Report for 2003TX90B: Quantification of Stochastic Crop-Water Production Functions and Net Profit-Water Functions for Agriculture on the Edwards Aquifer

- Other Publications:
  - Brumbelow, K. and J.Y. Lee, WGEN-Sky and WFILL: Extension of the WGEN model to include sky cover condition and data filling capabilities, Agric. and Forest Meteor., 2004. (in preperation)
  - Brumbelow, K. and J.Y. Lee, Use of net-profit water functions to assess implications of an irrigation limit policy for the Edwards Aquifer, Texas, J. of Water Resour. Plan. Mgmt., 2004. (in preperation)

Report Follows

Quantification of Stochastic Crop-Water Production Functions and Net Profit-Water Functions for Agriculture on the Edwards Aquifer

Progress Report

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1. Introduction

This report summarizes the progress to date of research supported by the Texas Water Resources Institute through the 2003-2004 USGS Scholarship Program. Mr. Ju Young Lee was awarded funding under this program for a project to quantify representative relationships between irrigation application and crop yield and net profit for the region overlying the Edwards Aquifer in central Texas. Toward that end, progress has been made in three primary tasks: (1) formulation of a data filling algorithm to estimate missing meteorological data for input into crop/irrigation simulations, (2) determination of crop-water production functions (CWPF's) for the study area, and (3) economic analysis to derive net profit-water functions (NPWF's) from the CWPF's. Results from this research will be used to prepare 2 articles for publication in peer-reviewed journals, and Mr. Lee has made progress in defining his doctoral dissertation topic. Each of the accomplishments made under the TWRI/USGS grant is described further below.

2. Data Filling Algorithm for Incomplete Meteorological Datasets

One of the chief difficulties in applying physiologically based crop models (such as those described by Tsuji et al., 1998, etc.) to long-term simulation has been the lack of suitable meteorological data in some locations needed for model input. Past studies have addressed this problem primarily through regression relationships and have often focused on a limited number of parameters (e.g., Hook and McClendon, 1992). One option that has been incorporated into commonly used software has been stochastic generation of all meteorological data, and the WGEN model (Richardson, 1981) has often been used for this purpose. This model is an attractive statistical descriptor of daily meteorology because of its well-defined cross- and auto-correlation structures, and its parsimony in parameter storage. In this project, the WGEN model has been modified in two phases for the purposes of developing a flexible and efficient data filling tool.

The first modification was to change the primary description of daily meteorological state from a binary wet/dry one to a quaternary one based on both precipitation and sky cover condition: "dry clear," " dry cloudy," " wet clear," and "wet cloudy." Thus, the Markov chain used to determine precipitation occurrence each day was changed from a two-state to a four-state model with 12 transition probabilities needed for each day rather than the 2 needed in the original model. All daily parameters (i.e., precipitation amount, maximum daily temperature, minimum daily temperature, relative humidity, number of hours of sunshine, and wind run) were then quantified for each of the four precipitation/sky states. Because of the newly determined importance of sky cover condition, this form of the stochastic weather generator was named "WGEN-Sky."

The increased number of parameters is significant in WGEN-Sky compared to the original WGEN. The original model required Fourier series expressions for 23 independent parameters as well as two 5 by 5 correlation matrices; WGEN-Sky requires expressions for 54 independent parameters as well as the same sized correlation matrices. However, comparison of long generated series to actually measured data has shown that

WGEN-Sky does generate improved sequences compared to WGEN. Figure 1 shows a comparison of mean number of sunshine hours for the calendar year divided into 14-day periods as measured at San Antonio, Texas, and as generated by the WGEN and WGEN-Sky models. While the original model provides an adequate representation of sunshine hours, the WGEN-Sky generated series more closely resembles the actual data including the mid-Spring "dip" in sunshine due to increased convective cloud cover. This improvement is significant for agricultural modeling where solar radiation is a driving input to photosynthesis and plant development. Figures 2a-c compare the frequency of occurrence of each of the four precipitation/sky states as measured at San Antonio (Figure 2a), as generated by WGEN (Figure 2b), and as generated by WGEN-Sky (Figure 2c). As expected, WGEN-Sky produces a more accurate set of frequencies than does WGEN. The full value of this fact is realized in the second modification to the original weather generator.

