# Simulation of Leaf Conductance and Transpiration in Western Juniper

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SUMMARY: Western juniper is a conifer species well adapted to semi-arid rangelands in portions of the western United States. Water relations of mature western juniper trees were observed, and soil temperature, soil water, air temperature, vapor density deficit ($D_a$), and solar radiation were recorded. A daily soil water budget was maintained by coupling the conductance model with the hydrology component of the model SPUR (Simulation of Production and Utilization of Rangelands). Results indicate that the model successfully simulated seasonal conductance trends. Conductance was strongly affected by soil temperature and $D_a$ in spring, while soil water potential and $D_a$ were important during summer. Western juniper transpired 5.6 inches of water, 47 percent of the total evapotranspiration for the site and 44 percent of total annual precipitation. Simulated western juniper conductance increased whenever environmental conditions moderated in late winter and spring. Juniper withdrew 1.5 inches of water between January and May, suggesting it has potential to significantly alter watershed value and site productivity.

Western juniper (*Juniperus occidentalis* Hook.) is a conifer species well adapted to semi-arid rangelands in portions of the western United States. It occurs throughout eastern Oregon, eastern Washington, north-eastern California and southern Idaho. During the last 100 years this species has increased in density, actively invading adjacent sagebrush-grass communities. The conversion of shrub steppe communities to juniper woodlands has influenced ecological processes on the landscape. As western juniper increases on a site, understory production decreases, subsurface flow decreases, and sediment production increases.

Because of western juniper's increased presence on semi-arid uplands, information is needed to evaluate the effects of these woodlands on the hydrologic cycle. Models have been developed for other conifers, however little work has been reported for western juniper. Recent water relations research has investigated relationships between western juniper conductance rates and environmental conditions, and this information provides the necessary data to develop a physiologically based conductance model for a western juniper woodland. In the present study we developed a conductance model for western juniper and estimated water use of an entire stand.

## MATERIALS AND METHODS

*Study Site.* The leaf conductance model was developed using data collected at the Squaw Butte Experimental Range located in the northern Great Basin, in southeastern Oregon. The study site was in an *Artemisia tridentata* ssp. *vaseyana/Festuca idahoensis* habitat type at 4,420 ft elevation. Western juniper encroachment began on the study site just after the turn of the century. Soil is a Typic Haploxeroll, varying from loam texture at the surface to gravelly loam at lower depths. Soils are underlain by columnar bedrock at approximately 44 inches. Average annual precipitation (39-yr mean) is approximately 11 inches, most of which is received as snow between September and June. During the study, precipitation was above average, with about 14.6 and 12.5 inches received in 1983 and 1984, respectively. March, 1983 was much wetter than average in

both years, and the entire soil profile was at or near field capacity during early spring.

**Data Collection.** Data for model development and testing was obtained by measuring western juniper stomatal conductance ($g_l$) ($cm*s^{-1}$) during two growing seasons, between January, 1983 and September, 1984. Environmental data included precipitation, air and soil temperature (°C), vapor density deficit ($D_a$) ($g*m^{-3}$), gravimetric soil water content (%), and solar radiation ($cal*cm^{-2}*s^{-1}$). Leaf conductance was measured with a steady state porometer (LiCor, Li-1600) fitted with a cylindrical chamber. Juniper total leaf area (LA) ($m^2$) was estimated from basal circumference, and leaf area index (LAI) was derived based on LA per tree and $trees*ha^{-1}$. All plant measurements were collected on mature trees. Analysis of data collected in 1983 indicated that solar radiation, soil temperature, soil water pressure ($\psi_s$) (MPa), and $D_a$ were important factors that could be used to predict diurnal patterns of $g_l$.

