‘A-68’ of Lehmann lovegrass (*Eragrostis lehmanniana* Nees) was related to seedling drought tolerance to physiological and morphological plant characteristics. Components of efficiency of water use (transpired water and dry matter produced) and the values of water-use efficiency (measured as the number of units of transpired water per unit of dry matter produced) varied among lines. Line L-38 was most efficient in water use (water-use efficiency value of 135), had the highest percentage of survival, 32.4 percent (seedling drought tolerance), and produced the most dry matter (8.31 g). The ratios of maximum recorder deflection of petroleum ether extract and the total area of optical deflection of petroleum ether extract to dry weight of leaves were variable among lines and significantly associated with high efficiency of water use and high percentage of survival. Stomate density was different among lines and was higher on the upper surface than on the lower surface of the leaf blade. Stomate density was not significantly associated with efficiency of water or seedling drought tolerance.

306. Wymore, I. F.

“Estimated Average Annual Water Balance for Piceance and Yellow Creek Watersheds,” *Technical Report Series No. 2,* Environmental Resources Center, Colorado State University, Fort Collins, Colorado, 1974, 60 pp.

This report provides a surface water balance estimate by elevation zones and vegetation types for the Piceance Creek and Yellow Creek watersheds. The original purpose of this study was to provide the U.S. Geological Survey with data for checking and calibrating the groundwater model for the Piceance Basin, but the resulting estimates have considerable application in answering plant water use questions related to the developing oil shale industry. The estimates developed are generally consistent with known water balance factors and vegetation indicators, but the water balance model is based on linear relationships to the maximum possible extent and the necessary simplifying assumptions ignore a number of complex relationships.

The climate of the Piceance Basin is arid-steppe and is subject to dramatic changes within short distances, or over short-time periods. The Piceance and Yellow Creek watersheds have elevation zones from less than 6,000 to more than 9,000 ft, wide variations in topography, at least seven major vegetation types, and many barren cliffs or canyons that create hot upslope winds. It is also in an area of water deficient sparse vegetation. These factors all emphasize and need for special evapotranspiration methodology, and the impossibility of providing specific evapotranspiration estimates for individual vegetation sites, or years, using any form of generalized methodology.

The Jensen-Haise method of estimating evapotranspiration was chosen for this study because, with modification, it can be used to estimate annual evapotranspiration by elevation zone, and provide quantification of observed differences in water use for various slopes and aspects. This method was also specifically developed for use in the arid or semiarid western United States. The modified Jensen-Haise method used in this report provides monthly water use estimates for both the winter (moisture accumulation period) and the growing season use. The methodology was also adapted to providing evapotranspiration estimates for specific vegetation types, and cover densities, on different slopes and aspects, and for areas having different temperature relationships. The study provides relatively simple equations that can be used to estimate evapotranspiration (or irrigation requirements) for specific vegetation types growing on 0-50 percent slopes and eight aspects.

The water balance evaluations for Piceance Creek watershed (629 sq. miles) provide average annual precipitation estimates of 17.40 in., of which 17.01 in. are used by evapotranspiration, and the net outflow is 0.39 inch. In terms of acre-ft, this would be a net outflow of 13,102 acre-ft which checks with the available streamgaging records for Piceance Creek at the White River is estimated irrigation by-pass at the gaging site is considered. The Yellow Creek watershed (258 sq. miles) water balance study estimates an average precipitation of 15.67 in., with 15.58 in. evapotranspiration, and 0.19 in. (2,578 acre-ft) net outflow. The evaluations, as conducted, also provided specific estimates of water use by native vegetation, irrigated cropland, sagebrush bottomland and seep or phreatophyte areas, and a division of evapotranspiration estimates for each vegetation type during the November–March and April–October periods.

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

"Use of Water by Native Vegetation," Division of Water Resources, State of California, *Bulletin 50*, 1942, 154 pp.

The purpose of this bulletin is to bring together the results of studies of consumptive use of water by a number of species of native vegetation. The results are those determined by the Division of Irrigation, Soil Conservation Service, U.S. Department of Agriculture, for various western climatic conditions and by other agencies. Such studies have been carried on for many years. The bulletin discusses four general methods by which consumptive use of water by native vegetation has been determined: tank studies, soil moisture investigations, streamflow studies, and water-table fluctuations. (From Author's Introduction)

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