The second modification to the original weather generator was to convert it to fill in missing weather data values using as much information from known values as possible. As mentioned above the quantification of cross- and auto-correlation structures in WGEN makes its original methodology well-suited to this task. In addition, the greater specificity in parameter trends determined by the combined precipitation/sky states in WGEN-Sky allow for greater confidence in the estimation for each missing value. The data filling version of the weather generator has been named WFILL in recognition of its heritage from WGEN and its new role.

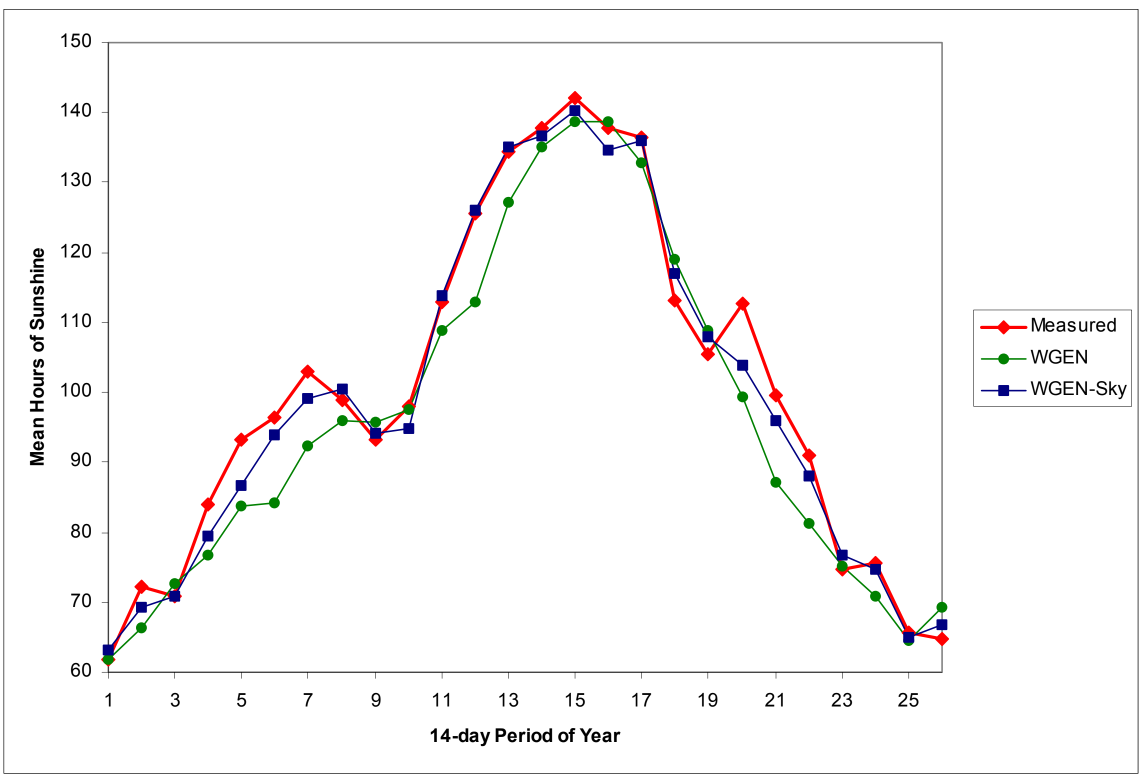

Figure 1. Comparison of mean numbers of sunshine hours generated by WGEN and WGEN-Sky versus measured data at San Antonio, Texas.

