AVRC Lysimeter Water Budget Process

*Process notes taken and compiled by Lane Simmons.*

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he AVRC water budget process was developed and used by Dale Straw, a former engineer with the Colorado Division of Water Resources. Dale built all of the lysimeter water budgets from 2007 – 2015. These notes were developed from a combination of two water budget process meetings led by Dale, plus water budget process experiences by Lane Simmons in subsequent years.

The first meeting was at the CSU Fort Collins campus January 30th – February 1st, 2013. This meeting was attended by Dale Straw, Tom Ley, Allan Andales, Lane Simmons, Jose Chavez, Abhinaya Subedi, and Abdulkariem Aljrbi.

The second meeting was at the AVRC, November 9th – November 10th 2015, and was attended only by Dale Straw and Lane Simmons. The bulk of these notes were taken from this November 2015 meeting. Later additions/modifications to these notes were made by Lane while actually working on budgets.

The process consists of four main steps:

1. Identify, collect, and check source data for quality; correct problems. This includes Etr values, data for Etr calculations, and load cell data. Etr source data may be from a single weather station, or multiple stations.
2. Identify and analyze non-standard days (NSD). There are a couple of methods that can be used.
3. Calculate daily Etr (alfalfa reference ET) for the season. Data must be sourced from a weather station in a reference environment (with the exception of the solar radiation source). This data may come ready-to-use from METS, or one can use Straw C-Programs and Excel tools to calculate Etr. Using Straw methods will require up-to-date C-programs (i.e. sensor coefficients).
4. Complete the water budget and crop coefficient curve. This may include calculating growing degree days, and adjusting (smoothing) for NSD’s.

# General Notes on the Water Budget Process

* The LL load cell range is approximately 0-4.5 mV/V, or 7,500 lbs.
* The lysimeter dataloggers (CR7) are programed to take sensor measurements (scan rate) every 6 seconds. The load cell is measured every 2 seconds.
* The METS datalogger (CR1000) is programed with a 5 second scan rate.
* Data is then averaged into 5-min and/or 15-min and/or 24-hour values (and 60-min in the case of METS).
* Calculating Reference ET (Etr) is needed so crop coefficient curves can be built, and Etr data can be necessary when using the Straw method to process non-standard days (NSD).
* Etr is computed using C-programs and Excel spreadsheets designed by Dale. Or, it can be obtained from the METS min60 table.
* Once Etr is computed, the results should be compared to Etr values from other sources:
  + RFD01 weather station – Daily Etr is calculated in post-processing and available from the CoAgMet web site.
  + METS weather station - Code included in the METS CR1000 datalogger program does an hourly Etr calculation, which can be summed into a daily total.
  + Straw Method
* Etr values, if they are used in the water budget to build a Kc curve, must come from an AVRC station located in a reference site. Currently, this data will come from METS, unless the RL or LL is in Alfalfa (or grass, but this will change things). Inputs into Etr include temperature, relative humidity, and 2m wind speed. Straw method Etr calculations uses solar radiation sourced from the CM14 on the LL if the sensor is above the canopy. The METS CR1000 datalogger Etr calculation uses its own Pyranometer for solar data.
  + ***WARNING****: With the installation of a linear-move sprinkler system on the LL field in 2018, the LL mast was no longer raised to keep sensors above the plant canopy; which was corn in 2018. Consequently, at some point in the season, the LL wind and solar sensors were covered up by vegetation. This means the resulting data from those sensors is unusable. This will be the case for the foreseeable future for tall crops such as corn and forage sorghum. Therefore, the LL ASCE-PM rate, as computed in the 15min ET Rate for NSD spreadsheet would be meaningless. LL NSD analysis would have to be done using other techniques.*
* **Note/explanation of the alternative method used for NSD/NSE analysis.**

For analyzing each NSE (i.e. irrigation, rain, drainage), the NSE start time, stop time, beginning load cell, and ending load cell were determined from the 5-minute lysimeter load cell data. The load cell reading one hour before the NSE start and the load cell reading one hour after the NSE end were also determined. Using this information, an ET slope was determined for the hour before and after the NSE. The weight change per minute was calculated for both slopes, averaged together, and then applied to the duration of the actual NSE, for an estimation of ET that occurred while the NSD was taking place. This estimated ET is used to adjust the water gain or loss caused by the NSE. As an example: a crop is still consuming water (ET) during an irrigation event, which “drags down” the amount of water being measured as irrigation; an estimated ET value is determined and added to the measured irrigation amount. Note that the one-hour slope time is arbitrary.

