A Bibliography of Evapotranspiration with Special Emphasis on Riparian Vegetation

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Julie L. Moore
James P. King
A. Salim Bawazir
Theodore W. Sammis

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By

Julie L. Moore, M.L.S.
Bibliographer
Department of Civil, Agricultural and Geological Engineering
New Mexico State University

James P. King, Ph.D., P.E.
Principal Investigator
Department of Civil, Agricultural and Geological Engineering
New Mexico State University

A. Salim Bawazir, Ph.D.
Research Specialist
Department of Civil, Agricultural and Geological Engineering
New Mexico State University

and

Theodore W. Sammis, Ph.D.
Co-Investigator
Department of Agronomy and Horticulture
New Mexico State University

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INTRODUCTION

The scarcity of water in New Mexico has prompted the search for additional approaches to planning and management. Agriculture and riparian evapotranspiration (ET) is one of the larger loss components in the Middle Rio Grande hydrologic budget. Evapotranspiration has been studied for many years throughout the world and many methods have been proposed and implemented around the world. However, estimating ET in natural conditions is still a challenge to researchers. Many methods exist for measuring and estimating ET including water budget, micrometeorological, physiological, and semi-empirical methods. Reviews and analyses of various methods have been documented by Gay (1993), Jensen and others (1990), Cuenca (1989), and Doorenbos and Pruitt (1992). As an example, Gay (1993) compared two meteorological methods (Bowen ratio and eddy covariance) and the systems used in measuring ET; and Jensen and others (1990) described and compared in detail many methods that can be used to measure and estimate ET such as the water budget as well as micrometeorological and climatological methods.

This bibliography was prepared in an effort to collect information related to methods and techniques used in measuring and/or estimating evapotranspiration of riparian and agricultural crops. It focuses on those studies the authors thought to be relevant to the ET of agricultural and riparian vegetation in the Middle Rio Grande with a major emphasis on the water use of phreatophytes such as saltcedar, cottonwood, Russian olive, and saltgrass. Evapotranspiration of agricultural crops have been studied and documented for many years but less is known about the riparian vegetation.

The bibliography includes information on: 1) the methods and techniques used in the past and present in measuring and estimating ET in both agricultural and riparian vegetation; 2) riparian ecosystem changes and various methods of management and control of exotic species such as saltcedar; 3) water requirements of agricultural crops and riparian vegetation; and 4) crop coefficients based on heat units (growing degree days).

Other bibliographies on the subject were reported by Robinson and Johnson (1961) and Johns (1989). Robinson and Johnson's (1961) bibliography covers references from the 1800s into 1958 while that of Johns (1989) covers from 1920 into 1984. The references selected here extend from the 1940s to the year 2000. While some of the references may overlap, the bibliography is by no means complete due to extensive literature on the subject. However, it provides an update for the subject. Secondary sources searched include CAB (Commonwealth Agricultural Bureaux), AGRICOLA (National Agricultural Library), Water Resources Abstracts (NISC), SciSearch (ISI, Institute for Scientific Information) and Dissertation Abstracts International.

Introduction References

Johns, Eldon L. (1989). Water Use by Naturally Occurring Vegetation Including an Annotated Bibliography. New York, American Society of Civil Engineers (ASCE).

Robinson, T.W. and Johnson, A. I. (1961). Selected Bibliography on Evaporation and Transpiration: Selected references emphasizing papers from the United States from the early 1800's into 1958; Water-Supply Papers of the U.S. Geological Survey No. 1539-R: 1-25.

BIBLIOGRAPHY

Allen, R. G., J. H. Prueger, et al. (1992). "Evapotranspiration from isolated stands of hydrophytes: cattail and bulrush." Transactions of the ASAE (American Society of Agricultural Engineers) 35(4): 1191-1198.

Evapotranspiration (ET) rates were predicted for cattails and bulrushes in narrow isolated stands using measurement from drainage lysimeters in Utah. Evapotranspiration coefficients and aerodynamic roughness and bulk stomatal resistance parameters were developed. Peak ratios of ET from vegetation in the center of 6 m wide stands of hydrophytes to ET from alfalfa averaged 1.6 for cattails and 1.8 for bulrushes. A ratio of momentum height to vegetative height of 0.3 for use in the Penman-Monteith equation estimated ET relatively well. Errors between prediction equations and lysimeter measurements were minimized using this equation.

Allen, R. G., L. S. Pereira, et al. (1998). Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements. Rome, Italy, FAO (Food and Agriculture Organization of the United Nations).

Methods of calculating reference and crop evapotranspiration (ET) from meteorological data and crop coefficients are reviewed. The Penman-Monteith equations are revised using new instrumentation to measure ET upon a hypothetical crop of "grass." Based upon analyses from numerous experts, it is recommended that the Penman-Monteith method be the standard for the definition and computation of reference evapotranspiration (ET_0). Crop evapotranspiration (ETc) was calculated for a 'well-watered hypothetical grass surface having fixed crop height, albedo and surface resistance.' Differences in evapotranspiration and transpiration between field crops and the reference grass surface were integrated into a single crop coefficient (Kc). Calculations for each stage of the final ET values are presented in detail.

Amatya, D. M., R. W. Skaggs, et al. (1995). "Comparison of methods for estimating REF-ET." Journal of Irrigation and Drainage Engineering 121(6): 427-435.

Six methods used to estimate reference evapotranspiration (REF-ET) were evaluated: the Penman-Monteith, Makkink, Priestley-Taylor, Turc, Hargreaves-Samani and Thornthwaite at three sites

in eastern North Carolina. The Penman-Monteith method, with grass as a reference crop, was selected as the standard of comparison. Good correlation was found between the REF-ET values estimated by each of the other five methods. Turc's method yielded the best average estimate of total annual REF-ET. All other radiation methods and the temperature-based Thornthwaite method under-predicted the annual REF-ET by as much as 16%. The Hargreaves method over-predicted annual REF-ET by 15% on the average. On the average, Turc's method was found to be the best predictor of the monthly REF-ET for all locations tested.

Amiro, B. D. and E. E. Wuschke (1987). "Evapotranspiration from a boreal forest drainage basin using an energy balance/eddy correlation technique." Boundary-Layer Meteorology 38: 125-139.

Evapotranspiration (ET) was measured at two sites in a boreal forest drainage basin located in southern Manitoba, Canada. An energy heat balance method was used in which net radiation and ground heat flux was measured directly. Sensible heat flux was measured by the eddy correlation technique, using a propeller anemometer and a fine-wire thermocouple. The instruments were mounted at heights of 6 and 12 m above the forest canopy. One set of instruments was located on an upland area characterized by a sparse jack pine *(Pinus banksiana)* canopy and rock outcrops over 75% of its area. The other 25% of the basin was a flat, low-lying region vegetated by willow (*Salix* spp.) and aspen (*Populus tremuloides*). A basin-wide ET was calculated by weighting the values for the two sites in proportion to their area. The measured ET agreed well with precipitation minus runoff for the basin.

Anderson, J. E. (1977). "Transpiration and photosynthesis in saltcedar." Hydrology and Water Resources in Arizona and the Southwest 7: 125-131.

Saltcedar transpiration and photosynthesis were investigated near Bernardo, New Mexico. Transpiration rates were similar to several herbaceous species (yellow sweetclover, yarrow, Canadian wild rye, crested wheatgrass), but photosynthesis and water use efficiency were significantly lower in saltcedar. Photosynthesis was light saturated at irradiance equal to 44% of full sunlight while the stomata were fully open at light levels greater than 1/3 of full sunlight. Optimum leaf temperatures for photosynthesis were between 23-28 degrees C. Photosynthesis was reduced about 20% at 35 degrees C. Stomatal resistance increased linearly with increases in leaf temperature between 14 and 50 degrees C with relative humidity held constant. Increased stomatal resistance at high temperatures and low relative humidity could account for afternoon depressions in transpiration and photosynthesis rates.

Anderson, J. (1982). "Factors controlling transpiration and photosynthesis in *Tamarix chinensis* Lour." Ecology 63(1): 48-56.

Photosynthesis and stomatal responses of saltcedar in response to temperature, light, and humidity were studied in New Mexico and in the laboratory. Transpiration rates of saltcedar were similar to other phreatophytes (cottonwood and Russian olive), but net photosynthetic rates and water use efficiency were lower. 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 1/3 of full sunlight, but increased linearly with decreasing photon flux density below that level. Optimal leaf temperatures for photosynthesis were 23-28 degrees C, corresponding roughly to ambient temperatures during the early part of the day when evaporative demand was relatively low.

Bawazir, A. S. (2000). Saltcedar and Cottonwood Riparian Evapotranspiration in the Middle Rio Grande. Ph.D. Dissertation. Department of Civil and Geological Engineering, New Mexico State University, Las Cruces, New Mexico. 214 pp.

The primary objective of this study was to create models to predict consumptive use of water by saltcedar (*Tamarix ramosissima)* and cottonwood *(Populus fremontii)* and to identify methods of long-term evapotranspiration (ET) quantification. Evapotranspiration was measured in 1999 using eddy covariance methods on the floodplain of the Middle Rio Grande at Bosque del Apache National Wildlife Refuge, New Mexico. Conclusions were 1) daily sensible heat from the OPEC system agreed closely with sensible heat measured by the 3DSEC (sonic anemometer system); 2) the OPEC system had proven robust and reliable for long-term ET measurements of forested areas; 3) the annual energy and water budget of deciduous saltcedar and cottonwood clearly showed a transpiration pulse during the summer, and defined effects of spring bud break and autumn senescence; 4) a dense stand of saltcedar used 1325 mm (4.35 ft) per year and 1193 mm (3.91ft) during the growing season from DOY 95-325 (April 5-November 21); 5) a sparse stand of cottonwood used 904 mm (2.97 ft) per year and 799 m (2.62 ft) during the growing season from DOY 95-325 (April 5-November 21); and 6) daily ET from saltcedar and cottonwood during the growing season was predicted adequately with a fourth degree polynomial function to estimate crop coefficients applied with the Penman equation.

Bernhofer, C., L. W. Gay, et al. (1996). "The HartX-synthesis: an experimental approach to water and carbon exchange of a Scots pine plantation." Theoretical and Applied Climatology 53(1-3): 173-183.

In May 1992 several independent estimates of stand water vapor flux were compared at a 12 m high Scots pine *(Pinus silvestris)* plantation on a fluvial terrace of the Rhine River near Freiburg, Germany. Micrometeorological methods included eddy covariance and eddy covariance energy balance techniques, with six independent systems on two towers separated by 40 m. Bowen ratio energy balance estimates of water flux were conducted, and measurement of the gradients in water vapor, carbon dioxide, and trace gases with and above the stand were performed. Tree transpiration contributed between 2.2 and 2.6 mm per day to evapotranspiration (ET) for a tree leaf area index (LAI) of 2.8. The understory of the pine stand was dominated by sedge and grass species with an overall average LAI of 1.5. Thus, transpiration by graminoid species was estimated at approximately 20% of the total stand ET. Carbon gain was estimated from the canopy models at approximately 425 mmol (square meter per day) for the tree needles and at 100 mmol (square meter per day) for the understory. Carbon gain remained relatively constant while water use efficiency in carbon fixation increased with decreasing vapor pressure deficit. The various methods support a reliable estimate of average ET of about 2.6 mm per day (a maximum of about 3.1 mm per day) with an insignificant decreasing trend in correlation with decreasing vapor pressure deficit and possible soil moisture. Hydrological estimates of soil water extractions and micrometeorological estimates of ET by the one-propeller eddy covariance (OPEC) system were in very good agreement.

Bidlake, W. R., W. M. Woodham, et al. (1990). "Evapotranspiration from areas of native vegetation in west-central Florida." Water-Supply Papers of the U.S. Geological Survey 2430: 1-35.

Three meteorological methods for estimating evapotranspiration (ET) were evaluated from selected areas of four types of native vegetation in west-central Florida. The vegetation types were dry prairie, marsh, pine flatwood, and cypress swamp. Evapotranspiration was estimated using the energy-balance Bowen ratio (EBBR) and eddy correlations. Potential ET was computed using the Penman equation. The EBBR method was used in both forested and non-forested areas. Analysis of eddy correlation and energy-balance data indicated the sum of sensible and latent heat fluxes accounted for 68% of available energy at the pine flatwood site, and 45% at the cypress swamp site. Daily potential ET, as computed by the Penman method, and daily ET, as computed by the EBBR method did not seem to correlate with each other at the dry prairie site during late spring and summer; however they did correlate at the marsh site during late spring and summer. Evapotranspiration was approximately 75% of potential ET at the marsh site. Annual ET was 1010 mm per year for the dry prairie, 990 mm per year for the marsh, 1060 mm per year for the pine flatwood, and 970 mm per year for the cypress swamp.

Blaney, H. F. (1954). "Consumptive-use requirements for water." Agricultural Engineering 35(12): 870-873.

The U.S. Geological Survey has estimated that 1.3 billion acre-feet of water is carried annually across the border of the United States into the oceans, equivalent to an average depth of about 8 inches over the entire country. Since the average annual precipitation of the United States is approximately 30 inches, less that one-third of the water delivered to the surface of the country flows beyond its borders, and that some 22 inches of moisture returns to the atmosphere annually as the result of evaporation and transpiration. In arid and semiarid regions, the water requirements of native vegetation are usually satisfied before water becomes available for other purposes. The USGS has estimated that there are some 11 million acres of phreatophytes growing in the 17 western states, consuming more than 16 million acre-feet of water annually. In the Rio Grande Basin, about one-half of the stream-flow depletion resulted from non-beneficial evapotranspiration losses, that is, water used by native vegetation.

Blaney, H. F. and E. G. Hanson (1965). "Consumptive use and water requirements in New Mexico." Technical Reports of the New Mexico State Engineer Office 32: 1-82 & 3 folded maps.

The most extensive water consumption in New Mexico is irrigation for agricultural crops. Data on consumptive use of water for various plants are necessary for efficient use of water resources. As part of this report, native phreatophytes (cottonwood, saltcedar, saltgrass, tules, and willows) were studied for water consumption. A comparison of studies made in Arizona, Colorado, New Mexico, and California were made with the evapotranspiration (ET) rates noted. Saltcedar was the primary plant in most studies, with ET being estimated from lysimeters. In New Mexico, along the Pecos River basin, riparian saltcedar stands ranged from 51.6 inches to 72.0 inches annually.

Blanford, J. H. and L. W. Gay (1992). "Tests of a robust eddy correlation system for sensible heat flux." Theoretical and Applied Climatology 46(1): 53-60.

Sensible heat flux estimates from a simple, one-propeller eddy correlation system (OPEC) were compared with those from a sonic anemometer eddy correlation system (SEC). The performance of the OPEC system improved with increasing height of the sensor, 5 m or more, above the surface. Initial comparisons between the OPEC and SEC systems were made above a bare field at the Campbell Avenue Experimental Farm in Tucson, Arizona, in September 1989. Flux totals from the two systems were in excellent agreement after frequency response corrections were applied. The OPEC system appeared suitable for long periods of unattended measurements. The sensible heat flux measurements, combined with net radiation and soil heat flux measurements, could estimate latent heat as a residual in the surface energy balance.

Bowen, I. S. (1926). "The ratio of heat losses by conduction and by evaporation from any water surface." Physical Review, 2nd ser. 27(6): 779-787.

The process of evaporation and diffusion of water vapor from any water surface, such as a lake or pond, into the body of air above it, is "exactly similar" to that of the conduction or diffusion of specific heat energy from the water surface into the same body of air. Due to this similarity, it is possible to develop and use a formula to represent the ratio of the heat loss by conduction to that by evaporation. The logical method for determining heat losses via formulas is presented, step-by-step. The basic equation of the relation between evaporation and radiant energy is I=S+LE+K, where I is the radiant energy. . . integrated over any time interval, S is the heat represented by the change in temperature of the water, KE is heat represented by the evaporation (E) during the same time interval, and K is a relative small correction to cover other losses.

Brako, L., A. Y. Rossman, et al. (1995). Scientific and Common Names of 7,000 Vascular Plants in the United States. St. Paul, Minnesota, APS (American Phytopathological Society) Press.

A list of common names and scientific (Latin) names are listed for all vascular plants in the United States. In the case of saltcedar (*Tamarix*), six different 'species' are listed: *T. aphylla, T. chinensis, T. gallica, T. hispida, T. parviflora,* and *T. ramosissima.*

Busch, D. E. and S. S. Smith (1995). "Mechanisms associated with decline of woody species in riparian ecosystems of the southwestern U.S." Ecological Monographs 65(3): 347-370.

