Annual Water Balance at the Hunter and Huntington Research Farms - PacifiCorp

Utah State University 2012 Report

Prologue

Since the contract did not begin until 1 June 2012, this report covers a seven-month effort. In addition, after the new instrumentation was tested at USU, the output of the water vapor sensors began to decay. It was determined that they were defective, and the project had to wait until the manufacturer replaced the defective sensors and recalibrated them. Hence, the actual data collection began on July 5, 2012. Further, data logger program bugs were not fully resolved until July 26.

Activities

I. Field Measurements

At each of the three irrigation sites (Hilo, Castle & Rock), eddy covariance stations were installed. Each site included: a 3-dimensional sonic anemometer; a krypton fast-response hygrometer, a slow response temperature and relative humidity sensor; a net radiometer; two soil heat flux plates; a set of averaging soil temperature sensors; and a soil water content transducer. The soil heat flux plates were installed at a depth of 8 cm, and the soil temperature sensors located at 2 and 6 cm were averaged to estimate soil temperature for the 8 cm layer above the plates. The soil water content probe was installed so as to read the average water content for the same 8 cm layer of soil.

All the sensors in each station were wired into a CR1000 data logger. The long and complex program in the CR1000 was based on a generic program provided by Campbell Scientific. This was modified in our lab to meet the sites' particular configuration and needs. The output of the sonic anemometer and krypton hygrometer were sampled at 20 Hz (20 times per second). The other sensors were sampled at 5 second intervals, and averaged into one hour periods. All data were written to the flash cards in the data logger. The first full day of data collection began on July 6, 2012, although summary data tables were not outputting correctly until July 26th. The eddy covariance sensors were removed for the season on December 11, 2012 and taken to USU for cleaning and calibration. A non-irrigation season winter logger program that measures wind, solar radiation, temperature and relative humidity, precipitation, and soil moisture and temperature was employed and continues to log.

Telemetry to the stations was established so USU and PacifiCorp could access the station loggers to download data and monitor sensor status. A website was setup for access to the hourly and daily summary data (http://twdef.usu.edu/PacifiCorp.html). These data and graphical displays were updated daily. The winter program data and plots continue to be displayed at this website.

II. Unforeseen Issues

A major difficulty that was not anticipated was the routine irrigation of the sensors with saline water. The sensors are designed to be water resistant, and though data collected when they are wet are not valid, once they dry proper data are again collected. However, the instrumentation was never designed for exposure to saline water. In this case, after the water dries it leaves a deposit of minerals on the lens of the hygrometer and likely the transducers of the sonic anemometer. Therefore, these sensors were unable to generate reliable data until they were manually cleaned.

Because of the saline deposition issue, there were many periods when the output of the sensors was unusable. These periods existed at various times and various lengths (sometimes for a few days), in the time series data sets. Given that each day has over 1.7 million lines of data, it has been a painstaking exercise to locate and remove these episodes of bad data. As a result, USU was unable to provide near-real time estimates from the eddy covariance of evapotranspiration (ET) for the first year. However, a procedure has been agreed upon for following years that should minimize or remove this problem. USU was able to provide in real time, the “weather” data from the stations, so that PacifiCorp could use a simplified ET equation to schedule irrigations.

The useable data are now being analyzed, and some examples of the results will follow in this report. These results can be used to compare with the irrigation estimates made with the simple equation.

III. Analyses of Data

A program to analyze time series data from each site was written in house in our lab. Analyses needed to achieve the best estimate of the sensible heat and ET fluxes include: shifting the raw data columns back and forth to find the maximum covariance values between the variables (accounts for separation of the sonic and humidity sensor); rotating the coordinate system to remove any tilt errors of the sonic (it can never be perfectly level), and adjusting the flux values accordingly, determining the air temperature from the sonic temperature with an iterative procedure that uses humidity measurements, and changes to fluxes from the small vertical motions that result from density changes resulting from temperature and humidity differences in the air.

The program was tested and verified. It successfully calculates the final flux values, assuming the input data are "clean". This means that spikes, unreadable data, and "bad" data points must be removed first. Sometimes such problems are discovered when the program yields an unreasonable value for the fluxes. We then must delve into the time series file to find and remove the spurious values.