In previous years, this alternative method has compared well with Dale Straw’s method which requires the use of an ETr curve.

* Water budgets may provide different seasonal water use totals, depending upon how the season is defined. **Be aware of the start and stop days when comparing results from one year to the next.**
  + Depending upon the crop, harvest is mainly done at a convenient time (assuming the crop is ready to harvest). When does the plant ‘shut down’ and quit using water?
* Many of Dale’s water budgets use the first NMM to the last NMM measurement as water budget start/stop dates. This allows one to compare the NMM change in soil moisture with the change computed via the load cell.
  + Dale used the Soil Moisture Budget worksheet to compare NMM data with load cell data. The column with the formula multiplies the NMM value by the volume of soil in that specific layer. Units cancel out to end up with mm of water.
* Hourly vs. Daily Etr Computations: Dale said that the sum of 24, separate, hour Etr values into a daily total maybe more accurate than the Daily computations.
* ASCE-PM ETr Equation: Units cancel out and you are left with mm/day or mm/hour.
* ***Up until now (end of 2019), the Straw C-Program and Excel tools are not adjusting wind speed for changing crop height at the Etr station (i.e. METS).*** *Crop heights are recorded in Lane’s log book; however – this may not be recorded on a consistent basis.*
* Sometimes Celsius is converted to Kelvins in the ASCE-PM (per Dale).
* Identifying and analyzing non-standard days for the water budget can be very time consuming. However, during the actual growing season, Lane identifies and does some analysis of these NSDs for his log books. So, it is possible that much of the NSD work has already been done by the time the water budget is started.
* Collecting, organizing, and checking ASCE-PM Etr source data for errors and quality, prior to starting the actual budget, can also be time consuming.
* Dale has never calculated measured (load cell), *hourly* ET. The water budget measured ET is based on load cell readings at the beginning and end of each day – *Daily* ET. The 15min load cell data, at 12:00 Midnight (24:00) is used.
* Jose is interested in how the weather affects the Penman Monteith (PM). For this research, he *may* only be able to use standard days.
* **Do not confuse 15min data at 2400 (midnight) with the separate, 24-hour (daily data) data set.** With lysimeter data (CR7), this is difference is denoted in the data rows. With METS data (CR1000), these are separate final storage tables.
* Kc curves can be charted against accumulated growing degree days (GDD). Be sure to use crop-specific upper and lower threshold temperatures.
  + For corn we have used 86 F and 50 F.
  + For winter wheat we have used 86 F and 32 F.
  + Use Celsius values for reporting.
* Regarding forage sorghum GDDs. Per an 11/18/16 email from Allan*: “The attached paper used Tbase = 11 C and no Tmax cutoff for sorghum (see Table 3 and figure 4). Maybe you can do the same.”* The attached paper was Maughan et al 2012 AgronJ sorghum.
* **In the Water Budget Spreadsheet – Use the season’s 15-min, 2400 values for columns C & I in the main budget page. Ensure an offset; one day’s ending load cell value is the next day’s beginning value.**
* **Make sure the correct scale calibrations are imbedded in the water budget spreadsheet**. Refer to the 12/26/2012 Word document written by Allan: Load Cell conversion coefficients for RL and LL.docx.  **As of 12/26/2012, the LL coefficient will by 74.58 mm/mV/V and the RL coefficient will be 151.09 mm/mV/V.** These two coefficients are based on a larger effective surface area measured from ‘gap-to-gap’ as opposed to the original surface area ‘inside-to-inside’. These ‘modified coefficients’ will result in lower ET rates from the lysimeter. Use of this larger surface area was recommended by the Bushland, Texas lysimeter group. The coefficients are based on the most recent scale calibrations: 2011 for the LL and 2009 for the RL.
* Allan Andales suggested designing water budget spreadsheet so there is one cell with the coefficient, and all formulas refer that cell. This would make changing the coefficient easy. As of 8/2/17 this has been done in multiple places; however, there may still be a few embedded scale coefficients in place.
* Dale has the option of using an Excel Spreadsheet, or a C-program to compute ET. He does both as a check. The Excel version does use an input file that is built using C-programs (not the C-program that does the actual Etr calculation).