**Model Overview.** The model JUOC operates at an hourly time step. At the start of each day, precipitation, diurnal temperature extremes (°C) and daily solar radiation ($cal*cm^{-2}*d^{-1}$) are input (Figure 1). JUOC simulates $g_l$ for a moderate density (50-60 trees/acre), even-aged stand of western juniper growing in the northern Great Basin. Transpiration ($J$) ($\mu g*cm^{-2}*s^{-1}$) is calculated based on $g_l$ and $D_a$. Descriptive parameters for the juniper stand are input at the beginning of the simulation, and do not change. Stomatal conductance is based on current soil temperature at 4 inches, soil water pressure in the wettest layer, and overnight minimum temperature. Stomatal conductance is set to the maximum potential rate just after sunrise. As the day progresses, ambient temperature and $D_a$ rise toward a diurnal maximum, and conductance rate declines. Hourly $J$ is summed to get total daily transpiration per unit LA. Stand transpiration is estimated at the end of the day and reported as mm of water. At the end of the day, soil water is uniformly removed from the soil profile, down to the maximum rooting depth. In this study we assumed a rooting depth of 35 inches, and a 39-inch
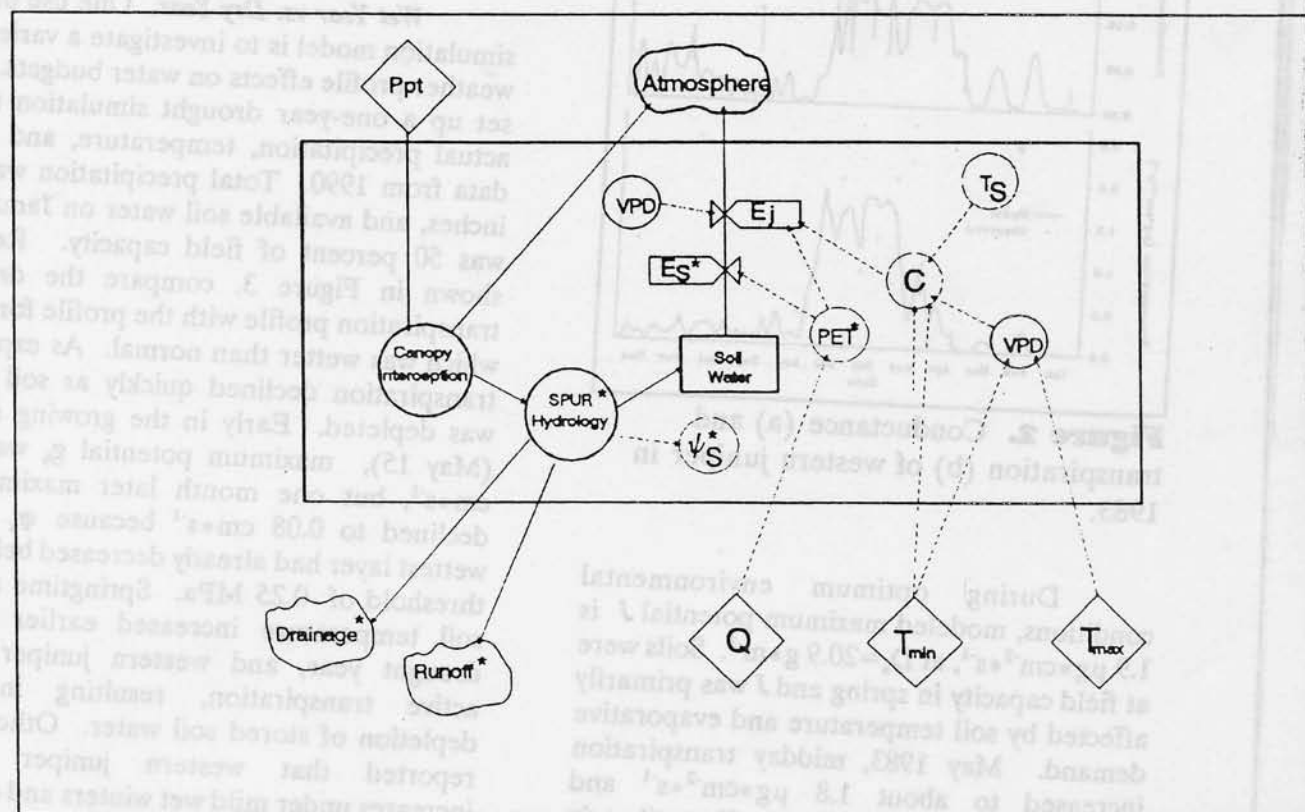


**Figure 1.** Flow chart for JUOC, a conductance model for western juniper, showing inputs and outputs for the model. 22

depth of profile.

Daily soil water balance is maintained by coupling the conductance model, JUOC, with the upland hydrology component of SPUR - Simulation of Production and Utilization of Rangelands. SPUR hydrology controls water routing to snow storage, snowmelt, runoff, soil storage, or deep percolation.

## RESULTS AND DISCUSSION

*Model Development and Testing.* We used actual precipitation and temperature data from 1983, which were collected at a weather station 1.25 miles from the study site. Simulations began on January 1, and continued through the end of the year. Simulated $g_h$ in 1983 (Figure 2) was generally within 1 SD of measured seasonal averages. Residual standard deviation (RSD) of model versus measured values was low (0.029).
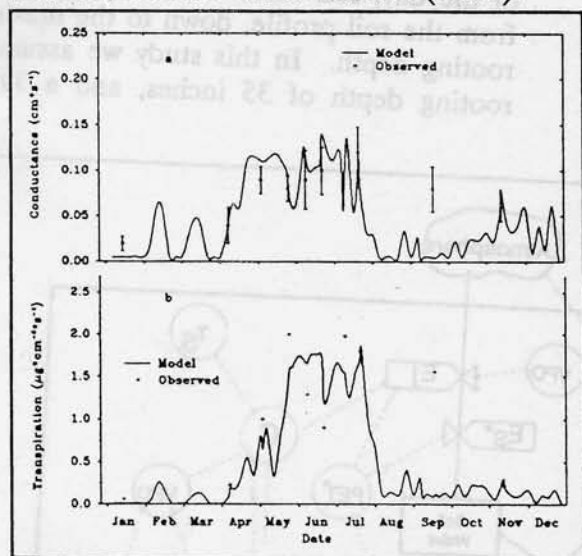
**Figure 2.** Conductance (a) and transpiration (b) of western juniper in 1983.