The objective of this study was to provide a functional interpretation of the transition from cottonwood-willow riparian forests to the saltcedar-arrowed riparian vegetation along the Colorado River and the Bill Williams River in Arizona, one a tightly regulated river for irrigation, the other less regulated. Tissue water relations, characteristics and leaf elemental analyses confirmed that saltcedar was likely to be more tolerant of a relatively high degree of salinity or water stress. Perturbations of the regulated Colorado River may have elevated salinity and caused depressed water tables, allowing the more salt-tolerant saltcedar and arrowed to replace the native cottonwood and willow species. With the prevalence of desiccated floodplain environments, saltcedar and arrow weed have increased in importance in riparian communities, while willow and cottonwood have decline, cottonwood more than willow due to water and salinity stress.

Campbell, C. J. (1961). Comparison of Eighteen Phreatophyte Communities on the Rio Grande River in New Mexico. M.S. Thesis. Department of Biology, New Mexico State University, Las Cruces, New Mexico: 58 pp.

Eighteen phreatophyte communities along the Rio Grande from Albuquerque, New Mexico to Canutillo and El Paso, Texas, were sampled by the line intercept method. An analysis of variance, a variance of an area mean, and a coefficient of variation were computed on cottonwood *(Populus fremontii)*, saltcedar *(Tamarix pentandra)* and screwbean mesquite *(Prospopis pubescens)* to determine statistically the validity of results. Cover, height, presence, structure, and composition were also determined for each of the eighteen phreatophyte communities. Highly significant differences in cover occurred in plots containing saltcedar and mesquite from north to south. In the northern plots, cottonwood and Russian olive *(Elaeagnus angustifolia)* attained their maximum coverage. Russian olive was not recorded on transects below the 190 mile plot. Vegetation was dependent almost entirely upon subsurface moisture created by high water tables.

Campbell, C. J. and W. A. Dick-Peddie (1964). "Comparison of phreatophyte communities on the Rio Grande in New Mexico." Ecology 45(3): 492-502.

The complex plant communities, called phreatophytes, common to ephemeral streams and rivers at elevations below 5000' could not exist without access to subsurface moisture in the deserts of the American Southwest. Eighteen relatively mature phreatophyte communities on 300 miles of the Rio Grande in New Mexico, from El Paso to Albuquerque, were censused by randomly spaced line intercepts. Vegetation between the north and south sectors were different; saltcedar and screwbean mesquite occupied quite different sections. Cottonwood cover was non-significant. Postclimax vegetation has been altered or modified in many areas to produce quasi-permanent disclimax vegetation due to grazing, irrigation, and agricultural practices along the Rio Grande Valley. The screwbean dominates mostly in the southern sections; the cottonwood in the north above San Antonio, New Mexico. In the last 50 years, the introduction and escape of saltcedar and Russian olive have changed the successional stages and ultimately dominants of some communities, especially in the middle sectors of the Rio Grande Valley.

Carman, J. G. and J. D. Brotherson (1982). "Comparisons of sites infested and not infested with saltcedar *(Tamarix pentandra)* and Russian olive *(Elaeagnus angustifolia)*." Weed Science 30(4): 360-364.

The incidence of saltcedar and Russian olive invasion into moist pastures and rangeland was investigated based upon site characteristics in north central Utah within 4 km of Utah Lake. Discriminant analysis indicated that Russian olive occurs on soils with low to medium concentrations of soluble salts (100-3500 ppm), whereas saltcedar occurs on soils with a much higher soluble salt concentration (700-15,000 ppm). Saltcedar infested sites with a more xeric vegetation; 15 plant species had been selected as indicators. Russian olive sites had a higher concentration of magnesium, clay content, and pH in the soil. But those sites not infested had much higher phosphorus content. Results indicated that plant species were a better indicator than soil type for differentiating sites infested or infestation-prone. Plant species associated with sites infested with Russian olive were typical of mesic meadows, whereas species associated with saltcedar-infested sites were characteristic of more halophytic communities. Further, perennial grasses were more prominent in the Russian olive sites; annuals were more prominent in saltcedar sites.

Carter, J. L. (1997). Shrubs of New Mexico. Boulder, Colorado, Johnson Books.

This work is a field guide to woody shrubs and trees found in New Mexico. Descriptions, scientific names, common names, and distribution of most woody plants are presented, with a line drawing of the leaves and branches of each plant. Saltcedar has only one species, *Tamarix ramosissima,* with all other names as synonyms. Field keys, using leaves and branches, are presented for each species.

Cavalieri, A. J. and A. H. C. Huang (1979). "Evaluation of proline accumulation in the adaptation of diverse species of marsh halophytes to the saline environment." American Journal of Botany 66(3): 307-312.

Eight species of halophytes, one of which was saltgrass *(Distichlis spicata)*, were grown under laboratory conditions to examine the conditions under which proline accumulation began. When plants were exposed to increasing salinities, they accumulated proline after threshold salinity had been reached. Rushes and saltgrass had threshold salinity levels around 0.5 m sodium chloride and accumulated proline to 27.4 micromoles per gram fresh weight. Water stress imposed by polyethylene glycol caused similar proline accumulations, but to a different extent. Proline levels in the salt grasses remained at low levels until a threshold salinity level was reached (around that of seawater). Therefore, it may not play a very significant role in the adaptation of these species to the salt marsh. However, under conditions of low rainfall or locations with high salinity, the higher levels of proline may be a significant adaptation.

Collier, P. and A. Olioso (1993). "A simple system for automated long-term Bowen ratio measurements." Agricultural and Forest Meteorology 66(1): 81-92.

The Bowen ratio method is used to estimate fluxes of sensible heat and evaporation between plants and the atmosphere. A simple system, using a capacitive hygrometer and alternate sampling of air at two levels with pumps to measure humidity gradients, was developed. It provided long-term measurements: low power consumption, low charge of maintenance, and low cost. Testing was done by a comparison of hourly sensible and latent heat flux measurements, performed by both eddy correlation and Bowen ratio, over a bare soil field and a fully developed canopy of a soybean crop in France. The system gave good flux estimates even with very low humidity gradients.

Christensen, E. M. (1963). "Naturalization of Russian olive *(Elaeagnus angustifolia* L.) in Utah." American Midland Naturalist 70(1): 133-137.

A brief history of the naturalization of Russian olive, *Elaeagnus angustifolia*, in Utah is presented. Prior to 1900 it did not occur, but trees planted or escaped in 1924 and 1929 are the earliest record of Russian olive in Utah. It had been planted extensively during the first three decades as evidenced by its common occurrence during the 1940s and 1950s. However, it was uncommon in nature prior to 1937. The first published record of naturalization was made by Holmgren in 1948. Today it is a conspicuous species in the Utah Valley, the Uinta Basin, and other valleys in north central Utah.

Cleverly, J. R., S. D. Smith, et al. (1997). "Invasive capacity of *Tamarix ramosissima* in a Mojave Desert floodplain: the role of drought." Oecologia 111(1): 12-18.

The response of gas exchange and stem sap flow of saltcedar, arrow weed, coyote willow, and screwbean mesquite to drought conditions in the Mojave Desert of southern Nevada was investigated. Xylem sap flow was highest in saltcedar under early drought conditions but was comparable between the four species toward the end of the summer dry season. Multivariate analysis of the gas exchange data indicated that the four species differentiated based on water use under early drought conditions and separated based on plant water potential and leaf temperature at the end the summer dry season. Saltcedar was the most drought tolerant of the four species, whereas willow was the least tolerant. Willow was well adapted to early successional stages in the floodplains, but as an area became more desiccated in time, saltcedar assumed a more dominant role due to its superior drought tolerance and its ability to produce high density stands and high leaf area.

Cooper, D., W. Eichinger, et al. (1996). "Estimation of spatially distributed latent energy flux over complex terrain using a scanning water-vapor Raman lidar." Conference on Agricultural and Forest Meteorology, 22nd, Atlanta, Georgia, 1996. Boston, American Meteorological Society, p. 231-234.

Remote sensing technology offers the ability to collect detailed spatially distributed data. The Los Alamos National Laboratory's volume-imaging, scanning water-vapor Raman lidar has been shown to be able to estimate the latent energy flux at a point. An array of hygrometers, eddy correlation flux systems, a 3-D sonic anemometer, and the Raman lidar were established on a study site at Split Wash, Yucca

Mountain, New Mexico. The lidar acquired water-vapor mixing ratio data with 1.5m resolution, in vertical scans up to an altitude of 80 m above the surface with a range of 5000 m in any direction, thus it was possible to collect 1 km data where the terrain permitted. It appears that two of the three lidar derived estimates and the eddy correlation values were within 10% of one another, while the values from the lidar and eddy correlation site 1 were within 20%.

Crawford, C. S., L. M. Ellis, et al. (1996). "The Middle Rio Grande Bosque: An endangered ecosystem." New Mexico Journal of Science 36: 276-299.

The Middle Rio Grande Bosque, located in central New Mexico, has changed in structure since its inception, about 14 million years ago. Ecological change during the 14th through the 19th centuries was caused by climatic cycles and increasingly intensive use of the floodplain by the Pueblo Indians, then by the Spanish settlers. At that time it was assumed that the Bosque was a mosaic of cottonwood-willow stands of different ages located at different distances from a relatively sinuous river channel. Hydrological changes began in the 1800s with watershed exploitation that generated erosion and flood-borne sediment deposition. In the early 1900s, dams and impoundments were constructed to channel the stream flow of the Rio Grande. Today the Bosque is mostly a narrow, linear strip of native and exotic trees, 'disconnected' from the flow-regulated, straightened river. Cottonwoods still dominate the overstory of most of the Middle Rio Grande Bosque. In disconnected stands, understory trees and shrubs crowd the forest. The exotic saltcedar, which is somewhat shade-intolerant, occurs in dense clusters where cottonwoods are absent.

Cuenca, R. H. (1989). Irrigation System Design: An Engineering Approach. Englewood Cliffs, New Jersey, Prentice-Hall. 552 pp.

This textbook is directed toward upper-division engineering students. It attempts to quantify the parameters necessary for the design, installation, and operation of various types of irrigations systems. It presents a broad scope of the various aspects of supply, distribution, and application of water for irrigation at the farm level. Specifically, Chapter Five refers to crop water requirements and briefly discusses methods of estimating evapotranspiration.

Culler, R. C., R. L. Hanson, et al. (1976). “Relation of the consumptive use coefficient to the description of vegetation.” Water Resources Research 12(1): 40-46.

Evapotranspiration from three reaches of the Gila River floodplain in Arizona was measured by a water budget during 1963-71. Initially the vegetation consisted of saltcedar and mesquite. In 1969, they were removed and grass planted. But the grass failed to become established and annual plants became the primary vegetation on the areas. Comparison of the evapotranspiration data from various reaches and comparison of data from before and after clearing of saltcedar and mesquite required the application of an empirical equation. A means of measuring the evapotranspiration of vegetation was developed using a consumptive use coefficient in relation to the description of vegetation. Aerial photography and ground surveys of the plant identification and ground measurements provided the means of developing this methodology. In 1967, remote sensing in the form of color infrared aerial photography was used to develop a spectral signature as the vegetation descriptor.

Culler, R. C., R. L. Hanson, et al. (1982). “Evapotranspiration before and after clearing phreatophytes, Gila River flood plain, Graham County, Arizona.” Professional Papers of the U.S. Geological Survey 655-P: 1-67.

Phreatophytes (mainly saltcedar and mesquite) were eradicated from the Gila River in southeastern Arizona from 1967-1971 based upon the assumption that they are high water consuming plants. Post clearing attempts to establish grass were unsuccessful, but annual plants did provide temporary cover when shallow soil moisture was available during the growing season. Evapotranspiration was evaluated in a water-budget equation for the study periods, 1963-1971, before eradication on each section of the river floodplain. Annual evapotranspiration averaged 43 in or 1090 mm before clearing, and ranged from 56 in (1420 mm) for dense stands of phreatophytes to 25 in (630 mm) on areas with no phreatophytes. 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’ due to the difference in the density of phreatophytes. A logical replacement for phreatophytes was considered to be a cover of grasses, but computations of previously published parameters indicated a consumptive use greater than the evapotranspiration from the Gila River floodplain before removing the phreatophytes.

Davenport, D. C., P. E. Martin, et al. (1976). "Conserving water by antitranspirant treatment of phreatophytes." Water Resources Research 12(5): 985-900.

A wax-based antitranspirant (AT) was sprayed on leaves of saltcedar, cottonwood, and willow as an alternative to eradication. Field experiments were conducted in Nevada and California. Scanning electron micrographs were used to collect information on the nature of foliar surfaces and coverage by the AT wax. A 10% solution of AT reduced the transpiration rates of container-grown plants 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% after a heavy application. The AT conserved water much more effectively when it was applied to the outer part of the canopy than to the inner shaded foliage where transpiration was already minimal. Data from these trial sprays applied from the ground provided a basis for aircraft AT application.

Davenport, D. C., P. E. Martin, et al. (1976). "Aerial spraying of phreatophytes with antitranspirant." Water Resources Research 12(5): 991-996.

A wax-based antitranspirant (AT) was applied to saltcedar, poplar, and willow in sites in Nevada and California by aerial spraying. Trials by a helicopter on saltcedar in California and a fixed-wing aircraft (crop-dusting biplane) on saltcedar, cottonwood, and willow stands in Nevada were performed. Spray coverage on the ground was 30-100% in the open, and 10-90% under the canopies. Average coverage ranged from 13% in the lower canopy to 70% in the upper after spraying the fixed wing plane and 40-98% after spraying by the helicopter. The AT 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 saltcedar was reduced 50% initially and 20% after two weeks without phytotoxicity.

Davenport, D. C., J. E. Anderson, et al. (1979). "Phreatophyte evapotranspiration and its potential reduction without eradication." Water Resources Bulletin 15(5): 1293-1300.

Spraying phreatophytes (saltcedar, cottonwood, Russian olive, mesquite) with an antitranspirant reduced the evapotranspiration (ET) rate without eradicating the plants. Transpiration rate per unit leaf area was similar for several species, but ET per unit land area depended 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. Laboratory tests showed a decrease of 50% where the foliage was thoroughly sprayed with an antitranspirant. Field studies in Davis, California and Bernardo, New Mexico using a backpack mistblower for spraying showed a 20-35% reduction initially and 10% a month later. No ET reduction occurred when the antitranspirant was sprayed on saltcedar using a helicopter because excessive droplet size and heavy salt deposits on the foliage resulted in poor spray adherence. Toxicity of the antitranspirant on mammals (cotton rat) and fish (mosquito fish) was also assessed. The helicopter spraying destroyed only 1 of 20 redwing blackbird nests. The AT appeared relatively harmless to mammals, birds, and fish. Although antitranspirants may reduce evapotranspiration of phreatophytes, the high cost and difficulties of application preclude current use.

Davenport, D. C., P. E. Martin, et al. (1982). "Evapotranspiration from riparian vegetation: water relations and irrecoverable losses for saltcedar." Journal of Soil and Water Conservation 37(4): 233-236.

Saltcedar evapotranspiration (ET) varied with weather factors in addition to stand density and water availability. Data were presented on rates of irrecoverable ET losses from saltcedar and the variability in those rates due to stand density, soil water availability, and stomatal resistance. In California, ET in a unit ground area of saltcedar in large drums varied from 2 mm per day in sparse stands to 16 mm in dense stands during July. 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 varied from 3 mm to 11 mm per day depending upon weather and plant density during June.

Davenport, D. C., P. E. Martin, et al. (1982). "Evapotranspiration from riparian vegetation: conserving water by reducing saltcedar transpiration." Journal of Soil and Water Conservation 37(4): 237-239.

Saltcedar was sprayed with a wax-based antitranspirant in field studies in Davis, California and Bernardo, New Mexico. A backpack mistblower was used to spray the antitranspirant, reducing evapotranspiration (ET) 20-35% initially and 10% after a month. No ET reduction occurred when a helicopter was used to spray because the large droplet size resulted in poor foliar adherence. Although the proper application of an antitranspirant reduces the irrecoverable loss of pure water through transpiration, an operation program for spraying cannot be recommended due to the 1) high cost of spraying, 2) need to improve aerial application, and 3) need to investigate more thoroughly its effect on wildlife.

Devitt, D. A., J. M. Piorkowski, et al. (1997). "Plant water relations of *Tamarix ramosissima* in response to the imposition and alleviation of soil moisture stress." Journal of Arid Environments 36(3): 527-540.

An extended drydown on saltcedar was investigated on the floodplain of the Virgin River, Nevada, during a hot, dry summer in 1995. Three 2-year old seedlings of saltcedar, grown in lysimeters (120 cm depth, 51 cm radius), were selected for the drydrown experiment; one each on the desert's edge, river's edge, and open stand. On July 7 1995, all irrigation was terminated for a 29-day drydown. Atmospheric water demand, characterized by estimates of potential evapotranspiration, averaged 6.2 mm per day during the drydown, and 6.0 mm during the 18 day wetup following. Irrigation was initiated at the end of day 29. Results indicated that sapflow decreased significantly as water tables and stored soil moisture declined. On day 26, sapflow reached zero in the open stand lysimeter. Upon irrigation resuming, all three plants responded by increasing sapflow within a 24-hour period. Relative stomatal conductance, leaf xylem water potential and sapflow measured during both the drydown and wetups stages were all linearly correlated with relative soil water in storage. Results indicated that relative soil water in storage could decline by as much as 90% without hysteresis.