# Raw Data

* The way the process is currently set up, the C-programs, that are used to compute Etr, expect data to be in the LL or RL Excel files respectively. So if you need to use data from another source, you must delate the data you want to replace, and then copy and paste data from the other source into the original LL or RL spreadsheet. So the programs are ‘fooled’ into using this substitute data instead of the original data. Make sure your time stamps match up correctly.

Example #1: You can substitute METS 15min temp, rh, and wind speed into the existing RL data file, replacing existing RL data for these parameters. This can be done if you want to use the Straw method to compute Etr for a Kc curve.

Example #2: You can substitute LL CM-14 data into the existing RL data file, replacing existing RL data (Epply) for solar radiation. The CM-14 is considered a slightly better solar radiation sensor than the Epply.

* You need a properly sited weather station for ETr calculations, but not for NSD analysis using the Straw method.
* Up to 3rd cutting, 2015, on the RL, the RL was used for the majority of the ASCE-PM source data. As of 2016, the RL is no longer in alfalfa, thus no longer a reference site. METS will become the primary source of data for the equation. The only exception to this could be the solar data which can sourced from the LL CM-14 – if it’s above the plant canopy.
* Raw data must be put through some sort of QC process.
  1. Check the number of lines in the raw data. This can be done in Excel.
     + 5min data: 288 lines per day
     + 15min data: 96 lines per day.
  2. Chart the data; look for bad or out of range data.
* Dale says that the CR7 will sometimes collect twice, resulting in two lines of data for the same time stamp. You will need to correct this when found. Pick the data line that looks the best, and delete the other.
* Sometimes a datalogger will skip time: i.e. hours 7:00 – 14:00 are missing.
* Sometimes data is missing due to maintenance or calibration.

Source data to be used – 2017 RL winter wheat example:

Air Temperature Source: METS 15min and Daily

Relative Humidity Source: METS 15min

2m Wind Speed Source: METS 15min

Solar Radiation\*: Large Lysimeter CM14 15min

Solar Radiation\*: METS Li-200 15min

Load Cell for Water Budget: Reference Lysimeter 15min

Load Cell for NSD Analysis: Reference Lysimeter 5min

\*If daily Etr values are obtained directly from the METS CR1000 hourly data set (METS\_Min60), the solar radiation source is the METS Li-200 pyranometer. If Etr values are obtained from the traditional Straw method, using C-programs and Excel spreadsheets, the solar source is the LL CM14. The origins of the Etr values used to build a Kc curve should be denoted on the final water budget spreadsheet.

Source date to be used – 2015 LL forage sorghum example:

* + 24hr RL: Daily max and min temperature.
  + 15min RL: 2m wind speed, temperature (HMP45), and relative humidity (HMP45).
  + 15min LL: CM14 solar radiation (incoming).
  + 5min LL: Load Cell (for NSD analysis).
* In 2014, Dale did use 24hr data from the LL for max and min daily temperature. Normally, you would use RL 24hr data (or METS).
* Dale uses one of Don D’s old C-programs (Don was involved with Texas lysimeters and was an advisor during the development of the AVRC project) for separating the 24hr and 15min data that are in the original CR7 data text files; this results in two comma delineated text files: 24hr and 15min. This method may not be available going forward. However, you can use Excel to filter and separate these two files.