During optimum environmental conditions, modeled maximum potential $J$ is 1.9 $\mu g*cm^{-2}*s^{-1}$, at $D_a=20.9$ $g*m^{-3}$. Soils were at field capacity in spring and $J$ was primarily affected by soil temperature and evaporative demand. May 1983, midday transpiration increased to about 1.8 $\mu g*cm^{-2}*s^{-1}$ and fluctuated with daily changes in $D_a$ until early July when $\psi_s$ of the wettest layer decreased to

about -0.3 MPa. By that time soil water pressure in the upper profile was at or below -1.5 MPa. As noted above, the model predicted stomatal closure in September, because of decreased $\psi_s$, resulting in a difference of about 1.4 $\mu g*cm^{-2}*s^{-1}$ between measured and modeled values.
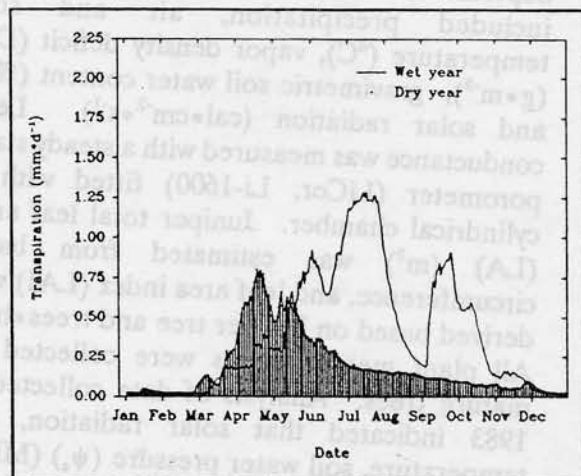
**Figure 3.** Modeled daily transpiration by western juniper in a dry year (1990) compared to a wet year (1984).

*Wet Year vs. Dry Year.* One use of our simulation model is to investigate a variety of weather profile effects on water budgets. We set up a one-year drought simulation using actual precipitation, temperature, and solar data from 1990. Total precipitation was 6.9 inches, and available soil water on January 1 was 50 percent of field capacity. Results, shown in Figure 3, compare the drought transpiration profile with the profile for 1984, which was wetter than normal. As expected, transpiration declined quickly as soil water was depleted. Early in the growing season (May 15), maximum potential $g_h$ was 0.13 $cm*s^{-1}$, but one month later maximum $g_h$ declined to 0.08 $cm*s^{-1}$ because $\psi_s$ in the wettest layer had already decreased below the threshold of -0.25 MPa. Springtime air and soil temperature increased earlier in the drought year, and western juniper began active transpiration, resulting in early depletion of stored soil water. Others have reported that western juniper growth increases under mild wet winters and cool wet springs. Early increases in $J$ have important

implications for understory herbaceous species that are just initiating growth. Drought effects on the understory may be intensified by western juniper's early withdrawal of soil water. Additionally, as western juniper stand density and/or LAI increases on a site, additional soil water will be withdrawn early in the year, altering western juniper seasonal $g_l$ patterns, which may help explain reported decreases in production of associated species.

## CONCLUSIONS

The conductance model, JUOC, successfully simulated seasonal leaf conductance patterns for western juniper. The model demonstrates how well western juniper is adapted to the environment of the northern Great Basin, where most of the annual precipitation is received as winter snow. The model closely matched observed springtime conductance. In spring, when soil water is highest, western juniper will begin active transpiration as soon as soil temperature increases, and this effect may be enhanced in dry years when fewer cloudy days occur.

During model development, we simulated a site stocked with 30 trees per acre, and 1.6 LAI. Even at this relatively moderate level of density and cover, western juniper was able to extract 1.9 inches of water during May and June, and transpired 5.6 inches during a wet year. This response illustrates one of the adaptations that makes western juniper so competitive once it establishes on a site. Because it is an evergreen, it can draw on available soil water any time environmental conditions are favorable. Based on the drought year simulation, even moderate density juniper stands appear to have the potential for significant impact on site hydrologic processes. By beginning active growth early in spring, soil water is depleted rapidly and development of understory species will be even further restricted. The model suggests that in dry years, western juniper could significantly impact growth and development of understory species by depleting soil water early in the year.

This model provides resource managers with important new information about the impact of developing western juniper woodlands on water use in the watershed, based on stand density, basal area, and environmental conditions. This information can be used to make stand management decisions such as what stand density is acceptable, and whether some control measure is justified. Further research needs include comparing model predictions with measured transpiration data on widely differing sites and for different climatic conditions.