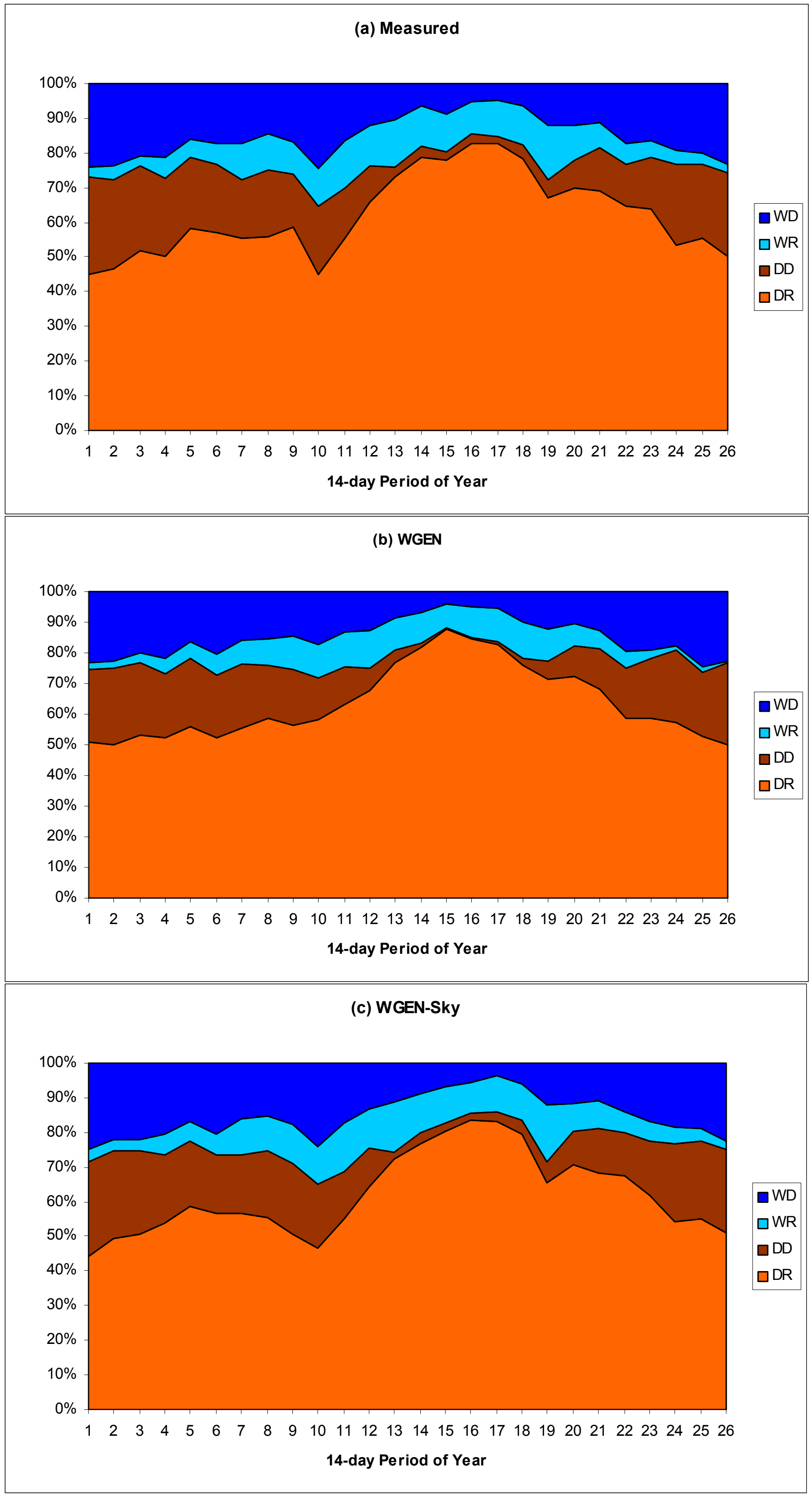

Figure 2. Comparison of frequency of occurrences of dry clear (DR), dry cloudy (DD), wet clear (WR), and wet cloudy (WD) days as measured at San Antonio and generated by the WGEN and WGEN-Sky models.

WFILL estimates each day's missing weather data by a three-step process. First, if the precipitation/sky state is not known from measured data, it is estimated using a Bayesian conditional probability calculation. All available data except wind run is included as possible in this calculation. Conditional probability of each possible precipitation/sky state is calculated by comparing each known data value to its expected statistical distribution under each state (Figure 3 provides a schematic example of this). The highest conditional probability found determines the estimated state for that day. In a verification study, the 6-year record at San Antonio was processed by WFILL, and precipitation/sky state was determined with a median conditional probability of 96.2%, a minimum conditional probability of 52.1%, and conditional probability was greater than 90% in over 46 years of the filled record. Thus, this procedure was judged to perform quite well in estimating precipitation/sky state.