# Non-Standard Day (NSD) Analysis – Straw Method

* Non-standard days are days during the season where there were irrigations, precipitation, drainage, harvests, and counter weight adjustments, etc.
* NSD – Non Standard Day
* NSE – Non Standard Event
* Dale Straw, retired CDWR engineer, developed this method (Lane calls it the Straw method).
* Allan hasn’t found other academic literature discussing how to handle non-standard days (as of the 2013 meeting).
* There may be multiple NSE during a single NSD.
* Often, if you threw out all of the non-standard days at the season, very few days would be left to work with.
* You may need to remove irrigation and rain NSDs, plus a day or two afterword, from the final Kc curve. These events create spikes in measured ET because of the increased surface evaporation. These NSDs can cause spikes for a day or two after the actual event.
* Sometimes, what appears to be a single NSE, will need to be divided up into separate events. For example a NSD may include a rain event. But the rain event may include periods of time where it stopped raining; so the rain would be divided up into several NSE.
* Dale has referred to the lysimeter as a 250k anemometer and rain gage.
* **The question for non-standard events is*:*** *What was the measured ET actually doing during this event? For example, while it may be raining, there is still some ET occurring. But the rain is altering the scale readings, making it difficult to measure ET.*
* **The working assumption:** *You can use the ASCE-PM ET curve to estimate what the measured ET rate would have looked like, had the NSE not happened.*
* The source data for the ASCE-PM curve, used in the NSD Straw method, does not need to be from a station in reference conditions. However, source data for ASCE-PM Etr used to develop a crop coefficient curve **must be** from a station in a reference site. There is a difference in the RL and LL Excel setups specific to this issue.
* There are seven pieces of information we need for each NSE:
  1. Date.
  2. Time event started.
  3. Time event stopped.
  4. Load cell reading when event started.
  5. Load cell reading when event stopped.
  6. Estimated ET rate when the event started.
  7. Estimated ET rate when the event stopped.
* Dale used an Excel workbook called DayPlot to analyze NSD date, time, and load cell values; and a workbook called PMprint to estimate ET.
* Dale used a seven day time scale as a first-pass to find potential NSDs. Dale used a handwritten worksheet with a line for each growing season day where he can note if a NSD occurred or didn’t occur.
* Using the worksheet as a guide, Dale goes to each NSD he identified, and scales down to a day or two for an ‘up close’ look.
* Dale uses PMprint to look at the 15min data for NSD analysis using the ASCE-PM measured ET charts.
* Dale’s PMprint file was so named because he used to print out each NSD chart and put it in a three ring binder.
* To find the first five pieces of information for each NSD event, chart the 5min load
* Lane uses an alternative (to DayPlot) Excel workbook to find NSE and NSD. He uses his QC/QA Excel file named RL 5min (or LL 5min) that contains 5min load cell data with charts. It really does not matter, as long as you are using 5min load cell data with a scatter chart using smooth lines and markers. Correctly formatting the data series line and markers can make the load cell analysis much easier. Each marker (at every 5min data point) should be visible. Data can be looked at in 3-7 day increments to find NSDs. Once a NSD is identified, that specific day can be selected (chart that one day only) and the view/zoom tool makes it easy to find event start and stop times and weight values (Lane likes 400%).
* Lane does much of the NSD/NSE identification and analysis during the season as part of his log book records. This includes a simplified variation of estimated ET rate. This allows a comparison between the Straw method results and what is in the log book. Any major differences can be investigated.
* Hold the mouse cursor over the 5min load cell curve/line in question to get your data points. You will need the low point and high point for each NSD event. If there are several time stamps with the same reading, go with the last for the low point and the first time stamp for the high point.
* NOTE: Once you have identified the NSD and recorded start/stop times and weight values, the next step is to estimate the start/stop ET rates for these events. The spreadsheets used to estimate NSE ET rates are very similar to the 15min spreadsheets used for every-day QC/QA data checks during the season. ***Currently, there is a difference between the Excel set-up for RL and LL NSD ET rate analysis****.*
* **Warning**: It seems this method can produce the rare, occasional, faulty number. For example: 4/25/17 (115), a rain event lasting from 14:45 to 0:00 totaled 0.468”. This matched CoAgMET pretty well. A good estimate of starting ET rate was made – 0.15mm/hr. However, this resulted in a rain total that was way off base – 2.125”. It is assumed that this may be a mathematical result from the fact that the rain event was a long one. This problem was discovered when comparing to the original, log-book records for rain. This illustrates the importance of having multiple ways of looking at data.
* It is important to double check the season’s 5min data via a chart; to make sure you didn’t miss a NSD.

# For the LL: Lane has renamed this workbook LL … 15min ET Rate for NSD.xls.

* ***WARNING:*** *With the installation of a linear-move sprinkler system on the LL field in 2018, the LL mast was no longer raised to keep sensors above the plant canopy; which was corn in 2018. Consequently, at some point in the season, the LL wind and solar sensors were covered up by vegetation. This means the resulting data from those sensors is unusable. This will be the case for the foreseeable future for tall crops such as corn and forage sorghum. Therefore, the LL ASCE-PM rate, as computed in the 15min ET Rate for NSD spreadsheet would be meaningless. LL NSD analysis would have to be done using other techniques****.***
* In the first worksheet (tab) you will copy and paste all of the LL 15min data for the entire season. This data doesn’t have to be mixed and matched as you are not using it for calculating real Etr values. Using this as your data source, copy and paste two days (48 hours) into the Input worksheet. The second day should be the NSD in question. A second worksheet named Data contains sensor coefficients. A third worksheet named Asce-PM calculates ASCE-PM Etr (using the 15min data) and measured ET. The results of which are graphed in a chart named ET rate. The chart shows the second day of data only. Using this chart, one can estimate the ET rate (mm/hr) at the start and end of the NSE. Those two data points will be entered into the NSD worksheet in the actual Water Budget Excel file.