Devitt, D. A., A. Sala, et al. (1997). "The effect of applied water on the water use of saltcedar in a desert riparian environment." Journal of Hydrology 192(1-4): 233-246.

A field study to quantify the response of saltcedar to supplemental water during a hot dry summer was conducted along the lower Virgin River, Nevada, in 1994. Water was applied to 4' square meter basins surrounding the saltcedar thickets once per week for six weeks. Plant water stress was observed in late June prior to the start of irrigation. However, all plants responded to irrigation. Transpiration was monitored with stem flow gauges; soil moisture with time domain reflectometry; plant water relations with a steady state porometer and pressure chamber. Results indicated that at least four weeks of irrigation were required before a significant use of water by saltcedar occurred. Closed stands transpired higher amounts of water than open stands. Atmospheric environmental demand was observed to decline over the course of the study, dropping from values of greater than 20 mm per day to values less than 8 mm per day when the transpiration response to irrigation was first observed. Results also indicated that saltcedar could not effectively utilize water from most summer rainfall events. But if alterations occurred along the river that increased the availability of water during the summer months (thereby increasing the water tables), saltcedar would have higher transpiration rates.

Devitt, D. A., A. Sala, et al. (1998). "Bowen ratio estimates of evapotranspiration for Tamarix ramosissima stands on the Virgin River in southern Nevada." Water Resources Research 34(9): 2407-2414.

A Bowen ratio energy balance was conducted on a saltcedar stand growing in a riparian corridor along the Virgin River in southern Nevada. Measurements from two separate years were compared on the basis of changes in growing conditions. In 1994, a drought year, record high temperatures, dry winds, and a falling water table caused partial wilt of outer smaller twigs in the canopy of many trees in the stand around the Bowen tower. Subsequently evapotranspiration (ET) declined dramatically over a 60-day period (11 mm per day to less than 1 mm per day). In 1995 the Virgin River changed course, hydrologically isolating the saltcedar stand near the Bowen tower. In 1996 a 25% canopy loss was visually estimated for the saltcedar stand. With a more open canopy, thermally induced turbulence was observed in 1996. Higher ET estimates were made in 1996 compared to 1994 (145 cm versus 75 cm). Results suggested that saltcedar has the potential to be either a low water user or a high water user, depending on moisture availability, canopy development, and atmospheric demand. Because of advective conditions, ET estimates should be used with extreme caution.

Di Stefano, C. and V. Ferro (1997). "Estimation of evapotranspiration by Hargreaves formula and remotely sensed data in semi-arid Mediterranean areas." Journal of Agricultural Engineering Research 68: 189-199.

A methodology was established for estimating evapotranspiration using the Hargreaves formula and image analysis of remotely sensed data from the Belice basin of Sicily. The data were collected using the energy balance equation, spectral data of two Landsat TM images, and ground agrometeorological measurements of several crops. The reference evapotranspiration values were obtained by a slightly modified Hargreaves formula, incorporating the outgoing short-wave radiation and an albedo coefficient equal to 0.23 to calculate crop coefficients. The weather and vegetation input data for the Penman-Monteith equation is often difficult and expensive to obtain. But the Hargreaves formula allows calculation of the reference evapotranspiration in a give time period (day, month) and requires only measured values of the mean maximum air temperature, the mean minimum air temperature, and incoming short-wave solar radiation. Results from this study showed that the Hargreaves formula gave results closest to the Penman-Monteith equation for reliability.

Di Tomaso, J. M. (1998). "Impact, biology, and ecology of saltcedar (*Tamarix* spp.) in the southwestern United States." Weed Technology 12(2): 326-336.

The author considers the introduction of eight species of saltcedar - *Tamarix (T. aphylla, T. chinensis, T. gallica, T. parviflora, T. ramosissima)* into the United States. By the 1920s, it (or they) had invaded about 4,000 ha of riparian habitat in the southwestern United States. By 1987, it was estimated to have increased to at least 600,000 ha. Unlike obligate phreatophytes, such as willow and cottonwood, saltcedar is a facultative phreatophyte able to survive under conditions where groundwater is inaccessible. The high evapotranspiration rates of saltcedar can lower the water table competing with willow and cottonwood. Mature plants are tolerant to a variety of stress conditions including heat, cold, drought, flooding, and high salinity, surviving in areas where groundwater concentrations of dissolved solids can average 8,000 ppm or higher. It is estimated that infestations of saltcedar along the riparian systems of Oklahoma to southern California and from Colorado to Sonora, Mexico are increasing 3-4% per year.

Doorenbos, J. and W. O. Pruitt (1992). Crop Water Requirements. FAO (Food and Agriculture Organization) Irrigation and Drainage Papers 24: 1-144.

Guidelines for determining crop water requirements are presented in this study. The first part deals with the methods to determine crop evapotranspiration (ET_0). The primary methods used are the Blaney-Criddle method, the radiation method, the Penman equation, and the pan evaporation method. To derive the evapotranspiration of a specific crop, relationships between crop evapotranspiration (ETc) and reference crop evapotranspiration (ET_0) are given. All crops mentioned are commercial agricultural vegetables or fruit trees. In the second part, crop water requirements are considered. Attention is given to irrigation efficiency and water requirements for cultural practices and leaching of salts.

Duell, L. F. W., Jr. (1990). "Estimates of evapotranspiration in alkaline scrub and meadow communities of Owens Valley, California, using the Bowen-ratio, eddy-correlation, and Penman-combination methods." Water-Supply Papers of the U.S. Geological Survey 2370: 1-39.

In the Owens Valley of California, evapotranspiration (ET) is one of the largest components of outflow in the hydrologic budget. Phreatophytes include saltgrass, the dominant species, and various shrubs, and other grasses. The measurement of ET included the Bowen ratio, eddy correlation, and Penman combination methods. Results of the analyses appear satisfactory when compared with other estimates of ET. Results by the eddy-correlation method were for a direct and a residual latent-heat flux based on sensible-heat flux and energy-budget measurements. The Penman-combination equation was determined to be unusable because ET was overestimated. Modification of this method to account for differences between heat-diffusion resistance and vapor-diffusion resistance permitted actual ET to be estimated. Simple linear regression analysis indicated that ET estimates are correlated to air temperature, vapor-density deficit and net radiation. Estimated ET ranged from 301 mm at a low-density scrub site to 1137 mm at a high-density meadow site. Monthly percentage of annual ET was determined to be similar for all sites.

Dugas, W. A., L. J. Fritschen, et al. (1991). "Bowen ratio, eddy correlation, and portable chamber measurements of sensible and latent heat flux over irrigated spring wheat." Agricultural and Forestry Meteorology 56(1): 1-20.

The objective of this paper was to compare measured Bowen ratios and calculated latent heat (LE) and sensible heat (H) from four Bowen ratio systems of different design with each other and with fluxes measured by three sets of eddy correlation instrumentation and a portable chamber for LE. Measurements were made on April 9-10, 1989 in an irrigated wheat field near Maricopa, Arizona. Bowen ratio system designs varied in terms of temperature and humidity sensors and measurement arm movement. The study showed that: 1) Bowen ratios from instrumentation of different designs were similar; 2) eddy correlation H from three systems were similar to each other but were slightly less than the Bowen ratio; 3) eddy correlation LE was consistently and significantly less than Bowen ratio LE; and 4) measurements of the portable chamber LE on the edge of a field were affected by surrounding conditions.

Dylla, A. S., D. M. Stuart, et al. (1972). Water Use Studies on Forage Grasses in Northern Nevada. Publication T-10 of the Agricultural Experiment Station, University of Nevada Reno and Agricultural Research Service, Soil and Water Conservation Research Division. vi, 56 pp.

Measurements were made of water used by three species of native meadow grass, bluejoint *(Elymus triticoides)*, sedges *(Carex spp.)* and saltgrass *(Distichlis stricta)* in northern Nevada. In addition, two domestic forage species (tall wheatgrass and Alta fescue) water use were also measured. Evapotranspiration (ET) was calculated by the combination model, Blaney-Criddle, and Olivier methods. Saltgrass, sedges, and bluejoint generally showed higher water-use efficiencies under high soil salinity levels than the domestic grasses, tall wheatgrass, and Alta fescue. Saltgrass used 19.1 inches ET in lysimeters in Winnemucca, Nevada in 1969; bluejoint and sedges used 21.8 and 21.9, respectively.

Everitt, B. J. (1998). "Chronology of the spread of tamarisk in the central Rio Grande." Wetlands 18(4): 658-668.

Historical changes in the Middle Rio Grande Valley have been implemented and exacerbated during the twentieth century. One paramount change is in saltcedar *(Tamarix* spp.) being introduced and expanding its range from an ornamental plant to covering thousands of acres along riparian habitat in New Mexico and the Southwest. Some of the valley changes include the creation of farmland and the shrinking of a channel depleted of flow by upstream water development, especially irrigation projects. There is no evidence that saltcedar actively displaced native species, especially cottonwood, nor that it played an active role in changing the hydraulic or morphologic properties of the river. Saltcedar was an opportunistic colonizer of disturbed land. Its present dominance in the Presidio Valley is due to the chance conjunction in 1942 of a large summer flood, a good seed source, and declining cotton prices that fostered abandonment of farm fields.

Fetter, C. W. (1988). Applied Hydrogeology. New York, Macmillan Publ. Co. vii, 592 pp.

This work is intended as an introductory textbook for hydrogeology. It stresses application of mathematics to problem solving rather than derivation of theory. In Chapter 2, evaporation, including evapotranspiration, and precipitation are covered in detail with appropriate tables and equations for measurement. Groundwater flow and soil moisture measurements are covered in Chapter 4.

Fritschen, L. J. (1966). "Evapotranspiration rates of field crops determined by the Bowen ratio method." Agronomy Journal 58(3): 339-342.

Evapotranspiration rates were determined biweekly for crop combinations of alfalfa and barley, alfalfa and cotton, alfalfa and sorghum, wheat and oats, and cotton grown under irrigation in the arid region of south-central Arizona. The Bowen ratio method was used as a continuous sampling method to determine the evapotranspiration rates. Calculated rates ranged from 1.0 to 1.8 times net radiation, indicating that large amounts of energy were extracted from the air mass. Alfalfa, prior to cutting, tended to use more water than the other crops.

Fritschen, L. J. (1985.). Characterization of boundary conditions affecting forest environmental phenomena. In The Forest-Atmosphere Interaction. B. A. Hutchison and B. B. Hicks. Dordrecht, eds. Netherlands, D. Reidel Publ. Co.: 3-23.

Analyses of environmental factors at forested sites, such as wind and radiation, are usually not applicable to other sites due to inadequate description of the site itself. A strategy for describing coniferous forests was presented. Only wind and radiation mensuration were considered in this paper. Discussion included transitions between clearcuts and forest, and holes within forests. Models of windspeed profiles within forests and radiation transmission through the canopy could be inverted and used with data from other sites to obtain vertical distributions of the vegetation density of biomass. The strategy discussed may vary with forest type and climatic zone. Items to be included are: latitude, longitude, elevation, location to the nearest large city, and adjacent large-scale topographic features. Specific descriptors included: vegetation type, plantation or naturally regenerated stand, and dbh, height, and crown length of each tree within a circular plot with a radius of at least one tree height from the tower location. When wind speed is measured, the descriptors should be extended one or two tree heights upwind for an area of 30 degrees parallel with the prevailing wind.

Fritschen, L. J., L. W. Gay, et al. (1985). “Eddy diffusivity and instrument resolution in relation to plant height. In The Forest-Atmosphere Interaction.” B. A. Hutchison and B. B. Hicks, eds. Dordrecht, Netherlands, D. Reidel Publ. Co.: 583-590.

Eddy diffusivities were computed from Bowen ratio-energy balance data for nine plant surfaces ranging from 0.5 to 30 m in height. The eddy diffusivities increased with plant height, surface roughness and atmospheric instability. Saltcedar, alfalfa, and Douglas fir had respective midday eddy diffusivities of 0.8, 0.08, and 8 m2s-1, when the evaporation rates ranged from 800 to 900 W m-2 over saltcedar and alfalfa, and 250 to 350 W m-2 over Douglas fir. Accompanying temperature gradients were about 0.20, 2.0 and 0.03 degrees C m-1 while the vapor pressure gradients were about 0.05, 0.4 and 0.0002 KPa m-1. Increased data recording resolution was required for Bowen ratio analysis over aerodynamically rough surfaces. If resistance thermometers with an output of 2 mV degrees C-1 are used, the effective recording resolution should be at least 0.02 mV over alfalfa, and 0.0006 mV over vegetation as rough as the Douglas fir stand.

Fuchs, M. and C. B. Tanner (1968). “Calibration and field test of soil heat flux plates.” Soil Science Society of America Proceedings 32(3): 326-328.

Soil heat flux plates were calibrated in the laboratory under steady-state conditions and then checked in the field vs. the soil temperature gradient thermal conductivity measurements of heat flux density. After correcting for the flux divergence in the layer of soil where the temperature gradient was measured, good agreement was obtained. The soil heat flux plates were constructed by winding approximately 120 turns of a 40 gauge (0.08 mm) constantan wire around a 7.6 cm x 2.5 cm x 0.14 cm microscopic slide at a 0.5 mm pitch.

Garratt, J. R. (1975). “Limitations of the eddy-correlation technique for the determination of turbulent fluxes near the surface.” Boundary-Layer Meteorology 8: 255-259.

Turbulent fluxes are measured using the eddy correlation technique. However, recent measurements by Desjardins and Lemon (1973) involved an underestimation of 40% or more due to poor sensor response during ‘high frequency’ fluctuations. Sensors with a time constant of 0.5 s appeared to be fast enough to detect most of the vertical carbon dioxide transfer of water vapor as long as the sensors were located at least one meter above the crop surface. But such sensors, when used so close to the surface, had poor response to high frequency turbulent fluctuations contributing to the vertical flux, resulting in a large fraction of the flux not being measured. When the Gill propeller anemometer is used as a sensor of vertical velocity fluctuation, it should be placed at heights greater than 5 m over land, and greater than 10 m over the sea. This keeps the high-frequency loss to less than 10% t during near-neutral and unstable conditions. If stable conditions exist, the situation is somewhat worse.

Garratt, J. R. (1984). "The measurement of evaporation by meteorological methods." Agricultural Water Management 8(1-3): 99-117.

The determination of evaporation (E) may be calculated by three methods based on energy budget and turbulent transfer formulae. The energy budget / Bowen ratio method involves relatively complex instruments to measure vertical differences of temperature and humidity in the air. With the exclusion of eddy covariance, it is potentially the most accurate method and should be applicable for crops and forests over a wild range of evaporation conditions. The residual energy budget method requires accurate estimates of atmospheric resistance and measurement of surface temperature. When the latter is available, this method is most reliable for surfaces of low roughness or in conditions of high evaporation. The combination method incorporates both energy budget and bulk relationships to eliminate surface temperature. This method is suitable for estimating daily or monthly evaporation using standard atmospheric observations. The eddy covariance method is not yet sufficiently developed to measure E reliably at the operational level over long periods, and over less-than-uniform terrain.

Gatewood, J. S., T. W. Robinson, et al. (1950). "Use of water by bottom-land vegetation in lower Safford Valley, Arizona." Water-supply Papers of the U.S. Geological Survey 1103: 1-210.

The principal phreatophytes in the lower Safford Valley along the Gila River in Arizona are saltcedar, baccharis (seepwillow), mesquite and cottonwood. Six methods of determining water use of phreatophytes (saltcedar, cottonwood, and seepwillow) were used: the tank method (lysimeters), transpiration-well method, seepage-run method, inflow-outflow method, chloride-increase method, and the lope-seepage method. Based on the results obtained by these methods, the total use of water by the vegetation during the twelve- month period (Sept. 1943-1944) was 28,000 acre- feet in a total of 9,303 acres along the 46-mile stretch of Gila River from Thatcher to Calva. Of the total water used, 23,000 acre-feet were derived from the ground-water reservoir, and the remainder from precipitation. Of the 23,000 acre-feet, more than 75% was used by saltcedar.

Gay, L. W. (1985). "Evapotranspiration from saltcedar along the Lower Colorado River." U.S. Forest Service General Technical Reports RM-120: 171-174.