The second step in the WFILL daily estimation process is to estimate deviations from mean values (i.e., normalized residuals) for each missing parameter. WGEN includes the equation of Matalas (1967) for a first-order autoregressive process on a multi-dimensional state with known cross- and auto-correlations among state variables. This equation includes a vector of same-day noise for generation purposes. In the data filling mode, WFILL back-solves this equation for the noise terms for known parameters and assumes zero noise for unknown parameters. The equation is then forward-solved with the newly determined noise components. This process capitalizes on all known parameters by including their correlative influence on unknown values at both lag-1 and lag-0 increments. The third step in the WFILL process is to then calculate values for missing parameters using mean and variance appropriate to the estimated state and residual estimated from the second step.

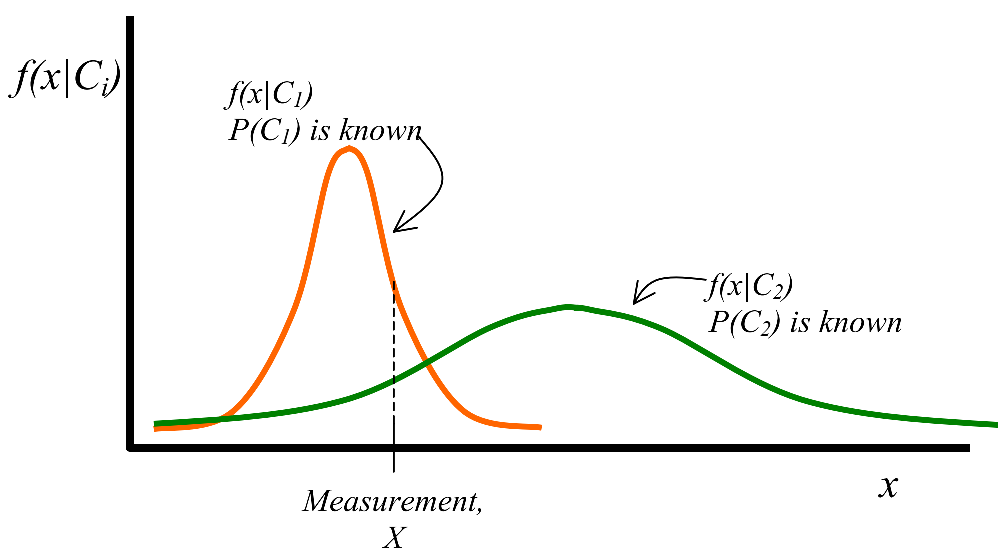

Figure 3. Schematic representation of conditional probability calculation for precipitation/sky state conditioned on measured meteorological data.

WFILL is flexible in that in can work with any number of missing values each day as long as WGEN-Sky parameters have been previously determined for the site in question. Metadata is produced for each day's computations to report on the likely quality of the estimated values (i.e., probability of precipitation/sky state, number of values estimated, frequency distribution of back-solved noise, etc.). The utility of the model is illustrated by the example of the San Antonio verification study where out of a 56-year record, only 5.8 years have all 6 needed parameters for crop model simulation. Use of WFILL allows the entire 56 years of data to be used with preservation of important climatic trends.

3. Functions of Irrigation versus Crop Yield and Net Profit for the Edwards Aquifer Region

The major goal of this project is to quantify representative functions of crop yield and net profit as functions of irrigation application for several crops on the western reach of the Edwards Aquifer. At this time only preliminary results have been obtained for these tasks. Work is continuing to finish this part of the research project. The preliminary results are discussed below.

To date, simulations have been run for corn grown at Uvalde, Texas, on Uvalde silty clay loam soil. Using measured meteorological data available at Uvalde (precipitation, daily maximum and minimum temperatures), parameters for other weather data derived from measurements made at San Antonio, and the WFILL algorithm, a record of 94 years of climatic data was reconstructed and used for 94 computational trials. Each computational trial produced a single crop-water production function (i.e., yield vs. irrigation function). These were then aggregated to construct a probability distribution of CWPF's as shown in Figure 4. These results are still considered preliminary and subject to continued revision as input data checks continue. There is also much work left to be done to assess the CWPF's for other soil types, locations, and crops. This work will be done in the next several months.