# For the RL: Dale named this workbook RefPMPrint.xls.

* In the first worksheet (tab) you will copy and paste all of the RL 15min data for the entire season. In a second worksheet (tab) you will copy and paste the entire season’s ***hourly*** Etr values. These values are from the Hourly C-program Etr calculations (Junk.xls). METS hourly Etr can also be used, but it will be necessary to rearrange, modify, and format the METS data to fit the existing Excel template; for example: 5:00 becomes 500. There will be three columns pasted: day (Julian Date format), hour, and Etr; these are actual, calculated Reference ET values. **Unlike the LL setup, the ASCE-PM curve used to estimate the ET rate during the NSE is not calculated using the 15min data from the first worksheet.** So these are true Etr values, as opposed the LL setup which uses inputted 15min data to calculate Etr – data that may not be from reference conditions unless the LL was planted to hay or irrigated grass. Using the first two worksheets inside PMprint as your data source, copy and paste two days (48 hours) into the Input worksheet. One or both of these days will include non-standard events (NSE). One part of the table will accept the 15min data, and another part of the table will accept the hourly Etr values for the two days in question. This worksheet feeds the ET rate chart. A second worksheet named Data contains sensor coefficients. Etr values and the measured ET rate are graphed in a chart named ET rate. This will be for a 48 hour time period (as compared to the LL setup which only charts the second day). Using this chart, one can estimate the ET rate (mm/hr) at the start and end of the NSE. Those two data points will be entered into the NSD worksheet in the actual Water Budget Excel file.
* Dale thinks an Excel tool could be build that would enable the cursor to display X/Y coordinates in the chart’s field; useful for estimating beginning and ending ET rates.
* The information gleaned from the previous steps are entered into the ‘Non-Standard Days’ worksheet in the Water Budget spreadsheet. *In this NSD page, each event, even within a single day, has its own line. So there may be multiple lines for a single day.*
* Data entered for each event: Date, Julian Date, Start Time, End Time, Starting Load Cell (mV/V), Ending Load Cell (mV/V), Starting ET Rate (mm/hr), Ending ET Rate (mm/hr).
* Use 24:00 for an end of day (midnight) time stamp, not 0:00. Excel may change the 24:00 you entered to a 0:00 automatically, but don’t manually enter 0:00, this may lead to incorrect calculations. Manually enter 0:00 for a start of day time stamp.
* Within the NSD worksheet, in the Water Budget Excel File, there is a column called “Change Load Cell mV/V”. The cells in this column calculate the average (estimated) ET rate during the event in question and multiply it by the length (time) of the event. This gives you the estimated total volume of water consumed by ET (mm of water) during the non-standard event. The formula then “adds back” this weight change that was caused by ET. Keep in mind that we need to know what the event’s load cell change would be without the effects of ET during the event. For example, during irrigation, the load cell change would actually be greater if ET wasn’t ‘dragging down’ the increase in weight. With drainage or harvest, you have the opposite situation; drainage or harvest is less than what the load cell might indicate, because ET is also causing a decrease in monolith weight. So the formula adds-back the weight change that was caused by ET. In summary, the mV/V value in the Load Cell Change cell is the weight change attributable to the event and, only the event, with no effects of ET.
* The results from the NonStandard Days worksheet can be compared with data from Lane’s log book. Lane uses a different method for estimating ET during the NDE for log book purposes.
* Within the water budget spreadsheet, complete the Non-Standard Days page first, using data from the DayPlot and PMprint files (or equivalent files). Copy and paste the ***values*** from the NSD page into the main Budget page. **Pay attention to the +/- signs.**
* The Water Eq. added (in) cell in the NSD page is simply the load cell change described prior converted to acre inches of water.
* In the main Budget page, the load cell change attributed to the event is removed from the end of day weight – beginning of day weight equation. Any remaining weight change, by definition, has to be ET.