Evapotranspiration (ET) was measured in a dense stand of saltcedar on the Lower Colorado River in Arizona using the Bowen ratio. The primary emphasis of this paper was on the development of a reliable system to measure ET, modified from the Bowen ratio. A generator-powered BREB system consisted of a set of specialized sensors, a data acquisition system, and a microcomputer. The field sensors were linked by long (80 m) cables. The key sensors were unique psychrometers which combined a ceramic wet bulb element, high output resistance thermometers and a new signal circuit to yield exceptionally precise measurements of humidity and temperature. Consistent, reliable results of ET were obtained using this system. It was felt that an estimate of 1700-1750 mm yearly ET was reasonable for the dense stand of saltcedar.

Gay, L. W. (1986). "Water use by saltcedar in an arid environment." Water Forum '86, Long Beach, California, New York. American Society of Civil Engineers, v.2 (8 pp.)

Evapotranspiration (ET) measurements were estimated from a dense stand of saltcedar along the lower Colorado River in Arizona, using a portable, computerized Bowen ratio measurement system. ET ranged from about 2 mm per day in the spring and fall up to 13 mm per day in mid-summer. Water use at night was less than 0.6 mm per day. The total ET for the growing season (March 23-November 11) was estimated to be 1680 mm per year including 42 mm of summer precipitation. Potential evapotranspiration (PET) estimates have been calculated from climatic data by various researchers but results vary in complexity and consistency. A simple net radiation model and the more complex Penman model can be used to estimate PET but seemed to perform poorly in the warm, arid conditions of southwestern Arizona.

Gay, L. W. (1988). “A portable Bowen ratio system for ET measurements. Planning now for irrigation and drainage in the 21st century; proceedings of a conference.” Lincoln, Nebraska, American Society of Civil Engineers: 625-632.

The AZET system was developed to measure evapotranspiration (ET) in arid zone environments, using the Bowen ratio model. The AZET sensor package consisted of two psychrometers, an exchange mast, cables, supports, and various standard sensors. It could be used with any data system that had sufficient resolution and a software-controlled actuator or switch. It used unique, ceramic wick psychrometers that were interchanged between readings. Sensors were sampled with a high quality data logger under the control of a microcomputer. Details of each instrument of the AZET system were described in this paper. A field test on alfalfa in Arizona provided ET measurements using this system. Agreement between latent energy estimated by the AZET system and by two other ET measurement methods was established. The AZET system cost $8,000. This system demonstrated excellent precision and the Bowen ratio model showed reasonable agreement with other methods for measuring ET.

Gay, L. W. (1993). “Evaporation measurements for catchment scale water balances.” Proceedings of the International Seminar of Watershed Management, Hermosillo, Sonora, Mexico, Universidad de Sonora-University of Arizona: 68-86.

The water budget concept is simple: gains of water minus the losses of water are equal to the change in storage within the boundaries of the region being examined. As the principle of conservation of mass, evapotranspiration (ET) can be calculated as a residual in the water budget. This concept has often been applied to water catchments, but results are not always reliable. As errors in each component occur, they can become large on a catchment scale. Two micrometeorological methods, the Bowen ratio and eddy correlation, offer the most promising alternatives to the water budget technique for measuring ET. Despite the increase in accuracy of the instrumentation for measuring ET, only two studies have been done on the catchment scale, possibly due to the difficulties of operating surface energy flux stations for extended periods.

Gay, L. W. (1998). "Evapotranspiration extremes for irrigated crops in the Arizona desert." Proceedings of Special Symposium on Hydrology, Phoenix, 1998. Boston, American Meteorological Society: Section P2.21 (2 pp.)

Evapotranspiration (ET) from irrigated alfalfa, cotton, and winter wheat were investigated in southern Arizona from 1980-1989. The Arizona Bowen ratio system was used to measure ET. A comparison of this system against eddy correlation-energy balance and lysimetric systems showed a good agreement for data obtained. The maximum ET values observed were substantial and defined the large values expected in southern Arizona. Of alfalfa ET values collected for 76 days, only 14 days exceeded 10 mm per day. Of those, only 3 exceeded 11 mm per day, with one exceeding 12 mm (12.7 mm on a very windy June 13th). Cotton ET exceeded 10 mm per day only three times with a maximum of 10.8 mm on June 18th. Winter wheat growth patterns occurred before the maximum solar energy period. ET values were collected only 17 of 155 days the summer and only one day exceeded 10 mm (10.6 mm on the windy day of May 2nd). Only four other days (in April) exceeded ET values of 9 mm per day. Observed maximums in southern Arizona substantially exceed available energy and can be maintained only by strong advection contributions of as much as 50% from the dry desert surroundings.

Gay, L. W. (1998). "Observed limits on moist-site evapotranspiration in the Arizona desert." Proceedings of Special Symposium on Hydrology, Phoenix, 1998. Boston, American Meteorological Society: Section 1.17 (2 pp.)

Evapotranspiration (ET) measurements were made on saltcedar, winter wheat, cotton, and alfalfa crops in southern Arizona using the Arizona Bowen ratio system. Seasonal water use curves were defined for saltcedar and each of the irrigated crops. Water use by saltcedar began with bud burst in early April, reaching a peak of about 11 mm per day near the summer solstice. Yearly use was about 1750 mm on the Colorado River floodplain with the water table at about 3 m. Winter wheat used irrigation water about the first of the year, reaching maximum ET rates of about 8 mm per day in late April. This crop used about 650 mm over its spring season growth cycle. Alfalfa grows year-round in Arizona. Maximum ET rates were about 9 mm per day in mid-summer. It would consume about 2000 mm per year of irrigation water if effects of harvesting would be ignored. Cotton consumed about 1000 mm per year from early April to fall harvest. Peak water use rates reached 9 mm per day in early August. Results indicated that water use of moist-site vegetation in the desert environment is closely linked to the seasonal availability of solar radiation. Data suggested that moist-site vegetation consumed a constant fraction of solar radiation and that this fraction can be approximated.

Gay, L. W. (1998). "Record rates of evapotranspiration from moist-site forests in the Arizona desert." Proceedings of Special Symposium on Hydrology, Phoenix, 1998. Boston, American Meteorological Society: Section P2.22 (2 pp.)

Evapotranspiration (ET) measurements from forest vegetation tend to show only modest rates of water loss. However, ET measurements over a vast saltcedar thicket on the Colorado River floodplain in western Arizona and over an irrigated pecan orchard in central Arizona demonstrated that trees adapted to moist conditions transpire at very rapid rates when grown in warm, arid climates. In the saltcedar thicket, in only four of the nine days of maximum solar radiation did ET exceed 10 mm per day; two of them exceeded 12 mm. Higher values were always associated with wind; lower values with cloud effects on solar radiation. In the pecan orchard, 22 days of maximum solar radiation were measured for ET rates. Eight days exceeded 10 mm, three of them at 11.8, 11.2. and 11.1 mm. The lower daily values were thought to result from overdue irrigation and from generally lower winds. Higher values of ET were observed more frequently over the rough-canopied, moist-site forest vegetation in this arid region. Rough canopies are more efficient in extracting sensible energy from the air, but results indicated that there was a limit of about 12 mm per day.

Gay, L. W. and L. J. Fritschen (1979). "An energy budget analysis of water use by saltcedar." Water Resources Research 15(6): 1589-1592.

Evapotranspiration (ET) of a stand of saltcedar *(Tamarix chinensis)* in the Rio Grande floodplain of central New Mexico was estimated using the Bowen ratio. Estimates of water use were made during the hot, dry summer weather; ET comparisons were measured at two different locations within the same stand; and ET comparisons over natural stands were compared with results obtained from four constant-level lysimeters. The mean ET for five consecutive days (June 14-18, 1977) was 8.2 mm per day by the Bowen ratio and 7.9 mm per day by the lysimeters. Vegetation on the lysimeters and at the Bowen ratio sites differed in density and vigor. Given these differences, the agreement between methods is judged excellent.

Gay, L. W. and R. K. Hartman (1982). "ET measurements over riparian saltcedar of the Colorado River." Hydrology and Water Resources in Arizona and the Southwest 12: 9-15.

Saltcedar evapotranspiration (ET) from a stand on the Colorado River floodplain in California was measured throughout the growing season by a series of Bowen ratio energy budget measurements in 1980 and 1981. The water table depth was about 3 m during the two summers. Daily ET totals ranged from 2.9 mm per day in early April up to 11.0 mm per day in late June, dropping to 1.8 mm per day in late October. The highest single day total of ET was 12.7 mm on June 18, 1981. The mid-summer ET rates from this site were substantial and ranked 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) was somewhat lower than prior estimates of up to 2100 mm per year.

Gay, L. W. and T. W. Sammis (1977). "Estimating phreatophyte transpiration." Hydrology and Water Resources in Arizona and the Southwest 7: 133-139.

Phreatophyte (saltcedar and mesquite) evapotranspiration on the Colorado River floodplain in western Arizona was evaluated under hot, dry, midsummer weather conditions. A simple transpiration model used related transpiration to the vapor pressure deficit of the air to the area and diffusion resistance of the transpiring foliage. There are no independent transpiration measurements for verification of the results. On a relative basis, however, mesquite (*Prospopis* sp.) transpired more rapidly per unit of leaf area than saltcedar (*Tamarix chinensis*). Stomatal resistance was the key factor controlling the transfer of water between the phreatophytes and the atmosphere. A simple leaf diffusion model gave reasonable estimates of transpiration, easily obtained with a porometer. Transpiration rates ranged from 0.5 - 2.78 micrograms per centimeter squared per second per unit of leaf area in saltcedar, and from 1.2 - 11.2 micrograms per centimeter squared per second in mesquite.

Gay, L. W., R. Vogt, et al. (1996). "The May-October energy budget of a Scots pine plantation at Hartheim, Germany." Theoretical and Applied Climatology 53(1): 79-94.

The energy budget for a Scots pine plantation in Germany was estimated for a 157-day period (May 11 - Oct. 14, 1992), using net radiometers and soil heat flux discs. Sensible heat exchange between the canopy and atmosphere was measured with two 'One-Propeller Eddy Correlation' (OPEC) systems.

Net radiation, change in thermal storage, and sensible heat flux were verified by independent measurements on May 11-12 and again on Sept. 10-29. The sensible heat estimates from the two OPEC sensor sets were in close agreement throughout the summer, and in excellent agreement with sonic eddy correlation systems during May and September. After taking dew into account, estimates of OPEC evapotranspiration totaled 358 mm over the 5.1-month period, which was close to an ET estimate of 328 mm from a hydrologic water balance. An observed decrease in forest ET in July and August was associated with low rainfall and an increased soil water deficit.

Gay, L. W., R. Vogt, et al. (1996). "Flux agreement above a Scots pine plantation." Theoretical and Applied Climatology 53(1): 33-48.

The surface energy exchange of 12 m high Scots pine plantation was measured during May 11-22, 1992 at Hartheim, Germany, using several methods. Net radiation and rate of thermal storage were measured with conventional net radiometers, soil heat flux discs, and temperature-based storage models. The turbulent fluxes were obtained with an interchanging Bowen ratio energy budget systems, two one-propeller eddy correlation (OPEC) systems, a one-dimensional sonic eddy correlation system (SEC) at 15 m, all on one 'low' tower. A 3-dimensionnal sonic eddy correlation system (SEC) was also placed on the 'high' tower at 22 m, approximately 46 m distant from the 'low tower.' Closure of turbulent fluxes from the two SEC systems was around 80% for daytime and 30% for the night. Turbulent fluxes on the low tower from OPEC system 2 and the adjacent SEC system 3 were in reasonable agreement, while the Bower ration system appeared to overestimate sensible heat and underestimate latent heat. Using measurements from OPEC and SEC on the high tower, both were lower. The turbulent flux measurements tended to converge, but the data had unexplained differences between days, between systems, and between locations.

Glenn, E. P. (1987). "Relationship between cation accumulation and water content of salt-tolerant grasses and a sedge." Plant, Cell and Environment 10(3): 205-212.

Twenty-four species of salt-tolerant grasses, including two species of saltgrass *(Distichlis spicata* and *D. palmeri)*, and a sedge were grown at three salinities in a controlled-environment greenhouse in Tucson, Arizona. They were measured for growth rate, ash content, water content, and cations (sodium, potassium, magnesium, and calcium). Saltgrass and 12 other grass species survived up to the highest salt treatment (540 mol per cubic meter of sodium chloride). These were designated as halophytes. Eleven species survived up to 180 mol per cubic meter sodium chloride; these were designated as salt-tolerant glycophytes. All species appeared to use sodium accumulation and loss of water as the main means of osmotic adjustment. The osmolality of the cell sap was measured directly by the vapor pressure method and compared to calculated values based on sodium, potassium, and water contents. Results indicate that grasses coordinate sodium uptake and water loss to maintain a constant osmotic potential gradient to salinity. Among the grasses, water loss seemed more important than sodium uptake.

Glenn, E., R. Tanner, et al. (1998). "Growth rates, salt tolerance and water use characteristics of native and invasive riparian plants from the delta of the Colorado River, Mexico." Journal of Arid Environments 40(3): 281-294.

Six riparian plants, pickleweed (*Allenrolfea occidentalis*), saltcedar (*Tamarix ramosissima*), arrow weed (*Pluchea sericea*), seepwillow (*Baccharis salicifolia*), willow (*Salix gooddingii*), and cottonwood (*Populus fremonti*), representing native and exotic species from the Colorado River delta in the Sonoran Desert of Mexico, were tested for salt tolerance and water use characteristics in a greenhouse study in Tucson, Arizona. Contrary to some previous reports, saltcedar did not have unusually high water use compared to the other species.

Glenn, E., T. L. Thompson, et al. (1995). "Effects of salinity on growth and evapotranspiration of *Typha domingensis* Pers." Aquatic Botany 52(1/2): 75-91.

The interactions between salinity, growth, and evapotranspiration (ET) were studied for cattails *(Typha domingensis)* under greenhouse conditions in Cienega de Santa Clara, a coastal desert marsh of the Colorado River delta, Mexico. Salinity imposed severe constraints on growth and distribution of the cattails. ET decreased with salinity in proportion to growth reduction. In the Cienega, *Typha domingensis* was found only in water of 5-8 ppt. or less. When inflow water was 3.2 ppt, cattail ET was estimated to be 1.3 times pan evaporation, whereas when inflow water was 3.2 ppt, estimated ET times pan evaporation was only .07. Table 1 gives saltgrass associated with a salinity factor of 0.8-5 ppt. The base rate of *Typha* ET was 15 mm per day. The mean annual rate was calculated to be 1.94 m per year. *Typha* is at the low end of salt tolerance and is already under salinity stress in the Cienega at 6 ppt. Unlike salt marsh genera such as saltgrass *(Distichlis, Spartina, Aelluropus, Paspalum* and *Puccinellia)*, which survived in full-strength seawater, cattail mortality occurred on only half-strength seawater.

Groenveld, D. P. and D. Or (1994). "Water table induced shrub-herbaceous ecotone: hydrologic management implications." Water Resources Bulletin 30(5): 911-920.

Environmental factors were studied across a shrub-herbaceous ecotone on a sloping site underlain by shallow groundwater on the arid floor of Owens Valley, California. Dominant plant species were salt rabbitbrush *(Chrysothamnus nauseosus)* and saltgrass *(Distichlis spicata).* Historic air photographs were analyzed, and soil properties, water table levels, and vegetative cover were measured at discrete sample points, apportioned on both sides of the ecotone. Land management practices and fire were ruled out as causal factors for the ecotone, which remained stable through a 45-year period of air photo records. This ecotone was located where the water table depth fluctuated periodically between 0.8 and 1.2 m; deeper water tables favored shrub cover while shallower depths favored meadow (saltgrass) vegetation. Shrub exclusion occurred at an average water table of about 1 m, confirming that saltgrass growth increases in vigor as the water table depths approach the surface, growing luxuriantly where the water table is 1.2 m. Water table depth, found to be the single environmental variable that changed across the ecotone, corresponds to a general one-dimensional environmental gradient. At the ecotone, the combined cover of shrubs and grasses was greater than on either side, demonstrating that conditions at the ecotone are favorable for both species.

Hagemeyer, J. and Y. Waisell (1989). "Influence of NaCl, $Cd(NO_3)_2$ and air humidity on transpiration of *Tamarix aphylla*." Physiologica Plantarum 75(2): 280-284.

Saltcedar plants grown in hydroponics were measured for sodium chloride- and cadmium nitrate-stress. Transpiration rates were negatively correlated with the relative humidity of ambient air at all sodium chloride concentrations. Low and intermediate concentrations of cadmium^{2+} (45 and 90 micromolar, respectively) in the medium caused an increase in transpiration rates, especially evident at low levels of relative humidity. At 180 micromolars cadmium^{2+}, transpiration rated dropped, probably as a result of root damage due to cadmium toxicity. The transpiration behavior of saltcedar indicated that the effect of water vapor pressure (present as relative humidity) on the degree of stomatal opening is small. Under conditions of ample water supply, transpiration follows the evaporative demand of the ambient air and is influenced by water uptake capacity of the root system as well as by other environmental factors, such as light.