Net profit-water functions are also left to be developed in this project. As these require derivation of the CWPF's first, this step will be done after those functions are complete. Required economic data to compute net profit relationships (i.e., fixed and variable costs, market prices for water, etc.) have been collected.

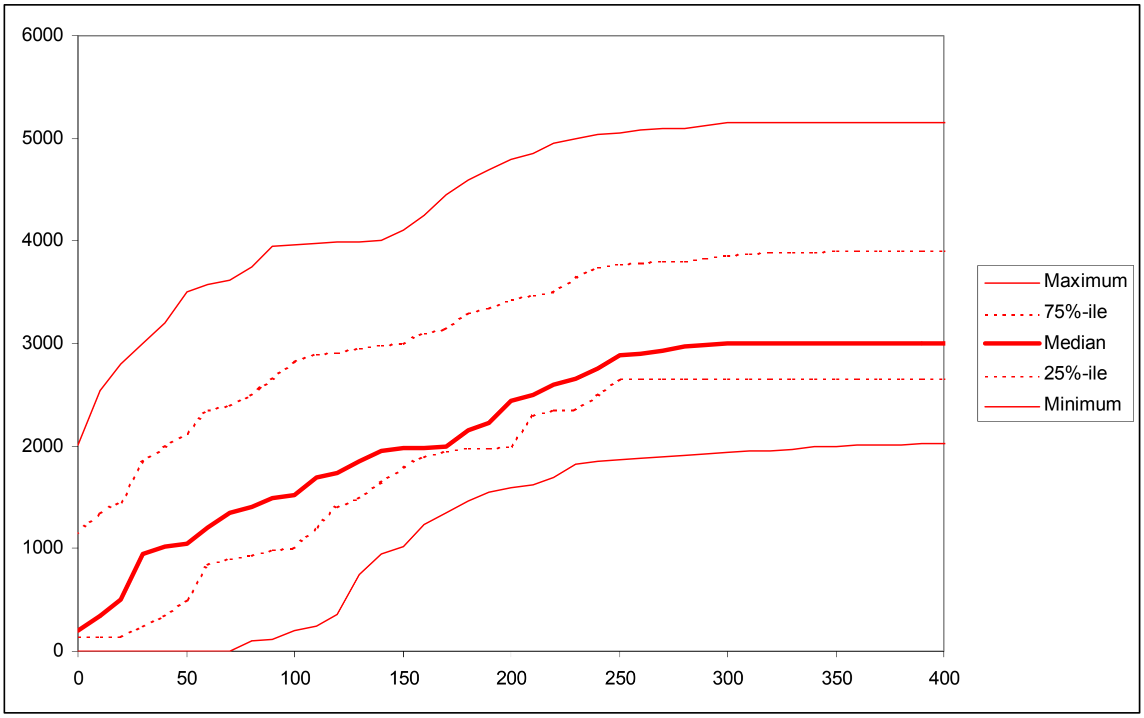

Figure 4. Preliminary result of determination for crop-water production function for corn grown at Uvalde, Texas, on Uvalde silty clay loam.

4. Publications and Other Research Products

The results from this project will be published as two articles in peer-reviewed journals. Preliminary citations for the articles are:

Brumbelow, K. and J.Y. Lee, WGEN-Sky and WFILL: Extension of the WGEN model to include sky cover condition and data filling capabilities, *Agric. and Forest Meteor.*, 2004. (in preparation)

Brumbelow, K. and J.Y. Lee, Use of net profit-water functions to assess implications of an irrigation limit policy for the Edwards Aquifer, Texas, *J. of Water Resour. Plan. Mgmt.,* 2004. (in preparation)

The modified weather generator WGEN-Sky and data filling program WFILL will be made publicly available from Kelly Brumbelow's professional web site http://ceprofs.tamu.edu/kbrumbelow/.

5. Student Progress

Mr. Ju Young Lee has made progress towards completion of his doctoral degree in the course of this project. During the project period he has completed doctoral qualifying examinations. He is currently at work in drafting a dissertation proposal on irrigation planning and management, which draws upon the experiences gained in this project.

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