# General C-program Notes

**The existing C-programs can be thought of as performing two separate tasks:**

* 1. Selection and organization of data needed for the ASCE-PM Etr calculations.
     + This could actually be done just using Excel. However using C can speed the process up, and eliminate some human error.
  2. The actual calculation of the ASCE-PM.
     + This calculation is also done with Excel, the results of which can be compared to C. It is good to run the ASCE-PM calculation in multiple ways for QA/QC purposes. The data inputted into Excel for computing Etr is from the portion of the C-program process that selects and organizes data.
     + A downside to using Excel, is that the Excel version requires a very complex spreadsheet, which would be very difficult to reproduce, and could easily become corrupted by an errant key stroke or mouse click.
* Currently, there are two separate C-Program ‘packages’ for calculating Etr.
  + Daily
  + Hourly
    - The hourly data is summarized into daily totals for a ‘final’ data set that can be compared to results from the Daily process as well as other Etr sources (METS, RFD01).
* Some programs are for the LL data set (crop), some for the RL data set, and some may work with both.
* **Important Note**: RL and LL data columns may not match up, so C-programs that are looking for specific columns may not be transferable between RL and LL without modification to the program. *C-program calls the first column ‘0’. This is important when comparing Excel columns to instructions within a C-program (i.e. column 1 = column 0).*
* Look in the C-program text files (containing code) for each program to know what that specific program’s input and output files are, as well as what columns the program is looking for.
* Computed ETr values are used within the water budget to develop crop coefficient curves.
* C-program source data can be from multiple stations. However, this data must be from stations in a reference environment, with the exception of incoming solar radiation.
* Excel can be used to build custom data sets from multiple sources.
* An Excel worksheet can be customized, so the C-program will look for, and find, the correct data columns.
* Originally, there was only one Daily comma program; it had to be modified and re-compiled to switch between the 15min and 24hr files. On 11/9/15, Dale wrote a second program so that one can be used for the 15-min data and one can be used for the 24-hour data. However, the Comma24 only works for the RL data set; it will not work for the LL data set. So if you need to use 24 hour METS data, you must plug those data columns into a 15min RL data file. It is possible to create a raw text file without commas using Excel; therefore one would skip the Comma programs.
* The Hourly program sequence is a little simpler than the daily setup in that you don’t need to rename as many files (you still have to rename the Comma output file).
* Make sure you have 96 lines for a complete one-day (15min) data set. If one line is missing the whole C program will fail.
* Any length of time will work: i.e. one week, or one year. However, things must be in daily increments.
* Dale used the ASCE-PM manual’s examples to test his C programs and spreadsheets.
* Dale has been using 2m wind speed for ASCE-PM calculations (3m wind speed is available).
* Computing the Daily ASCE-PM is the only place we use the 24 hour data set. This data set consists of the each day’s Max and Min temperature.
* The hourly ASCE-PM, or predicted ET, is used to plot alongside the measured non-standard events.
* We only use incoming solar radiation on the Albedometer for PM computations. So the reflective surface may not matter.