IV. Issue of Energy Balance Closure

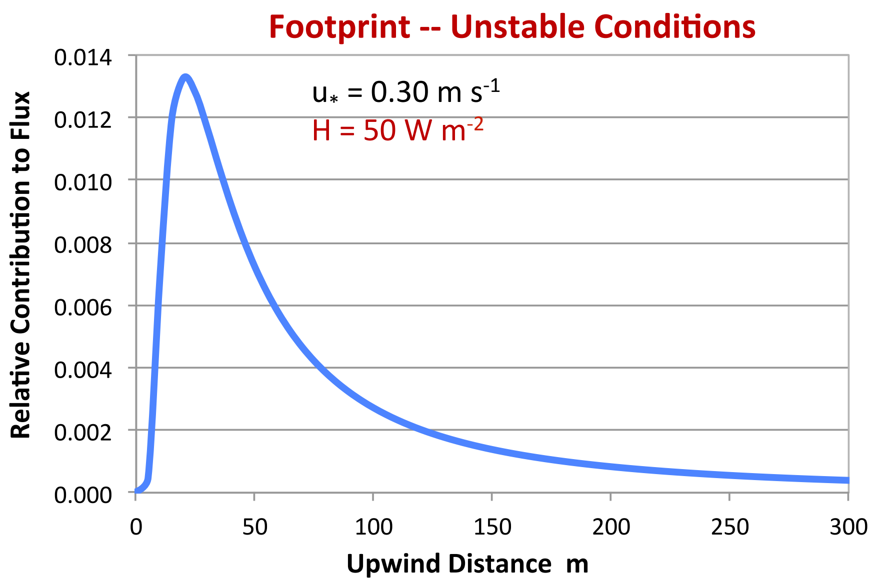
The final estimates of ET from the eddy covariance sensors are inherently too low to some extent. This is because any uncertainty or error acts to reduce the covariance and hence, flux. The best way to check this is to compare with available energy measurements. If all measurements and calculations were perfect, the sum of the sensible heat (H), and latent heat (LE) fluxes would exactly match the available energy, which is net radiation (R_n) minus soil heat flux (G). If the ratio of $(H+LE)/(R_n-G)$ is significantly smaller than 1.0, then flux values are often increased to force conservation of energy; this is referred to as forcing energy balance closure. Of course, this assumes that the R_n and G estimates are of high quality. We propose to force closure for any values under 0.85.

Results

a. Footprint Seen by Measurements

The sensors were mounted about 3.5 m above the surface. This height was chosen in an attempt to balance the minimization of irrigation water reaching them with the size of the upwind fields. It is important to verify from what region the flux estimates are coming from. A footprint model by Hsie et al. (2003) was used to approximate the upwind region seen by the sensors under typical conditions at the site.

The first analysis is for unstable conditions typical of many daytime situations. The results are depicted in Figures 1a and 1b, which show contribution towards the flux and cumulative flux from each upwind distance. Most researchers note the upwind distance where 80–85% of the flux originates; this is because the mathematical form of these models has an almost infinite tail. In Figure 1b the value for 85% of the flux is shown to be about 250 m.



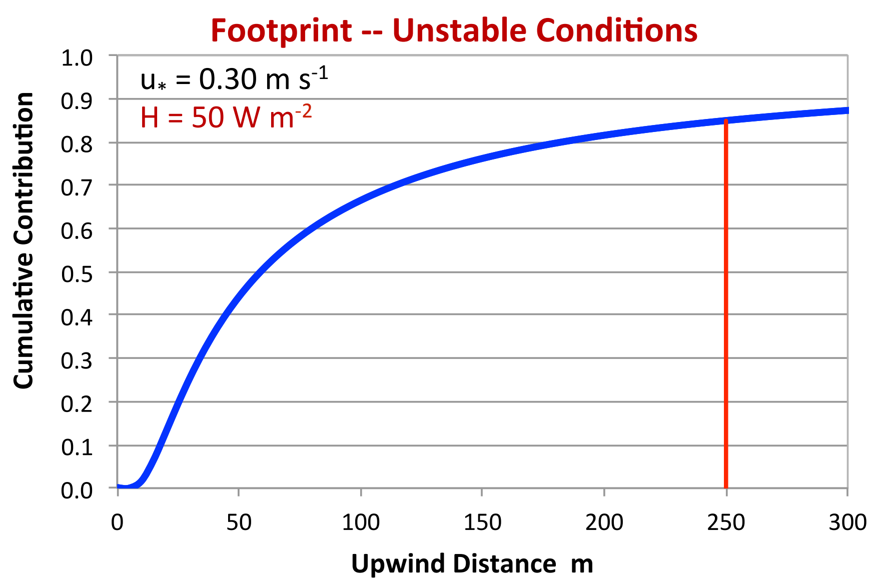


Figure 1. *(a) Contribution to flux vs. upwind distance. (b) Cumulative contribution vs. upwind distance. The value producing 85% of the total flux marked.*

The footprint for neutral conditions, where there is little surface heating and sensible heat flux, is shown below. These conditions are less common. Only the cumulative distribution is shown in this case.