Hagemeyer, J. and Y. Waisel (1990). “Phase-shift and memorization of the circadian rhythm of transpiration of *Tamarix aphylla*.” Experientia 46(8): 876-877.

Circadian rhythm of transpiration in saltcedar seemed to be governed by two distinct components: an externally induced one initiated by the ‘light on’ signal and an endogenous clock, whose memorization of the period length is independent of the instant environmental signal (light). Experiments in a controlled environment were conducted using a twelve shift of light and darkness, then continuous light, followed by continuous dark. A free-running rhythm of transpiration was exhibited by the plants under continuous light, occurring at similar time intervals after the ‘light on’ signal indicating an endogenous rhythm of the plants. The clock allows the plant to open its stomata just at daybreak in order to access the available humidity in the cool morning, and then to close in the afternoon to reduce water loss.

Hansen, D. J., P. Dayanandan, et al. (1976). “Ecological adaptations of salt marsh grass, *Distichlis spicata* (Gramineae), and environmental factors affecting its growth and distribution.” American Journal of Botany 63(5): 635-650.

Saltgrass is an important pioneer plant in early stages of succession. In salt marshes of southern Utah, saltgrass contributes to a hummock-building process that favors localized removal of salt by capillary action and evaporation. The epidermis of saltgrass contains salt glands that are active in the extrusion of salt. In laboratory tests, maximum growth for saltgrass was obtained at 15,000 ppm soluble salts in nutrient solution cultures. Comparable concentrations of salts occurred in soils from which the plants were taken. Nearly equal concentrations of sodium and potassium were found in plant tissue where growth conditions were optimal; such a ratio was maintained during most of the growing season. In the field, the greatest amount of growth took place when temperatures were cool and soil moisture high. During mid-summer, crude protein in the plant decreased as air temperature rose. Relative humidity reached 100% every night except for six days during the growing season. During periods of high salt and water stress, morphological and anatomical adaptations of the stomata, salt glands, and trichomes of saltgrass were evidenced.

Harcum, J. B. and J. C. Loftis (1987). "Design and evaluation of regional weather monitoring networks." Transactions of the ASAE (American Society of Agricultural Engineers) 30(6): 1673-1683.

A weather-monitoring network frequently supports irrigation scheduling on a regional level to estimate reference evapotranspiration (ET). The estimation error for ET can be used as a quantitative basis for designing new networks or modifying existing networks. The Kalman filtering provides a means for both estimating ET in multi-station networks and quantifying the estimation error. Application of the Kalman filtering approach to network design and evaluation was illustrated using an existing network (PROFS) in Colorado. This procedure was used to develop contour maps of estimation error for proposed network configurations. Then the maps are used to evaluate adequacy of station density and locations. The error of ET estimates can be quantified based upon the location and adequacy of the weather stations. The stochastic formulae of the Kalman filtering method can identify the optimum location of weather stations in relation to ET estimation.

Harcum, J. B. and J. C. Loftis (1987). "Spatial interpolation of Penman evapotranspiration." Transactions of the ASAE (American Society of Agricultural Engineers) 30(1): 129-136.

It is often necessary to estimate reference evapotranspiration for irrigation scheduling at points located some distance from a weather station. For areas served by weather station networks, interpolation may be done using the monitoring locations. The use of Kalman filtering offers a stochastic process to reduce error of evapotranspiration estimates using a weather-monitoring network. The filter was found to be an acceptable algorithm for spatial interpolation of reference evapotranspiration based on diagnostic checks, lowest sum of squared error, and minimum variance estimates. Two weather-monitoring networks (PROFS in Colorado and AGNET in Nebraska) were used as historical climatic data sets to test the validity of Kalman filtering algorithm to estimate reference evapotranspiration.

Hargreaves, G. H. (1994). "Defining and using reference evapotranspiration." Journal of Irrigation and Drainage Engineering 120(6): 1132-1139.

Values of reference evapotranspiration (ET_0) are used with crop coefficients (KC). Many methods are used for estimating ET_0 including different versions of the Penman combination equation. Some international organizations would like to promote the use of a single equation or method for estimating ET_0 to avoid confusion caused by the current diversity. Due to its simplicity and the accuracy of estimates, the equation proposed by Hargreaves and others (1985) is recommended for general use. The Food and Agriculture Organization has considered using the Penman-Monteith method as the standard method for computing ET_0. The Hargreaves and others (1985) equation was selected as the one with results closest to the classic Penman equation, using only measured values of maximum and minimum temperatures. Crop coefficients need to be standardized and made appropriate for use with the reference method selected for calculating ET_0.

Hargreaves, G. H. and Z. A. Samani (1982). "Estimating potential evapotranspiration." Journal of the Irrigation and Drainage Division ASCE (American Society of Civil Engineers) 108(IR3): 225-230.

A method for estimating potential evapotranspiration (ETp) is proposed. It requires maximum and minimum temperatures and a general knowledge of the approximate percentages of relative humidity for the time periods used. Four methods for estimating ETp were compared, the pan evaporation, Hargreaves, Hensen-Haise, and Blaney-Criddle methods. Of these, the Class A pan sited in an irrigated grass pasture and the product of temperature in degrees Fahrenheit times solar radiation at the surface provide the highest coefficients of determination and the lowest standard deviations.

Hashmi, M. A. and L. A. Garcia (1998). "Spatial and temporal errors in estimating regional evapotranspiration." Journal of Irrigation and Drainage Engineering 124(2): 108-114.

Computations of regional crop evapotranspiration (ET), the prime variable in estimating irrigation demand, have largely ignored the spatial and temporal variability of ET parameters, thus introducing errors. A methodology has been developed to estimate regional ET while considering the spatial and temporal variability of parameters. Spatial databases were developed for agricultural land-use, relevant climatic parameters, and topographic data using geographic information systems (GIS). The Cache la Poudre Basin in Colorado was selected as the study area due to the availability of field verified land-use survey data. A spatial simulation ET model (GISETMA) was used to develop a baseline estimation of regional ET incorporating analytical GIS functions of map algebra and map overlay to calculate ET for each field in the system and for each day of the growing season. Various scenarios were developed and compared to the baseline scenario. Time-step errors were the largest (i.e., when monthly mean values are used for daily ET estimates). The standard deviation is 60.4%. Errors due to land-use classification were

40%. The range of errors implies that maximum benefit can be achieved if the 'time-step' is reduced. This fact recognized that daily ET estimates are crucial calculations in order to reduce the error rates of regional ET measures.

Hem, J. D. (1967). "Composition of saline residues on leaves and stems of saltcedar *(Tamarix pentandra* Pallas)." Professional Papers of the U.S. Geological Survey 491-C: 1-9.

Saltcedar leaves and stems collected along the Gila River in Arizona and various sites along the Rio Grande and Pecos River basins of New Mexico were analyzed for inorganic ions. The total contents of calcium, magnesium, sulfate, and chloride in the leaves ranged between 5-15% of their dry weight. From a few tenths of a percent to more than 3% of the dry weight of the leaves consisted of inorganic ions, which could be washed off by rainfall. In most samples, the predominant inorganic anion was sulfate. Leaves obtained from trees growing where ground water had a high salinity were highest in sodium and chloride content. The total solute content of leaves was not closely related to composition of the ground water in the area where the plants were growing. But where the available water was lower in dissolved solids, the solute content of the leaves was lower. The amounts and composition of inorganic solutes present in saltcedar leaves were influenced by the composition of water available to the plant, the time of year, the rates of growth and transpiration before sampling, and the amount and frequency of antecedent rainfall.

Hibbert, A. R. (1997). "Potential for augmenting flow of the Colorado River by vegetation management." Proceedings of the Arizona Watershed Symposium 21(10): 16-21.

The management of riparian vegetation and snow to reduce evapotranspiration seems to be one way to augment water in the Colorado River basin. Only 16% of the basin supports vegetation that, if altered in various ways, might be expected to yield additional stream flow. If precipitation averages less than 18 inches per year, there is no opportunity to reduce transpiration since one cover type is about as efficient as another in extracting available water.

Hicks, B. B. (1972). “Propeller anemometers as sensors of atmospheric turbulence.” Boundary-Layer Meteorology 3: 214-228.

Propeller anemometers used as sensors of atmospheric turbulence were found to give outputs deviating from the desired cosine relationship by an amount that varied with wind speed. Their output per unit wind speed was a function of the angle of attack. Calibration factors differed by as much as 30% when they were used as sensors of the vertical or horizontal cross-wind components since they were originally calibrated in a normal wind-tunnel environment (in which the wind velocity is parallel to the anemometer shaft). When they are used in the eddy correlation equipment, it is best to vane-mount the horizontal sensor to ensure the appropriate calibration factor. The response lengths of propeller anemometers also vary with angle of attack. Due to their limited response, these anemometers underestimate the Reynolds stress near the surface. The extent of the loss is about 8% when the anemometers are placed at a height of 5 m. Operation at a greater height would allow this error to be reduced.

Horst, T. W. (1973). “Spectral transfer functions for a three-component sonic anemometer.” Journal of Applied Meteorology 12: 1072-1075.

Sonic anemometers measure the speed of the wind by transmitting sound waves between a pair of acoustic transducers. The transfer functions, which describe the effect of line averaging and path separation on the response of a three-component sonic anemometer, have been computed specifically for the Kaijo-Denki PAT 311. These computations account for the two parallel paths that compose each measurement axis and the vertical separation of the two horizontal axes. There is only a minor additional attenuation of response for the vertical wind component due to the measurement axis being composed of two paths rather than one. However, differences between the horizontal transfer functions calculated using this anemometer and earlier two-component sonic anemometers are significant and could be important for correcting sonic spectra in the inertial subrange.

Horton, J. S. (1964). "Notes on the introduction of deciduous tamarisk." Research Notes of the U.S. Forest Service RM-16: 1-7.

A brief history of the introduction of saltcedar (*Tamarix* spp.) into the United States is presented. It was listed as an ornamental plant in the early 1800s in several nursery catalogs. Saltcedar apparently was not naturalized in the Southwest during the 1850s because none of the U.S. Government explorers reported the genus. In 1868, the U.S. Dept. of Agriculture began growing species. But by 1903, saltcedar was common along roadsides in waste places. A table of herbarium species collected prior to 1920 gives the early 1870s specimens with collection notes. Horton lists several species although only one species is currently recognized, *Tamarix ramosissima* - a species not recognized in Horton's list.

Hughes, W. C. (1972). "Simulation of salt cedar evapo-transpiration." Journal of the Irrigation and Drainage Division (ASCE) 98(IR4): 533-542.

Saltcedar water consumption was measured from the Bernardo site, New Mexico, in the middle Rio Grande Valley. Measurements were made using a modified Penman equation. This equation required three input variables: 1) the surface albedo, 2) the surface roughness height and 3) the surface diffusion (or stomatal) resistance. Of the three dependent variables, stomatal resistance was found to be the most critical because the equation is quite sensitive to small variations. It showed a definite seasonal distribution and was found to be related indirectly to temperature (in the range of 50-75 degrees F) and directly with wind speed. In contrast to earlier findings, there was no apparent difference between consumptive use with water depths set at 3' and 5'; at least during summer months when plant transpiration was high. In early spring and late fall, consumptive use varied directly with water depth due largely to differences in soil evaporation.

Jackman, J. A. and M. K. Harris (1988). "Managing the pecan nut casebearer by predicting timing of insecticide spraying using a computer program." Proceedings of the Western Pecan Conference 22: 15-25.

The pecan nut casebearer *(Acrobasis nuxvorella)* is an important pecan insect pest in Texas. It overwinters as larva in a cocoon attached to a dormant pecan bud, becoming active coincident with bud break of the pecan in spring. The decision to spray the pecan orchard with an insecticide is dependent upon the development of the pecan bud break. This insect attacks nuts late in years with cold springs and early in years with warm springs, since the insect (PNC) develops faster in a warm temperature and slower when it is cooler. A degree-day model was developed to assist in determining when the best time for spraying should occur in a particular place in a given year. Three variables must be determined: the base temperature, the starting date, and the tally of degree days to a particular event. The base temperature is 38 degrees F. Degree days are determined by calculating the average temperature each day after the PNC becomes active and subtracting the base temperature. The start date is determined by examining bud break for the orchard to 50% and then backing up 10 days. Since each year is different, the start day must be recalculated each year.

Jensen, M. D., R. D. Burman, et al., Eds. (1990). Evapotranspiration and Irrigation Water Requirements. ASCE Manuals and Reports on Engineering Practice no.70. New York, American Society of Civil Engineers. 332 pp.

This work is a basic summation of the role of evapotranspiration and irrigation waters. Oriented toward crop irrigation, it nonetheless defines all major terms for estimating crop water requirements. The manual is expected to serve as a valuable reference for specialists working in agrometeorology, hydrology, and water planning and management. It was designed as a source of basic information in the field. Equations of calculating evapotranspiration (ET) as part of the energy exchange are presented, including a summary of methods to estimate solar radiation and long-wave radiation as part of the heat balance. Detailed formulae are presented as relevant to each aspect of the evapotranspiration process.

Kaimal, J. C. (1979). "Sonic anemometer measurement of atmospheric turbulence." Proceedings of the Dynamic Flow Conference 1978 on Dynamic Measurements in Unsteady Flows. Alpen aan den Rijn, the Netherlands, Sijthoff and Noordhoff: 551-565.

The sonic anemometer was developed to measure atmospheric turbulence and its role in transporting momentum, heat, water vapor, and other constituents within the layers close to the ground. Since the sonic anemometer has no moving parts to come into dynamic equilibrium with the atmospheric flow, its frequency response is limited only through the attenuation in the spatial response imposed by line averaging along the path. It responds linearly to wind velocity and is relatively fee of contamination for other velocity components or temperature. The author's orthogonal, three-dimensional array was used on the Boulder Atmospheric Observatory's 300 m tower. It was designed for wider azimuth coverage of wind directions than had been possible in earlier versions. The basic principal of the sonic anemometer is to measure wind velocity components from arrival times (or phase) of acoustic signals transmitted in opposite directions across a fixed path. A single-axis, dual path sonic anemometer is illustrated. The paths are parallel and closely spaced to minimize errors arising from velocity and temperature differences between the two paths. This instrument has a rapid response, linear output, and stable calibration. It provided high-quality turbulence data in a number of field experiments during the last decade.

Kartesz, J. T. (1994). A Synonymized Checklist of the Vascular Flora of the United States, Canada, and Greenland. Portland, Oregon, Timber Press. 2 v.

A taxonomic list of all vascular plants in the United States, Canada, and Greenland is presented alphabetically by family. Under *Tamarix* (saltcedar), nine species are listed: *T. africana*, *T. aphylla* (syn. *T. articulata*), *T. aralensis*, *T. carariensis, T. chinensis (*syn. *T. pentandra), T. gallica, T. parviflora (*syn *T. tetrandra), T. ramosissima*, and *T. tetragyna*.

Khelifi, M., R. B. Brown, et al. (1993). "Prediction of temperature, wind speed, and actual vapor pressure at different heights above the crop canopy." Transactions of the ASAE (American Society of Agricultural Engineers) 36(6): 1755-1760.

The movement of chemicals away from the intended target under the effect of weather factors (drift hazard) is a serious environmental problem. A simple model for the prediction of air temperature, wind speed, and vapor pressure at different heights above the crop canopy was developed to minimize the drift. This model was based on the incoming short-wave radiation, soil and crop types, crop height, relative humidity, windspeed, and air temperature measured in the field at heights of 4 and 0.8 m, respectively. Using this model, predicted values for wind speed were closer to the measured ones than those for air temperature. Results of the study showed that the approximations made throughout the development of the model were reasonable. The model was tested using meteorological data collected at the Elora Research Station, University of Guelph and conducted over a short grass crop from late July to late September 1990.

Kohsiek, W. (1984). "Inertial subrange correlation between temperature and humidity fluctuations in the unstable surface layer above vegetated terrains." Boundary-Layer Meteorology 29: 211-223.

This study focused on the effect of sensor separation on the cospectrum of humidity and temperature. Observations of the temperature-humidity cospectrum and correlation spectrum were made with a cold platinum wire and a Ly-alpha hygrometer at 3, 7, and 10 meters above vegetated surfaces, primarily grass, during unstable atmospheric conditions in August and September 1983 near Eindhoven, Netherlands. It was found that a separation (delta) between the temperature and humidity sensors caused a drop-off of the correlation spectrum at wave numbers less than 0.3 over delta. The observed drop-off followed the theoretical one reasonably well. Measurements made with the temperature sensor placed in the center of the Ly-alpha gap revealed a f-5/3 dependence of the temperature-humidity cospectrum in the inertial subrange up to frequencies of 20 hertz (Hz). The drop-off at higher frequencies is thought to be caused by limitations inherent to the Ly-alpha humidiometer.