# Computing Daily Time Step Etr with Straw C-programs

1. Make sure you have access to all of Lane’s log books for the year.
2. Make sure you have access to that year’s Julian date calendar.
3. Create a working file folder for the current water budget.
4. As needed, paste *copies* of the original LL, RL, and METS raw data files (comma delimited text) into the folder. You might not need all three data files, depending upon what you are using for Etr source data and what C programs are available.
5. Import the raw data files into Excel.
6. Use Excel to filter out the 5min, 15min, and 24 hour data as needed. Label worksheets.
7. Add column headers to the worksheets.
8. Decide which data sets and data columns are needed for ASCE-PM Etr computations.
   1. You will not need 5min data for Etr calculations. This data is used for other applications such as non-standard-day analysis.
   2. You will need 15 min data (solar, temp, RH, and 2m wind speed).
   3. You will need 24 hour data (daily high and daily low temp).
   4. This data must be in data tables (specific column order) where C-programing knows where to look.
   5. Clearly mark the data to be used.
   6. Data may be from multiple sources.
9. Check raw data for problems.
   1. Duplicate lines, missing lines, missing data, out of range values.
   2. Compute how many lines of data should be present for a given date range.
   3. Chart each of the data sets needed for the ASCE-PM computation, looking for data problems.
10. If needed, substitute alternative data to replace bad data.
11. Copy the 15min data (data only, no labels) and paste into a temporary Excel workbook. .
12. Convert the Excel data into comma delimited text files (\*csv) via the ‘save as’ command. Do not save any changes to the original Excel file.
13. Change the newly created text file’s extensions to \*dat. The names of these \*dat files will be what the first C-program is looking for.
14. These new comma delimited text files will be the input files for the first C-Programs you run (Comma-type programs).
15. If the Excel file is saved as Formatted Text Space Delimited (\*.prn), you will run into column space problems in WordPad or Notepad; there won’t be enough room for all of the columns in the original Excel file. However; later on step 18, you will use the \*prn extension.
16. Within the C-program sequence, the output data from each program will be used as input data for the next program in the sequence. You will have to rename output files.
17. **Comma15 (or Comma)**
    1. Input file: original, raw, 15min
    2. Output file: out.dat
    3. Rename the file: 15 min in
    4. Program removes the commas and replaces them with spaces.
    5. Run for LL and RL (if you need data from both sources). *However, if you use data from multiple sources, you could have already created a custom 15 min Excel table (converted to csv) for the 15min input file, wherein you replaced LL or RL 15min data columns with those from METS/LL/RL as needed. The C-program is ‘fooled’ into grabbing this replacement data when it runs one of the lysimeter tables.*
18. **Comma24**
    1. Input file: original, raw 24hr file
    2. Output file: out.dat
    3. Rename the file: 24 hr in
    4. Program removes the commas and replaces them with spaces.
    5. You will typically only need to run this for the RL since you are only needing the daily max and min temperature.
    6. If you are using METS 24 hour data, you will want to replace the RL data columns with the corresponding columns from METS.
    7. **NOTE:** Comma24 is the final program used to process the 24hr data. The *Avgdaily* program will use this file for one of its two inputs.
19. **Table**
    1. Input file: 15 min in
    2. Output file: out.dat
    3. Rename the file: input.dat
    4. This program selects the data columns needed for the ASCE-PM. The load cell column is selected but it is not used.
    5. Table must be run for both LL and RL 15min data. There will be a different program for the LL and RL because of different column locations.
    6. **If you built a custom Excel table already in step 1 (table contains columns from proper data sources) you will not need to do steps g and h. The input.dat file can be used directly with the Avg program. This will be the case if METS is used (unless a METS C-program gets written).**
    7. Copy the resulting LL and RL data to Excel and create a third data set that consists of specific data columns from each of the two original input files
    8. Save this newly created input file as Formatted Text Space Delimited (\*.prn) and then change it to a \*dat file. Do not save it as a \*.csv because it must not have commas.
    9. Table program will select the following columns, in-order.

* RL: Day, Hour, LC, Temp, RH, WS, Precip, Epply
* LL: Day, Hour, LC, Temp, RH, WS, Precip, CM14

1. **Avg**
   1. Input file: input.dat (combination file previously created in Excel)
   2. Output file: output.dat
   3. Rename the file: hourlyin.dat
   4. **Before running Avg, make sure you your input file is the combination data set.**
   5. This program contains the calibrations coefficients for the scale and the CM14. It will also change the CM14 data from W/m2 to MJ/m2. The program also does the vapor pressure calculations and averages the 15 minute data into hourly data.
   6. Dale might modify the program so it will ask you for what coefficient you would like to use (as opposed to having to modify the program itself). Right now you are stuck with whatever coefficients are inside the program unless you change the program.

**As of 8/1/2017, Etr calculations cannot proceed past the Avg program due to the issue described immediately above. Dale indicated he could work on this issue around the middle of August. Until then, METS Etr will be used. It might be wise to move the LL CM14 to the METS station in the future.**