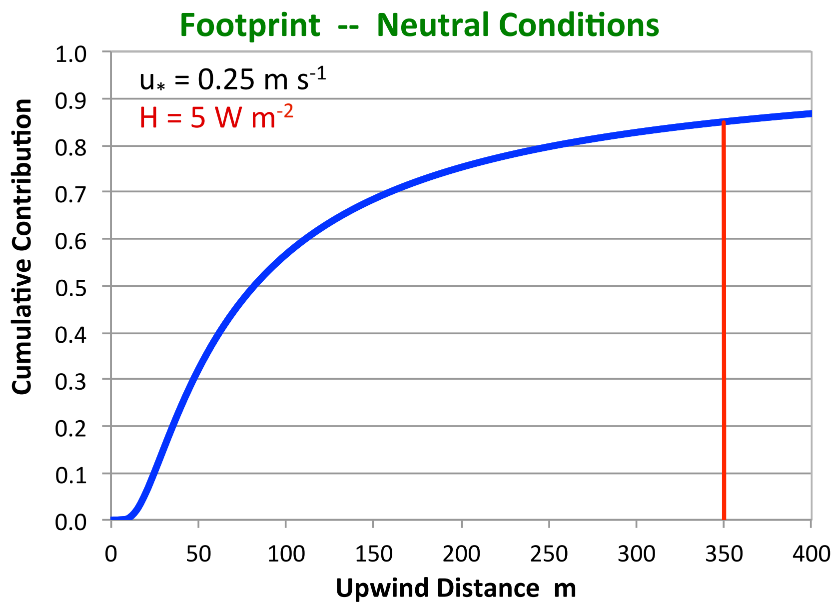


Figure 2. *Cumulative footprint for sites under neutral atmospheric conditions.*

The upwind distance responsible for most of the flux has increased to about 350 m. The results of the footprint analyses suggest that the sensors may be marginally too high, and should be lowered; this will be discussed in the conclusions.

It is well known that footprint models are not appropriate for apparent stable conditions that occur when heat from drier surroundings is transported over a surface with high ET. This is very common for this location. Hence, no analyses were conducted for such cases.

b. Examples of Energy Balance and ET for Several Days

As discussed earlier, the data files were very corrupted with bad data due to being irrigated with saline water; this has greatly increased the effort and time to perform the proper analyses for ET estimates. However, we have cleaned up most of the files, and plan on completing the estimates for those days with adequate data.

Here we will show some results for the Hilo site. An example of the course of the sensible heat and ET fluxes is shown in Figures 3 and 4, for 26 and 27 July 2012. These were complete days with relatively large fluxes.