Konrad, S. L., L. W. Gay, et al. (1998). Temporal and spatial variability of evapotranspiration from irrigated alfalfa in the Arizona desert. Proceedings of the Special Symposium on Hydrology, Phoenix, 1998. Boston. American Meteorological Society: Section 2.24 (2 pp.)

This paper examined the variability of evapotranspiration (ET) in the southern Arizona desert, using an irrigated alfalfa crop as a reference baseline. The solar radiation/wind evapotranspiration (SWET) model used was based on the assumption that solar radiation and wind are the most important variables for estimating latent energy from alfalfa. The validity of the Bowen ratio system used to calculate SWET was confirmed by comparison to independent Bowen ratio, lysimeter, and eddy correlation systems from prior studies. Data for wind and solar radiation was obtained from the AZMET (Arizona Agricultural Meteorology network) of 21 weather stations that had 10 years (1987-1996) of data available. Temporal variability of mean daily ET was calculated using a single AZMET station, the University's Maricopa Agricultural Center. The 10-year mean is variable but the mean monthly ET is very smooth over the summer readings. Using an average of the 21 stations, the mean regional rate varies from 3.3 mm per day in December up to 9.1 mm in June. Spatial variability between the stations is quite small.

Kranjcec, J., J. M. Mahoney, et al. (1998). “The responses of three riparian cottonwood species to water table decline.” Forest Ecology and Management 110(1-3): 77-87.

Three species of cottonwood *(Populus deltoides; P. angustifolia, P. balsamifera)* were studied to determine the influence of the rate of water table decline upon their growth and propagation. Shoot cuttings were taken from specimens in Alberta and British Columbia and transplanted into rhizopods in a nursery in Alberta. Three rates of water table decline were applied: 0, 4, and 10 cm per day to each rhizopod. *Populus balsamifera* (balsam poplar) grew the fastest under all three treatments, followed by *Populus deltoides* (prairie cottonwood). Under the 10 cm per day treatment, *P. deltoides* grew as slowly as *P. angustifolia* (narrowleaf cottonwood). In all three species, shoot growth and apparent transpiration were progressively reduced as the water table declined. Conversely, root growth was promoted by the water table decline and root elongation was most rapid under the gradual 4 cm per day treatment. Under the decline of 10 cm per day, root elongation was insufficient for such abrupt treatment and some *P. angustifolia* and *P. deltoides* saplings died. This study demonstrated that tolerance to water table decline varied across cottonwood genotypes; *P. balsamifera* was the most vigorous. This genotype occurs in mountain regions where the water table depths often change abruptly as opposed to the more gradual changes on riparian floodplains where *P. deltoides* tended to grow.

Kuramoto, R. T. and D. E. Brest (1979). “Physiological response to salinity by four salt marsh plants.” Botanical Gazette 140(3): 295-298.

Water relations, rates of photosynthesis and respiration, and patterns of carbon dioxide fixation were studied in four salt marsh plants: *Spartina foliosa, Distichlis spicata, Salicornia europea* and *Batis maritima*. Water potential is a better indication of the water-absorbing capacity of plants than low osmotic potentials. Both were studied in the four plants, two grasses, and two succulents. Mean water potentials of all four species ranged from -29.82 to -42.20 atm. The phosphoenolpyruvate (PEP) carboxylase activity was higher in the grasses. Succulents lacked dark acidifications, and day/night tests of PEP carboxylase gave the same enzyme activity.

Luo, W. (1994). Calibrating the SCS Blaney-Criddle crop coefficients for the Middle Rio Grande basin, New Mexico. M.S. Thesis. Department of Civil and Geological Engineering, New Mexico State University, Las Cruces, New Mexico. 91 pp.

The Blaney-Criddle method has been used to estimate seasonal evapotranspiration (ET) of various crops. In New Mexico, the U.S. Bureau of Reclamation modified the original Blaney-Criddle equations by adding a climatic factor to estimate ET on a monthly basis. This study presented the calibrated SCS (Soil Conservation Service) Blaney-Criddle crop coefficients for phreatophytes and agricultural crops in the Middle Rio Grande basin, New Mexico. Among the phreatophytes, saltcedar, cottonwood, Russian olive, and saltgrass were measured for ET. Saltcedar ET ranged from 1.4 to 4.7 ft. Russian olive ET ranged from 1.5 to 9.5 ft depending upon volume density and plant age. Saltgrass ET ranged from 1.4 to 2.8 ft. Cottonwood ET data were not available for New Mexico, so data from California were introduced to develop consumptive use coefficients for New Mexico. Seasonal ET was estimated as 59 in. when the water table was 3 ft., and 55 in. when the water table was 4 ft.

Mahoney, J. M. and S. B. Rood (1998). "Streamflow requirements for cottonwood seedling recruitment - an integrative model." Wetlands 18(4): 634-645.

The 'recruitment box' is an integrative model that defines the stream stage patterns that enable successful establishment of riparian cottonwood seedlings. In western North American, seed dispersal generally occurs after annual peak river flows (flooding). The receding stream exposes moist sites upon which seeds land after transport by wind and water. Germination is rapid, and initial seedling establishment is often prolific, but most die due to subsequent drought stress since their root growth is insufficient to maintain contact with the receding zone of moisture. A capillary fringe of the riparian water table, often 30 to 40 cm above the water table itself, provides some seedlings with enough moisture to continue growth. The recruitment box model was consistent with dendrochronological interpretations, based on literature reports that moderated flood events, which had naturally occurred for cottonwood recruitment.

Massman, W. J. (1992). “Correcting errors associated with soil heat flux measurements and estimating soil thermal properties from soil temperature and heat flux plate data.” Agricultural and Forest Meteorology 59(3/4): 249-266.

A linear model of soil temperature and heat flux was used to show that errors in the measurements of soil heat flux by the combination method can occur whenever the mean time rate of temperature change of soil slab is estimated from a set of discrete temperature measurements. Uncertainties in the soil heat flux complicate the ability to close the energy balance. There remain about 5-10% uncertainties in both net radiation and the eddy correlation approach. Using the present methods of estimating soil heat flux, it seems reasonable to expect to close the energy balance equation on a 24-hr basis to 85% at worst and frequently much closer.

Miyamoto, S. (1983). “Consumptive water use of irrigated pecans.” Journal of the American Society of Horticultural Scientists 108(5): 676-681.

Consumptive water use of seven irrigated commercial pecan orchards of the Las Cruces-El Paso area was evaluated. Evapotranspiration (ET) loss was converted to crop coefficients by dividing with potential evaporation rates. Test trees (8 to 35 years old) with various sized trunk diameters (13-53 cm) were surface irrigated. Consumptive water use was dependent on tree size and planting density, with close-spaced, full-grown trees using 100-130 cm of water per season. Indications were that bud break of this pecan variety ‘Western’ does not occur until the mean daily temperature reaches about 15.5 degrees C (60 degrees F). Defoliation seemed to occur when a minimum temperature dropped to about -4 degrees C (25 degrees F). Actual water need in late September or October depends upon the nut maturity and the first freeze.

Monteith, J. L. (1965). “Evaporation and environment.” Symposia of the Society for Experimental Biology 19: 205-234.

A turgid leaf exposed to bright sunshine can transpire an amount of water several times its own weight. The path for the diffusion of water vapor from leaf cells to the free atmosphere is divided into two parts, one determined primarily by the size and distribution of stomata, and the other by wind speed and the aerodynamic properties of the plant surface. Diffusive resistances for single leaves and for plant communities were established from measurements in the laboratory and in the field. Local rates of evaporation at the surface can be estimated from net radiation and from temperature, humidity, and wind speed measured within the boundary layer. Equations are given for latent heat from temperature and vapor pressure. Leaf resistance using the time in which 1 cm^3 of air exchanges heat with 1 cm^3 of surface (ra) can be calculated. Wind speed can also be included in the calculation depending upon the geometry of the surface. Diffusion by atmospheric turbulence governs the processes of exchange between the atmosphere and the surface of a crop.

Monteith, J. L. (1981). "Evaporation and surface temperature." Quarterly Journal of the Royal Meteorological Society 107(451): 1-27.

When water evaporates at the interface between a wet surface and the atmosphere, the temperature at each point on the surface tends to an equilibrium value at which the local loss of latent heat is balanced by the net supply of heat by processes such as radiation, convection, and conduction. Penman in 1948 developed a formula to address the thermodynamic and aerodynamic aspects of evaporation. However, when determining evaporation of vegetative surfaces, the stomatal resistance (Rs) must be considered within the context of aerodynamic resistance (Ra) of the leaf. This physiological resistance of the leaf's surface must be calculated as part of the evapotranspiration formula.

Nichols, W. D., R. J. Laczniak, et al. (1997). "Estimated ground-water discharge by evapotranspiration, Ash Meadows area, Nye County, Nevada, 1994." Water-resources Investigations Reports of the U.S. Geological Survey 97-4025: 1-13.

Ground-water discharges from the regional ground water flow system underlying the eastern part of the Nevada Test Site and seeps into the Ash Meadows National Wildlife Refuge, south of the Test Site. The total spring discharge was estimated to be about 17,000 acre-feet per year. Previous studies estimated that about 10,500 acre-feet of this discharge were lost to evapotranspiration. A study was initiated in 1994 to provide a detailed field investigation of evapotranspiration. Results indicated that an estimated 13,100 acre-feet of ground water was evapotranspired from about 6,800 acres of saltgrass (*Distichlis spicata)* and wiregrass *(Juncus spp.)*. An additional 3,500 acre-feet may have been evapotranspired from open water and from about 1,460 acres of other areas of Ash Meadows in which studies have not yet been made. Discharge rates of 2.1 ft and 1.3 ft for saltgrass evapotranspiration are estimated.

Olson, T. E. and F. L. Knopf (1986). "Naturalization of Russian-olive in the western United States." Western Journal of Applied Forestry 1(3): 65-69.

Russian olive *(Elaeagnus angustifolia)* was introduced into the United States during Colonial times. It has become naturalized in the 17 western states bounded by the Dakotas, Nebraska, Kansas, Oklahoma, and Texas. This study determined the history of escapement and range extension from each of the western states. In New Mexico, it was observed along the Rio Grande from Albuquerque to El Paso, Texas. The heaviest concentration occurred from Española to Socorro where it is the dominant riparian tree species. It can also be found along the Pecos and San Juan Rivers, though in less density than along the Rio Grande. Postulation of the effects of the continued range extension of Russian olive include the overbank deposition, degradation of the river channel and decline in river stage level. Eventually a site may become a relative dry upland with Russian olive as the climax species. Its presence may also decrease suitability of the site for cottonwood germination.

Owen-Joyce, S. J. and S. L. Kimsey (1987). "Estimates of consumptive use and ground-water return flow using water budgets in Palo Verde Valley, California." Water-Resources Investigations Reports of the U.S. Geological Survey 87-4070: 1-50.

The Palo Verde Valley in California is an irrigated agricultural area. The plain is underlain by a shallow alluvial aquifer in conjunction with Colorado River and a network of irrigation ditches. These ditches control the direction of groundwater movement and the saturated thickness in the shallow aquifer. Annual water budgets were used to determine consumptive use by vegetation and groundwater return flow from 1981 to 1984. The movement of groundwater and the changes in groundwater storage did not significantly affect the computation of consumptive use by vegetation. Groundwater return flow was estimated to be 31,700 acre-feet in 1981, 24,000 acre-ft in 1982, 2,500 acre-ft in 1983 and 7,900 acre-ft in 1984. Year-to-year variations in the groundwater return flow indicated that 1) rising river stage within a year causes the groundwater to move toward the river, decreasing the area drained by the river, and 2) changes in crop types, especially when fields are left fallow, caused the largest changes in the groundwater return flow.

Owen-Joyce, S. J. and L. H. Raymond (1996). "An accounting system for water and consumptive use along the Colorado River, Hoover Dam to Mexico." Water Supply Papers of the U.S. Geological Survey 2407: 1-94.

The Lower Colorado River between the Hoover Dam and Mexico is the source of water for a large distribution system used to export water to agricultural and densely populated areas in adjacent states and for irrigation of agricultural lands along the river. The water budget that computed consumptive use by vegetation also included consumptive use by phreatophytes on the flood plain. Landsat MSS (satellite systems) resolutions proved insufficient for separating phreatophyte species from each other in mixed stands. Photographs and maps were used to complement satellite data. Phreatophytes were mainly saltcedar, cottonwood, willow, mesquite, arrow weed, Atriplex, inkweed, and creosote. Evapotranspiration for saltcedar was 8.5 ft followed by cottonwood and willow at 7 ft in 1986. Water consumption varied by stand - dense, medium, and sparse - and geographic location. In 1984, total evapotranspiration of phreatophytes in Arizona was 105,014 acre-feet; in California 88,015 acre-ft., on federal national wildlife refuges 74,330 acre-ft.

Penman, H. L. (1948). "Natural evaporation from open water, bare soil and grass." Proceedings of the Royal Society of London, Series A: Mathematical and Physical Sciences 193(1032): 120-146.

This work provides an opportunity to make theoretical estimates of evaporation rates from standard meteorological data, estimates that can be retrospective. Two requirements must be met to permit continued evaporation. There must be a supply of energy to provide the latent heat of vaporization, and there must be some mechanism for moving the vapor. A test site in Rothamsted, England provided the basic equipment for developing the formulae necessary to calculate evaporation rates on a vegetative surface, bare soil, and open water (catchments). These formulae were presented as part of the continuum of evaporation processes. Where all necessary measurements were made or values forecasted, reliable evaporation rates can be estimated regardless of surface evaporation.

Penman, H. L. (1963). "Vegetation and hydrology." Technical Communications of the Commonwealth Bureau of Soils (U.K.) 53: 1-124.

The hydrological cycle is the study of what happens to rain, snow, and minor forms of precipitation. This study was concerned with the part played by the surface ground cover in the disposal of rain. Evaporation is the upstroke of "rainfall," which provides water for re-precipitation on the surface from which the evaporation took place. Though the main action of vegetation is in providing a barrier or a channel for vertical transfers of energy and water, there are edge effects on horizontal movement that may be of local hydrological significance. The transpiration-ratio carries with it the idea that the transpiration rate is proportional to leaf area, but as the Leaf-area Index increase, the separation of leaves decrease and mutual interference becomes more effective. The rate of transpiration depends on conditions in the soil, in which root development and the availability and accessibility of water will be dominant, on the conducting characteristics of roots, stems and leaves for liquid water, and of the leaf epidermis for water vapor; and on the state of the ultimate sink for the vapor, that is, atmospheric humidity, ventilation, and turbulence.

Potter, K. W. and R. B. Lott (1997). Estimating evapotranspiration in natural and constructed groundwater dominated wetlands: traditional and geochemical approaches. Madison, Wisconsin, Water Resources Center, University of Wisconsin-Madison.

Evapotranspiration (ET) studies were conducted at adjoining natural and constructed wetlands in southwestern Wisconsin. Rates of ET were estimated from lysimeters and water table measurements. Results were compared to potential ET (PET) estimated by the Penman, Priestley-Taylor, and Thornthwaite methods, based on meteorological measurements made on site. Relative rates of ET were also estimated using solute and stable isotope investigation. Potential ET estimates did not predict significant differences between the natural and constructed wetlands. However, monthly Penman, Priestley-Taylor, and Thornthwaite estimates of PET differed as much as 30% at each site. Field ET rates estimated by lysimeter and water table methods exceeded the PET rate estimated by the Penman method. Water isotope (carbon-18 and hydrogen-2) and geochemical profiles collected at 3-week intervals during the growing season also demonstrated higher ET rates. The established, sedge-dominated natural wetland evapotranspired more water from the root zone than the grass-dominated constructed wetland. Results indicated that vegetation type must be accounted for if the assumption is made that wetland plants remove water at the potential rate.

Robinson, T. W. (1965). "Introduction, spread and areal extent of saltcedar *(Tamarix*) in the Western States." Professional papers of the U.S. Geological Survey 491-A: 1-12.

Saltcedar was introduced into the United States more than 100 years ago. This species in a high water-consuming, salt-tolerant shrub that escaped from cultivation and spread from one stream valley to another. Since 1930 it has expanded its range to 15 of the 17 Western States and is now a nuisance plant. A total area of growth has increased from an estimated 10,000 acres in 1920 to more than 900,000 acres in 1961. The consumptive waste of groundwater was estimated as 40-50,000 acre-feet in 1920, 3.5 million in 1961 and possibly 5 million by 1970. Its dense growth presents a barrier to flood flows, and thereby increases flood hazards and sediment deposition. Within the Rio Grande and Pecos rivers, substantial deposition of sediment is attributed to the dense saltcedar thickets.

Robinson, T. W. (1970). "Evapotranspiration by woody phreatophytes in the Humboldt River Valley near Winnemucca, Nevada." Professional Papers of the U.S. Geological Survey 491-D: 1-41.