1. **Avgdaily**
   1. Input file: hourlyin.dat file AND 24 hr in file
   2. Output file: out.dat
   3. Rename the file: in2
   4. In2 Columns
      * A: Day of Year
      * B: Tmax
      * C: Tmin
      * D: Vapor Pressure
      * E: Rs
      * F: Wind Speed
   5. The 24hr data is needed for the daily max and min temperature. The 24 hour table is the only place to find this data.
   6. The hourly data is averaged into daily data.
   7. **This is the input data set (in2) for input into the Excel spreadsheet AscePMDaily. The day column will need to be moved to a new spot when you put it in AscePM.**
      1. The AscePMDaily is the spreadsheet ETr calculation tool (as opposed to finishing the Etr calculations using C-program.
   8. The Julian dates go in the ***Day of Year*** column. The Month and Day columns appear to be unused.
   9. **NOTE:** It appears that it is very important that the correct AscePM Excel file is selected, depending upon if one is doing hourly or daily Etr. The version living in the hourly folder is used for hourly calculations, and the version living in the daily folder is used for daily calculations. On the surface the two versions do appear to be the same, and were both named the same: AscePM.xls. Each AscePM.xls spreadsheet was built with two worksheets: Hourly Asce-PM and Daily Asce-PM. It appears there must be some differences, specifically in the Hourly worksheet(s) between the version in the hourly folder and the version in the daily folder. During the RL 2016 budget process, the versions appeared to return different hourly results. Of course this could have been due to operator error (Lane). Lane renamed the Excel files AscePMDaily and AscePMHourly to make things more clear. The ‘other’ worksheet inside each of the spreadsheets was darkened to discourage use until such time as the spreadsheets can be more closely examined for errors and/or deleted.
2. **Daily**
   1. Input file: in2
   2. Output file: out.dat
   3. Rename the file: dailyout
   4. **Performs ASCE-PM calculations resulting in ETr values (displayed in the last column).**
   5. Creates an output file that is essentially the same as the alternative Excel AscePM spreadsheet.
   6. The dailyout file can be pasted into the Excel file C\_Program Daily. This Excel file has column labels. Also bring in the Etr values that were calculated in AscePM (Excel file). The two methods of computing Etr can then be compared.

# Computing Hourly Time Step Etr with Straw C-programs

Use the LL, RL, and METS 15min source data created in the Daily Time Step process. You will not need the 24 hour data.

1. **RemoveComma**
   1. Input File: 15min (raw data file).
   2. Output File: out
   3. Rename the file: 15mininput
   4. Run the Comma for LL and RL, you can use the same program; just make sure the correct raw file is where Comma will find it.
2. **Parameter Input**
   1. Input file: 15mininput
   2. Output file: 15minparameterinput
   3. Selects the necessary columns for the ASCE-PM.
   4. Run the Parameter Input program for LL and RL. Different programs are required for each (different column locations).
   5. If you are using METS data, you will not need to do steps f and g as you most likely had to create a custom Excel table for the 15min source data for the RemoveComma program (unless a METS C-program gets written).
   6. Copy the resulting LL and RL data to Excel and create a third file that consists of specific data columns from each of the two original 15minparameterinput files.
   7. **Save this newly created input file as Formatted Text Space Delimited (\*.prn) and then change it to a \*dat file. Do not save it as a \*.csv because it must not have commas.**
3. **Avg**
   1. Input file: 15minparameterinput (combination file created in Excel).
   2. Output file: hourlyinput
   3. Converts 15-min data into hourly averages.
   4. The program applies coefficients and multipliers.
   5. **This is the input file for the Excel spreadsheet AscePMHourly.**
   6. The AscePMHourly is the spreadsheet ETr calculation tool (as opposed to finishing the Etr calculations using C-program.
   7. Paste hourlyinput data into AscePMHourly, **starting with 1200 hours** (midday). You will need to rearrange the columns.
   8. The Julian dates go in the ***Day of Year*** column. The Month and Day columns appear to be unused.
   9. In columns AW – BA of the AscePMHourly spreadsheet the hourly data is summed into daily Etr totals (this is the step that is done in the junk.xls if you use the C-program to compute Etr).
   10. **NOTE:** It appears that it is very important that the correct AscePM Excel file is selected, depending upon if one is doing hourly or daily Etr. The version living in the hourly folder is used for hourly calculations, and the version living in the daily folder is used for daily calculations. On the surface the two versions do appear to be the same, and were both named the same: AscePM.xls**.** Each AscePM.xls spreadsheet was built with two worksheets: Hourly Asce-PM and Daily Asce-PM. It appears there must be some differences, specifically in the Hourly worksheet(s) between the version in the hourly folder and the version in the daily folder. During the RL 2016 budget process, the versions appeared to return different hourly results. Of course this could have been due to operator error (Lane). Lane renamed the Excel files AscePMDaily and AscePMHourly to make things more clear. The ‘other’ worksheet inside each of the spreadsheets was darkened to discourage use until such time as the spreadsheets can be more closely examined for errors and/or deleted.
4. **Hourly**
   1. Input file: hourlyinput
   2. Output file: hourlyout
   3. **Performs ASCE-PM calculations resulting in ETr values (displayed in the last column).**
   4. Paste the hourlyout data in the Excel file Junk. **Junk starts at 1200 hours** (midday) and will total each hour’s Etr value into a daily total. *Make sure you start your paste at 1200 so the daily totals include the correct hours.*