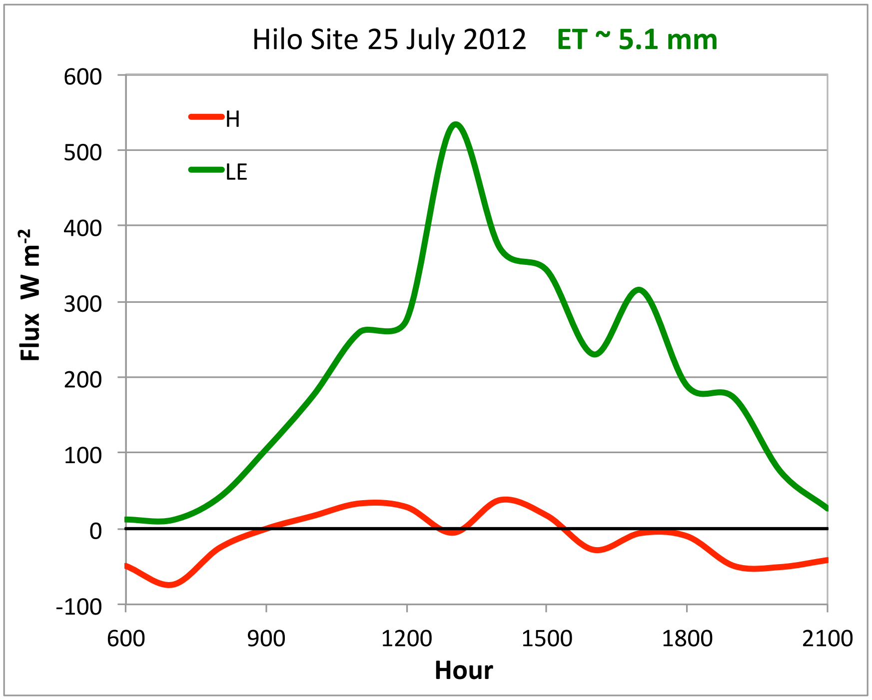


Figure 3. *Daytime fluxes of H and LE for Hilo, July 25, 2012.*

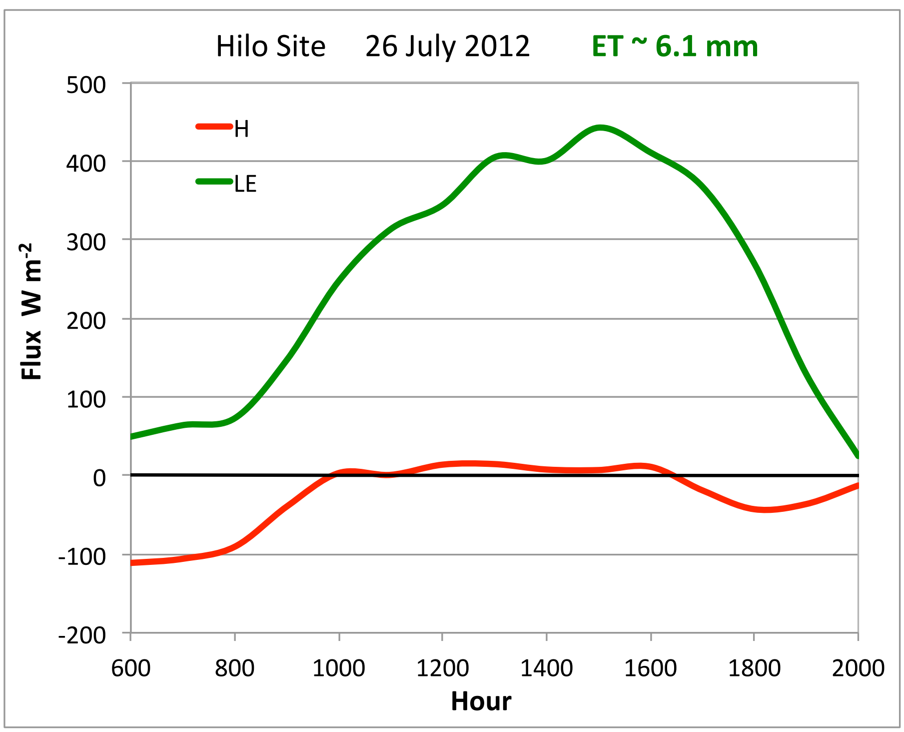


Figure 4. *Daytime fluxes of H and LE for Hilo, July 26, 2012.*

The daily ET values are not adjusted for energy balance closure at this point. The net radiation and soil heat flux data are being double-checked to verify their reliability. At that point, the fluxes will be adjusted upward. But even the unadjusted values are typical for irrigated alfalfa in northern Utah.

c. Daily ET Values at Hilo

The daily totals for ET have been computed during a period in the middle of the summer for the Hilo site. For about a 5 week period, the daily totals were determined from the eddy covariance data for each day with a complete set of clean data. Figure 5 shows these results, as well as the daily reference ET estimates that were provided by USU to PacifiCorp.