Studies of water use of greasewood, rabbitbrush, willow, and wildrose were undertaken using evapotranspiration tanks at a Winnemucca, Nevada site. Evapotranspiration was computed as the sum of rainfall, soil-moisture depletion, and water supplied to the tanks during the growing season (April 1-October 20 from 1961-1967). Each species was affected by climatic conditions of which temperature was the most important. Water consumption by greasewood and rabbitbrush was only 2% of the total in April but 28% during the months of peak growth. More than two-thirds of the annual use occurred during June, July, and August. The annual use of water ranged widely over the study period, as the plants responded to insect or rabbit damage, boron toxicity, depth to the water level, and warmth and length of the growing seasons.

Roelle, J. E. and D. N. Gladwin (1999). "Establishment of woody riparian species from natural seedfall at a former gravel pit." Restoration Ecology 7(2): 183-192.

A former gravel pit in Ft. Collins, Colorado was used as a site for reclamation by trying to establish native riparian communities through natural seedfall. From 1994 to 1996, a series of annual drawdowns during the period of natural seedfall of plains cottonwood *(Populus deltoides)*, peachleaf willow *(Salix amygdaloides)* and sandbar willow *(Salix exigua)* were performed, thus providing the bare, moist substrate conducive to the establishment of these species. In the fall following establishment, frequency of occurrence on 0.5 square meter sample plots ranged from 8.6% to 50.6% for cottonwood, 15.9% to 22.0% for peachleaf willow, and 21.7% to 50.0% for sandbar willow. Concurrent establishment of the exotic saltcedar *(Tamarix ramosissima)* was a problem, but most seedlings were eradicated by reflooding the lower elevations of the annual drawdown each fall. At the end of the 3-year period, at least one of the three native riparian species survived on 41.1% of the plots while saltcedar was present only on 6.1%.

Sala, A., S. D. Smith, et al. (1996). "Water use by *Tamarix ramosissima* and associated phreatophytes in a Mojave Desert floodplain." Ecological Applications 6(3): 888-898.

Water use by tamarisk and three co-occurring phreatophytes (arrow weed, mesquite, and willow) was measured in the lower Virgin River floodplain on the Mojave Desert, Nevada, using the stem-heat-balance method. During the 1993 growing season, measurements were conducted on saltcedar in a closed, monospecific stand, and in a mixed community with arrow weed, mesquite, and willow. Leaf-area-based sap flow rates were comparable in all four species despite large differences in individual leaf area and total water loss. Daily water use of saltcedar weighted by the daily potential evapotranspiration increased linearly with total leaf area per plant, suggesting that water uptake was sufficient to compensate for water loss at the leaf level. Under moderate to high water tables, key variables controlling water use by riparian stands include structural characteristics such as leaf area index and density.

Sammis, T. W., E. G. Hanson, et al. (1979). Consumptive use and yields of crops in New Mexico. Las Cruces, New Mexico, Reports of the New Mexico Water Resources Research Institute, 115, 1-107.

The primary objective of this report was to determine consumptive use of selected crops at Los Lunas, Las Cruces, Farmington, Artesia, and Clovis in New Mexico, each from a very different region of the state. Lysimeters were installed in the center of the fields, and yields with monthly and yearly evapotranspiration (ET) rates were measured in 1976 and 1977. In 1978, a sprinkler-line source was used to irrigate alfalfa and cotton for the measurement of yields and evapotranspiration. The maximum daily evapotranspiration rate ranged from 5.5 mm/day for bluegrass in June at Los Lunas to 10.6 mm/day for mature alfalfa in June at Las Cruces. Seasonal ET values computed for cotton, corn, and sorghum are higher by the Blaney-Criddle method than they are by the crop-production-function method using average county yields. For alfalfa, the results by the two methods are approximately the same. These results are supportive of the Blaney-Criddle formulas as a method to evaluate ET.

Sammis, T., C. L. Mapel, et al. (1985). "Evapotranspiration crop coefficients predicted using growing-degree-days." Transactions of the ASAE (American Society of Agricultural Engineers) 28(3): 773-780.

Crop coefficients have been used to estimate evapotranspiration (ET) for particular crops from estimates or measurements of potential or reference evapotranspiration (E_0). Monthly ET of alfalfa, cotton, corn, and sorghum was measured in non-weighing lysimeters for various years and locations in New Mexico. Potential E_0 was determined for each month of the growing season for each crop. Growing-degree-days (G) was determined from temperature data. A third order polynomial crop curve, relating crop coefficient to cumulative G, was estimated for each crop. There was no statistical difference in the crop curve between locations in New Mexico. When crop coefficients are related to growing degree days instead of Julian date, a common crop curve can be developed that is applicable for different years and locations having different climatic conditions.

Scherer, T. F., F. Fox, Jr., et al. (1990). "Near real time irrigation scheduling using heat unit based crop coefficients." Visions of the Future; proceedings of the National Irrigation Symposium, 3rd, Phoenix, Arizona. St. Joseph, Michigan. American Society of Agricultural Engineers: 544-551.

An interactive computer program (SCHEDPEN) was developed for scheduling irrigation for cotton and other crops in Arizona. This program utilized growing-degree-days based on crop coefficients during 1988 and 1989 at two locations (Maricopa and Safford) in Arizona. The program accepted direct weather data files from Arizona's automated agricultural weather station network (AZMET) via phone access and a computerized bulletin board. The development of the crop coefficient curve based on accumulated heat units formed a major factor in the program (SCHEDPEN). At both locations the program was compared to two other methods of irrigation (historical records and the Crop Water Stress Index). While yield and water use were not significantly different among all three methods, some algorithmic errors were found in SCHEDPEN that have been corrected.

Schmugge, T. J. and J. C. Andre, Eds. (1991). Land Surface Evaporation; Measurement and Parameterization. New York, Springer-Verlag. 424 pp.

The objectives of this book were to present a review of land surface evaporation processes, both from measurement and modeling points of view. The various chapters address the description, modeling, and parameterization of these processes for atmospheric, hydrological, and climatic studies. The described methods range from the local in situ techniques to the airborne and satellite remote sensing techniques. Each chapter was written by a different author based upon his research in the field. All chapters are based on papers presented at a workshop held at Banyuls, France in October 1988.

Sebenik, P. G. and J. L. Thames (1967). "Water consumption by phreatophytes." Progressive Agriculture in Arizona 19(2): 10-11.

Water consumption by tamarisk (saltcedar) in the San Pedro floodplain of Arizona was measured using the tent enclosure method. Results showed that in an area where the ground water table is at considerable depth, water consumed by saltcedar equals or is greater than evaporation from a free water surface. If phreatophytic areas were cleared, the water table would rise in most cases.

Shafroth, P. B., J. M. Friedman, et al. (1995). "Effects of salinity on establishment of *Populus fremontii* (cottonwood) and *Tamarix ramosissima* (saltcedar) in southwestern United States." Great Basin Naturalist 55(1): 58-65.

Saltcedar *(Tamarix ramosissima)* has replaced the native cottonwood *(Populus fremonti)* along streams and rivers in the southwestern United States. The influence of salinity on germination of first-year survival of these species was examined, using seeds planted in containers of sand subjected to a declining water table and solutions containing 0, 1, 3, and 5 times the concentrations of major ions in the Rio Grande at San Marcial, New Mexico. Germination of cottonwood declined by 35% with increasing salinity (P = 0.008), but germination of saltcedar was not affected. Neither were there any significant effects of salinity on mortality or above- and below-ground growth of either species. Cottonwood germination was more sensitive to salinity outdoors than in covered Petri dishes, probably because water scarcity resulting from evaporation intensified the low soil water potentials associated with high salinity. River salinity appeared to be a minor factor in determining relative numbers of cottonwood and saltcedar

seedlings on newly deposited sandbars in the Rio Grande. However, over the years salt becomes concentrated on the floodplain as a result of evaporation and salt extrusion from saltcedar leaves. Saltcedar, being more tolerant of salinity than cottonwood, could indirectly replace cottonwood as the floodplain becomes saltier.

Shuttleworth, W. J. (1991). Evaporation models in hydrology. Land Surface Evaporation: Measurement and Parameterization. In T. J. Schmugge and J.-C. Andre, eds. New York, Springer-Verlag: 93-120.

Natural evaporation occurs when liquid water at or just below the earth's surface is converted into water vapor and transferred in this form into the atmosphere. The process of evaporation from a natural surface is expressed, on a physical basis, by models that describe the effect of molecular and turbulent diffusion resistances on the partition of energy from the sun or the atmosphere. An overview of the broad range of models available to measure evapotranspiration is presented, with subcomponents of latent heat, sensible heat, radiation, wind speed, and stomatal resistance explained. Large-scale evaporation measurements should use a single point model ensuring that the essence of the hydrological cycle is present. The data necessary to calibrate the equivalent single point models are simple to define but difficult to provide. Land surface parameterizations are required to describe surface fluxes of radiant energy, momentum, evaporation, and sensible heat when provided with model-generated time series of incoming radiation and precipitation, and the temperature, humidity, and wind speed at a level close to the ground.

Smith, M. O., J. R. Simpson, et al. (1985). "Spatial and temporal variation of eddy flux measures of heat and momentum in the roughness sublayer above a 30-m Douglas-fir forest." In The Forest-Atmosphere Interaction. B. A. Hutchison and B. B. Hicks, eds. Dordrech, Netherlands, D. Reidel: 563-581.

The validity of point measurements of heat and momentum covariance fluxes within the roughness ($z/z0 \sim 10$) of a Douglas fir forest near Seattle, Washington, was tested using three simultaneous measurements. The application of relations equating gradients to covariances test whether the flux measurements for uniform surfaces apply near rough surfaces. Sources of variation in measurements considered included the instrumentation, coordinate orientation, averaging period, covariance flux and mean flux. Results indicated that long-term spatial differences in heat transport of 30% suggesting fetch-height requirements were greatly reduced compared to measurements over surfaces

where z/z0 greater than 100. The non-dimensional wind shear and atmospheric stability indicated a highly varied momentum deficit compared to the expected relation found over uniform surfaces.

Snyder, R. L. (1985). “Hand calculating degree days.” Agricultural and Forest Meteorology 35: 353-358.

Growing degree days are used to monitor the development of biological processes, especially in crop and pest management. But the computational difficulties involved in the derivation of degree days have limited their use. This method allows for the calculation of degree days with any threshold temperature(s) using simple arithmetic and a table of normalized areas from the trigonometric sine curve method of calculating degree days.

Spittlehouse, D. L. and T. A. Black (1979). “Determination of forest evapotranspiration using Bowen ratio and eddy correlation measurements.” Journal of Applied Meteorology 18(5): 647-653.

Evapotranspiration rates from a 14 m high coastal Douglas-fir forest in southwest British Columbia were determined, using the energy balance/Bowen ratio method and an energy balance/eddy correlation method. The Bowen ratio was measured using reverse diode psychrometers. The eddy correlation method used a fast response thermistor and Gill anemometers mounted horizontally and at 30 degrees from the vertical. Low wind speeds above the forest occasionally stalled the anemometers and made obtaining adequate eddy correlation data difficult. Spectral analysis indicated that a significant fraction of the sensible heat flux was at low frequencies. Under moderate wind speeds, values of forest evapotranspiration obtained by both methods agreed to within 0.07 per hour, plus or minus. Results suggested that the energy balance/Bowen ratio method, with periodic sensor reversal, was preferable in long-term water balance studies of forests. They also suggested that an eddy correlation system using mechanical anemometers was not suitable for forest studies where low wind speeds predominate.

Stark, N. (1967). “The transpirometer for measuring the transpiration of desert plants.” Journal of Hydrology 5: 143-157.

The objective of this study was to compare the results from a transpirometer to those from the quick weighing method to determine water loss from greasewood, saltgrass, sagebrush, rabbitbrush, and

shadscale. All studies were conducted in August near Winnemucca, Nevada. The quick weighing results compared closely to hygrometer data in direction for all major fluctuations in water loss, but not as closely in magnitude. The dark green leaves of greasewood appeared to be able to control water loss better than the yellow-green leaves. In saltgrass, the wet weight loss per sample per hour did not agree as closely with the average grams of water lost per sample per hour. It was found that water loss was more closely related to dry weight in this case. All other species studied showed a close relationship of the two methods.

Stromberg, J. C. (1997). "Growth and survivorship of Fremont cottonwood, Goodding willow, and salt cedar seedlings after large floods in central Arizona." Great Basin Naturalist 57(3): 198-208.

During the winter 1993, Arizona experienced region river flooding. Cottonwood *(Populus fremonti)*, willow (*Salix gooddingii)* and the introduced plant saltcedar *(Tamarix chinensis)* seedlings became established as the floodwaters receded. Three sites were studied with the objective of determining how abundance, distribution, growth, and survivorship of seedlings and other vegetative sprouts of cottonwood, willow, and saltcedar were impacted by the 1993 floods. Saltcedar had a lower density at all three sites than Fremont cottonwood or willows. However, each species had different growth rates. Fremont cottonwood and Goodding willow showed zonation within the floodplain, while saltcedar was equally abundant in zones with saturated and dry surface soils. Willow seedlings were taller in saturated soils than dry surface soils; Fremont cottonwood seedlings were taller in the dry surface soils; saltcedar were equally short in both soil moisture zones.

Stromberg, J. C. (1998). "Dynamics of Fremont cottonwood *(Populus fremontii)* and saltcedar *(Tamarix chinensis)* populations along the San Pedro River, Arizona." Journal of Arid Environments 40(2): 133-155.

Exotic saltcedar *(Tamarix chinensis)* has replaced forests of native Fremont cottonwood *(Populus fremonti*) and willow *(Salix spp.)* along many rivers in the American Southwest. In the middle basin of the San Pedro River in Arizona, saltcedar dominates only at the drier sites where the surface and groundwater conditions no longer support cottonwood-willow forests. However, saltcedar has been declining in sites that support Fremont cottonwood through frequent winter flooding, high rates of stream flow during spring, and exclusion of livestock browsing. In the upper basin, in contrast, saltcedar has increased in relative abundance at sites that show evidence of ground-water decline. The critical factor in both saltcedar and cottonwood forests seems to be the level and amount of groundwater available in spring and summer. Winter and spring floods provide the soil moisture needed for cottonwood forest, while saltcedar prefers a drier soil.

Swinbank, W. C. (1951). "The measurement of vertical transfer of heat and water vapor by eddies in the lower atmosphere." Journal of Meteorology 8(3): 135-145.

An apparatus (instrument) has been developed to measure the vertical transfer of heat and water vapor by eddies in the lower atmosphere. This apparatus can provide a continuous record, over a five-minute interval, of the detailed structure of temperature, vapor pressure, and total wind speed and its vertical component, of the air passing a fixed point. This method of measurement of flux of heat and water vapor is independent of the nature of eddies. The apparatus uses the techniques of hot-wire anemometry to measure the wind fluctuations. In order to calculate the vertical airflow, two hot-wire circuits form a separate head of the apparatus. A detailed description of each segment of the apparatus with the various formulae of calculation was presented.

Taylor, J. P. and K. C. McDaniel (1998). "Restoration of saltcedar (*Tamarix* sp.)-infested floodplains on the Bosque del Apache National Wildlife Refuge." Weed Technology 12(2): 345-352.

The introduction of saltcedar (*Tamarix* sp.) along the middle Rio Grande has resulted in a permanent riparian vegetation mix of saltcedar, cottonwood, and willow. A full description of the vegetation of this area was given for 1996. Saltcedar thickets were considered to be a major habitat for a wide array of fauna. Riparian restoration efforts to control saltcedar and reestablish cottonwood and willow habitats, providing diversity, were undertaken by the U.S. Bureau of Reclamation and the U.S. Fish and Wildlife Service at the Bosque del Apache National Wildlife Refuge in New Mexico. Saltcedar control (clearing) was accomplished, in part, by a combination of herbicides, burning, and mechanical techniques, such as disking or chaining and mowing. Irrigation was the most successful method of providing diversity of habitat, allowing the native vegetation to establish itself with the aid of manual plantings of cottonwood, black willows, and shrubs on saltcedar-cleared areas. This project has allowed an increase in avian and reptilian/amphibian species richness along the middle Rio Grande.

Taylor, J. P., D. B. Wester, et al. (1999). "Soil disturbance, flood management, and riparian woody plant establishment in the Rio Grande floodplain." Wetlands 19(2): 373-382.

One of the most extensive remaining cottonwood gallery forests exists in the Bosque del Apache National Wildlife Refuge in the middle Rio Grande floodplain, New Mexico. Seedling germination and survival were compared on 9.9 ha divided into 16 adjacent 50x50 m plots along the west channel bank of the Rio Grande. In 1993, half of the plots were cleared of vegetation by bulldozer to provide a test site for comparison. Prior to clearing, saltcedar comprised 94.5% of the vegetation, with seep willow comprising the remaining 5.5%. In 1994, the Rio Grande flooded its banks. After two seasons of growth, cleared areas supported more 1993 cohort cottonwoods and saltcedar than uncleared control areas. Elevation and soil moisture indices were the most influential variables on seedling density. Saltcedar clearing in conjunction with peak river flows in late May or early June encourages recruitment of native riparian plants, including cottonwood seedlings.

Thompson, C. B. (1958). "Importance of phreatophytes in water supply." Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers 84(IR 1): 1502-1 - 1502-17.

Since 1990 the growth of saltcedar has resulted in the gradual replacement of infestations of other phreatophytes. Recent estimates (prior to 1958) indicated that phreatophytes of all types infest a total area of 440,000 acres in New Mexico and waste 869,000 acre-feet of water annually. Of these phreatophytes, saltcedar is the dominant type and is spreading rapidly throughout Southwest river systems. This article reviews the prior studies of water consumption of saltcedar ranging from 7.2 ft per year in Safford, AZ to a maximum of 10.8 ft in Socorro, NM. The primary emphasis of this paper is on the control measures for saltcedar, none of which worked successfully over time.

Tomlinson, S. A. (1997). "Evapotranspiration for three sparse-canopy sites in the Black Rock Valley, Yakima County, Washington, March 1992 to October 1995." Water-Resources Investigations Reports of the U.S. Geological Survey 96-4207: 1-88.

Evapotranspiration of ground vegetation at three sites in Yakima, Washington, was measured using both the Bowen-ratio and the Penman-Monteith methods. The objective was to evaluate the methods to estimate evapotranspiration. The primary vegetation consisted of sagebrush and grasses. At the Black Rock Valley and Firewater Canyon sites, big sagebrush (*Artemesia tridentata*), bluebunch wheatgrass (*Agropyron spicatum*) and bluegrass (*Poa sandbergii*) predominated. At the Bird Canyon site, an abandoned field of natural grasses predominated, including wheat (*Triticum aestivum*), crested wheatgrass (*Agropyron cristatum*) and cheatgrass (*Bromus tectorum*). For October 1994 to September 1995, cumulative precipitation at all three sites differed by only 4%, but the Black Rock Valley and Bird Canyon sites showed 30% more cumulative evapotranspiration than the Firewater Canyon site. Cumulative evapotranspiration at the Black Rock Valley, Bird Canyon, and Firewater Canyon was 129%, 136% and 97.2%, respectively. Generally the latent-heat flux and evapotranspiration estimated with the Penman-Monteith and fixed-sensor instruments agreed closely with latent-heat flux and evapotranspiration estimated with the Bowen ratio instruments.

Turner, P. M. (1970). Annual report of phreatophyte activities - 1968. Denver, U.S. Bureau of Reclamation: 23 pp.

Herbicides were evaluated on saltcedar test plots along the Arkansas River, Colorado. The herbicides were tested first on greenhouse-cultured saltcedar plants to evaluate their use in the field. The saltcedar in the test plots were three years old, having become established after the floods in 1965. A combination of picloram with 2, 4-D and silvex were the most effective herbicides tested. Helicopter herbicide spraying was performed on 920 acres of saltcedar around Rye Patch Reservoir. A large portion of the Bernardo, New Mexico, study area was sprayed with 2, 4, 5-TP during the growing season in 1968. Mechanical and mowing control methods were also used. Various other sites were tested for saltcedar control especially in the Colorado Indian Reservation near Parker, Arizona. Another 38,600 acres along the Pecos River in New Mexico were mowed, plowed, sprayed, and crushed in an effort to control saltcedar. A combination of 1 pound of picloram plus 2 pounds each of 2, 4-D and silver per acre was the most effective herbicide combination for controlling saltcedar.

U.S. Bureau of Reclamation (1997). Middle Rio Grande Water Assessment. Middle Rio Grande Land Use Trend Analysis Geographic Information System Data Base, n.13. Albuquerque, BoR. 33 pp.

A survey of the Albuquerque (New Mexico) basin was conducted in 1994 for land use trends over the past 58 years. Designated as LUTA (land use trend analysis), this survey identified four periods of time for historic land use data: 1935, 1954/55, mid 1970s and 1992/93. A geographic information system

(GIS) database was constructed for each of the time periods. Historic and current aerial photography and 1992 Landsat satellite imagery were used as the primary data sources for compiling the database. As part of this report, the Middle Rio Grande Valley was included, allowing for the analysis of changes in vegetation historically. Cottonwood, saltcedar, Russian olive, and willows were identified from 1989 aerial photographs.

Unland, H. E., A. M. Arain, et al. (1998). "Evaporation from a riparian system in a semi-arid environment." Hydrological Processes 12(4): 527-542.

Measurements of micrometeorological variables were made to provide the basis of an estimate of evaporation from a one-mile long reach of a riparian corridor on the Santa Cruz River, Arizona from January 1995 through March 1996. The total evaporation was calculated as the area-weight average of the measured evaporation for sampled areas. Measurements showed a substantial, seasonally dependent evaporation for the taller, deep-rooted riparian vegetation while the short, sparse vegetation provide little evaporation. Cottonwood evapotranspiration (ET) was overestimated, since prior studies maintained that it had been underestimated. Irrigated crops accounted for almost half the total evaporation loss, while the remaining loss was from the taller vegetation, including cottonwood estimated to be about one-fourth of the remaining loss.

van Bavel, C. H. (1966). "Potential evaporation: the combination concept and its experimental verification." Water Resources Research 2(3): 455-467.

A combination of a surface energy balance equation and an approximate expression of water vapor and sensible heat transfer were used to formulate an equation to relate potential evaporation for net radiation, ambient air properties, and surface roughness. The proposed model, based upon the Penman equation, contains no empirical constants or functions. The model was tested in Phoenix, Arizona, using open water, wet bare soil, and a well-watered alfalfa crop. The model gave excellent agreement for 24-hour totals and acceptable agreement on an hourly basis, despite the large amounts of advection that occurred over the alfalfa surface as a result of a typical oasis situation. The use of daily average values for air temperature, vapor pressure, and windspeed on a series of mostly clear days gave results essentially identical to the use of hourly values in this combination model. Results indicate that the model, using daily totals for net radiation, a simple wind function accounting for the roughness of the surface, and daily values for standard meteorological data, appears capable of giving accurate estimates of potential evapotranspiration on a daily basis.

van Hylckama, T. E. A. (1970). “Water use by salt cedar.” Water Resources Research 6(3): 728-735.

Six years of observation on water use by saltcedar on the Gila River, Arizona, demonstrated that thinned-out stands use nearly as much water as saltcedar in control evapotranspiration tanks if the water is of good quality. Conclusions indicated that thinning and cutting are ineffective methods of saving water. The assumption that phreatophytes always transpire at a potential rate was not substantiated. When differences in depth to water as small as 1.5 to 2.1 meters and 2.1 to 2.7 meters affect the water use, it seemed reasonable to conclude that with a water table at 4 meters, saltcedar still may thrive but use comparatively little water. Claims as to the quantity of water potentially saved by saltcedar eradication could well be overestimated.

van Hylckama, T. E. A. (1974). “Water use by saltcedar as measured by the water budget method.” Professional papers of the U.S. Geological Survey 491-E: 1-30.

Saltcedar water use was studied along the Gila River, Arizona, from 1961-1967. Evapotranspiration rates and quantities were observed in six tanks. When depth to ground water, or water table, was 1.5 meters, the average water use was about 215 cm per year. When the water table was 2.1 m, the use diminished to about 150 cm per year. Salinity of the soil moisture caused great variation of water use. When vegetation was cut twice a year from an original average height 3m to 50cm, water use decreased to about half. The maximum yearly water use (311 cm) was measured in 1965 in a tank with a high water table, dense vegetation, and a salinity index of less than 10. When the water table was high, the salinity was comparatively low, and the stand density was medium to high.

van Hylckama, T. E. A. (1978). “Evapotranspiration from saltcedar in the Gila River flood plain in Arizona.” Professional Papers of the U.S. Geological Survey P-1100: 239-240.

Evapotranspiration of saltcedar is limited during periods of high demand by stomatal closure. This study used micrometeorological methods to determine the rate. Transport constants for momentum, heat and vapor were equal for more than 80% of the record. However, during hot afternoons when temperatures exceeded 40 degrees C, vapor fluxes and photosynthesis diminished. Saltcedar reacts to extremely high wind speeds and temperatures by stomatal closure restricting evapotranspiration even though water is readily available.

van Hylckama, T. E. A. (1980). “Weather and evapotranspiration studies in a saltcedar thicket, Arizona.” Professional Papers of the U.S. Geological Survey 491-F: 1-78.

Rates and quantities of evapotranspiration of saltcedar were observed in six plastic-lined tanks of 81 square meters surface area. The following data was measured: solar short-wave radiation; long- and short-wave net radiation; albedo; humidity, temperature, and wind profiles; soil-temperature gradients and soil-heat flux; moisture content of the soil; and carbon dioxide content of the air. Estimates of potential evapotranspiration rates using various models were plotted against measured values. Saltcedar reacts to extremely high windspeeds and temperatures by stomatal closures, thus diminishing evapotranspiration even though water is freely available.

Verma, S. B., N. J. Rosenberg, et al. (1978). “Turbulent exchange coefficients for sensible heat and water vapor under advective conditions.” Journal of Applied Meteorology 17(3): 330-338.

Sensible heat advection was measured over alfalfa and soybeans at Mead, Nebraska, a semi-humid region. Air temperature and vapor pressure profiles were measured at six elevations in the 2 m air layer above the canopy of an alfalfa field. Measurements of evapotranspiration and microclimate for a soybean field, studied in 1970, were used for comparative purposes. Micrometeorological measurements have shown that the exchange coefficient for sensible heat is generally greater than the exchange coefficient for water vapor. This result is at variance with the time-honored assumption of equality between sensible heat and water vapor. Under advective conditions, these are transferred in opposite directions. The results support Warhaft’s theoretical analysis in which he concluded that the greatest departure of sensible heat and water vapor from unity would occur when temperature and humidity gradients are of opposite sign.

Vogt, R., C. Bernhofer, et al. (1996). "The available energy of a Scots pine plantation: What's up for partitioning?" Theoretical and Applied Climatology 53(1): 23-31.

Errors influencing the calculation of available energy above a forest were considered. A surface energy balance experiment was conducted in and above a Scots pine plantation in Freiburg, Germany from May 11-22, 1992 to measure net radiation. Five different radiometers of three different designs were used in the Hartheimer Experiment (HartX). The initial agreement between the net radiometer readings was improved by introducing different responses for the short- and longwave range. The mean deviations to the relative net radiation after correction varied between -1.4 and 1.2 watts per meters squared (Wm-2) with standard deviations between 5.4 and 6.6 (Wm-2). The total error referring to the available energy was estimated to be up to 36 (Wm-2) around midday decreasing to 10 (Wm-2) during nighttime.

Warren, D. K. and R. M. Turner (1975). "Saltcedar *(Tamarix chinensis)* seed production, seedling establishment, and response to inundation." Journal of the Arizona Academy of Sciences 10(3): 135-144.

Three aspects of saltcedar ecology were studied in on the San Carlos Reservoir of the Pedro River in Arizona; seed production, seedling establishment, and mortality from submergence. Seed production over a 5 1/2 month period yielded one major production peak and one minor peak. Seed production in cottonwood occurred earlier than for saltcedar or seepwillow, was of shorter duration, and was almost completed before the flowering season for the other species began. Saltcedar seedling establishment were probably derived from wind or wave action. The data suggested that establishment rate was a function of current seed production, modified by climatic conditions. Mature saltcedar plants were able to survive complete submergence for as long as 70 days. Without complete submergence, plants survived longer periods of flooding - the maximum was 98 days.

Webb, E. K., G. I. Pearman, et al. (1980). "Correction of flux measurements for density effects due to heat and water vapour transfer." Quarterly Journal of the Royal Meteorological Society 106(447): 85-100.

When the atmospheric turbulent flux of a minor constituent, such as carbon dioxide, is measured by either the eddy covariance or the mean gradient technique, consideration should be taken of variations of the constituent's density due to the presence of a flux of heat and/or water vapor. In this study, the basic relationships are discussed in the context of vertical transfer in the lower atmosphere and required corrections to the measured flux. If measurement involves sensing of the fluctuations or mean gradient of the constituent's mixing ratio relative to the dry air component, then no correction to the measured flux is required. But in the case of sensing of the constituent's density fluctuations or mean gradients in the *in situ* air, corrections arising from both heat and water vapor fluxes are required. Given this case, the fluctuations due to the heat flux is about five times as great as those due to an equal latent heat (water vapor) flux. In carbon dioxide flux measurements, the magnitude of the correction will commonly exceed that of the flux itself. The correction to measurements of water vapor flux will often be only a few percent, but sometimes will exceeded 10 percent.

Weeks, E. P., H. L. Weaver, et al. (1987). "Water use by saltcedar and by replacement vegetation in the Pecos River floodplain between Acme and Artesia, New Mexico." Professional Papers of the U.S. Geological Survey 491-G: 1-33.

Water consumption for saltcedar and for replacement vegetation was estimated following root plowing in the Pecos River floodplain between Acme and Artesia, New Mexico. Measurements were made using the eddy correlation energy-budget technique during 1980-82. Results indicated that annual water use by saltcedar probably was about 0.3 meters greater than that by replacement vegetation. Such reductions in water use should have resulted in an increased base flow of the Pecos River of 11.2-2.5x107 cubic meters per year (10,000 to 20,000 acre-feet per year). However, such gains could not be identified from stream-gage records. Results also indicated that evapotranspiration from different saltcedar thickets varied greatly but no relationship among volume density of the plant cover, depth to water, and water use was apparent.

Wilkinson, R. E. (1972). “Water stress in salt cedar.” Botanical Gazette 133(1): 73-77.

Water stress in saltcedar was studied in the Rio Salado area in New Mexico. Saltcedar cladophylls developed water potentials of -5 bars by early July and -20 bars by late September when the plants grew in deep sand with a high water table. Water consumption closely paralleled pan evaporation and solar radiation. Relative water content was correlated with season, solar radiation, air temperature, wind velocity, relative humidity, and prior growing conditions. Relative water content of trees growing on a 3-ft. water table did not significantly differ from those growing on a water table 10-ft or deeper. Relative water content decreased throughout the summer but increased in September, reaching 100% in mid-October. It was concluded that water stress was probably partially responsible for the variability of herbicide treatment results on saltcedar growing in New Mexico.

Williams, M. E. and J. E. Anderson (1977). “Diurnal trends in water status, transpiration, and photosynthesis of saltcedar.” Hydrology and Water Resources in Arizona and the Southwest 7: 119-124.

Relative water content, water potential, and gas exchange were measured on saltcedar at a Bernardo, New Mexico, lysimeter site. Relative water content and water potential were closely correlated, but water potential measurements taken with a pressure bomb were more convenient and reliable. Relative water content and water potential decreased sharply from sunrise till about 9:00 am. Water status then remained constant or improved slightly through late afternoon. Evapotranspiration rates remained high until about noon and then began a steady, gradual decrease that continued throughout the afternoon. This suggested that water stress might be a factor in initiating stomatal closure. Afternoon depressions in transpiration and photosynthesis suggested that a diurnal rhythm might be involved on control of gas exchange.

Worthington, J. W., J. Lasswell, et al. (1987). Water use and irrigation of pecan trees. Combined Proceedings of the Texas Pecan Growers Conference, 65 & 66th, Fort Worth and Austin, Texas, 1985:61-78.

Pecan trees are reported to require about 55 inches of water a year. Irrigation water is needed to supplement natural rainfall since rain may not fall when the trees need the water. Most of the 55 inches of water will be needed during the growing season (225 days). For a give size of pecan tree, under given weather conditions, water use is the same, regardless of soil type. Tables are given for tree water use, based on pan evaporation and canopy size for May and September, June and August, and July. In June and August pecans use about 80% as much water as evaporates. In July, the amount is equal to 100% of pan evaporation.

Young, A. A. and H. F. Blaney (1942). "Use of water by native vegetation." Bulletins of the California Division of Water Resources 50:1-159.

This report is a comprehensive presentation of research data dealing with the consumptive use (or evapotranspiration) of water by various non-crop plants native to California and the Southwest in general. As part of the comprehensive studies, studies of the Upper Rio Grande Basin in Colorado and the Middle Rio Grande Valley and Mesilla Valley in New Mexico are presented in Chapter 4, p. 88-100. Evapotranspiration of tules, sedges, grasses, saltgrass, cattails, and willow is given for 1936-1937. In the Middle Rio Grande Valley studies, saltgrass *(Distichlis stricta)* used 31.59 inches of water yearly from June 1936-May 1937. In the Mesilla Valley, saltgrass used 39.81 inches. Records for southern California show a much higher use.