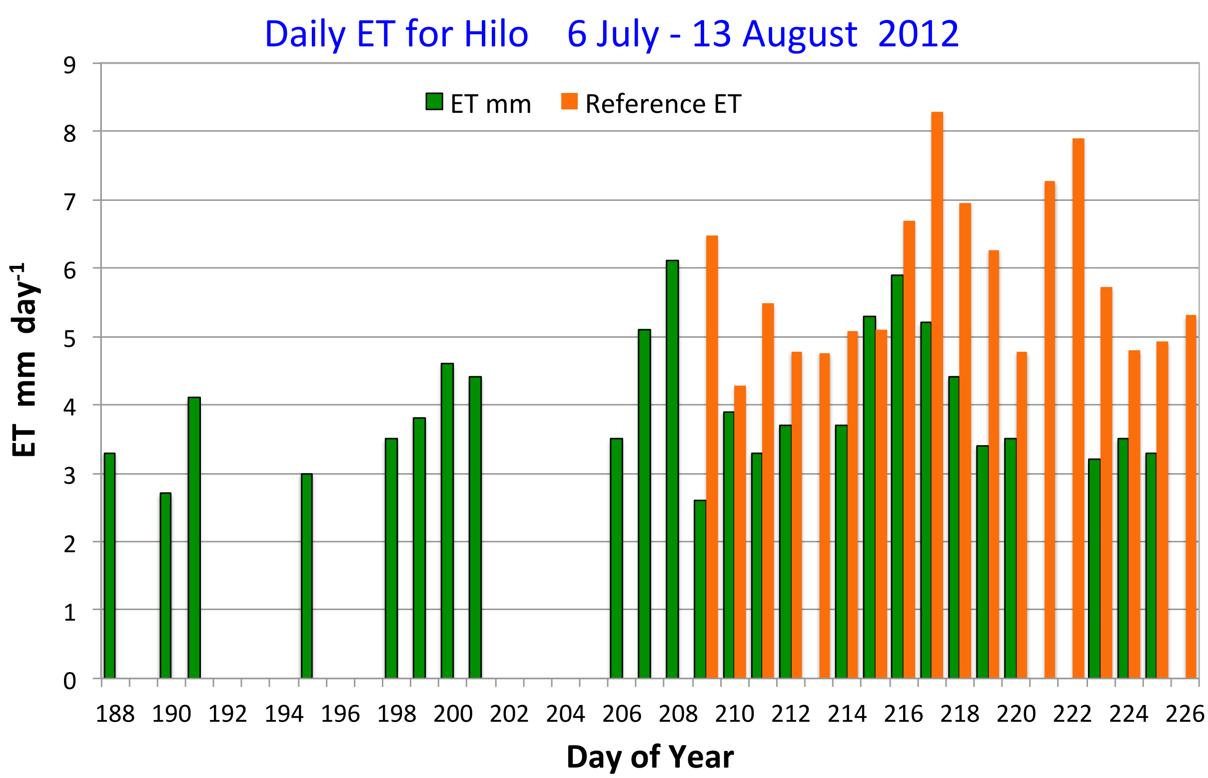


Figure 5. *Daily ET at Hilo for complete days in a 5 week period.*

These are not yet adjusted for energy balance closure. Values range from about 3 to 6 mm per day. The lower values appear to be associated with periods of clouds during the days. There may also be a connection to stage of growth and cutting.

Additional Analyses Being Conducted

The cleaned data files will be produced for each of the three sites for the period of measurements. These will allow daily ET to be estimated for all complete days of reliable data. For partial days of data (there are a number of them), a gap filling procedure will be employed to fill in the missing hours. This will use a combination of a reference ET value and the so-called evaporative fraction, the ratio of ET to available energy. This is often conserved during much of the day.

As stated earlier, the energy balance closure will be examined for each day, and ET values will be increased as appropriate. The final results will be ET estimates for all possible days during the measurement season. A number of days will not have any eddy covariance estimates due to the contamination of the sensors from the saline water.

Conclusions and Proposed Changes

The plans for the measurements and analyses were seriously compromised by several unforeseen problems that included; defective instrumentation, and irrigation of sensors. As a result, it has been a monumental effort to clean the data and perform the analyses. However, we have now developed procedures to QA/QC the raw data and perform the analyses necessary for fluxes. A procedure has been agreed upon to minimize irrigation of instrumentation in the future.

The daily ET fluxes have been calculated for much of the Hilo data, and the other sites will now soon follow. After forcing the fluxes to match available energy, daily totals will be available for many of the days. These can be used to compare with the operational daily estimates made with a modified reference ET equation, using the weather data from the eddy covariance stations

The sensors should be lowered to ensure they see only the irrigated fields. This would likely improve the ability to match available energy and provide more reliability to the ET estimates.

A fairly simple algorithm can be developed to make estimates of ET from the rough hourly values written into the data logger table each hour. Since these data can be accessed remotely, the algorithm could be implemented in real time by PacifiCorp. These results would be available on a daily basis.